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their Effects on the Technological Value of Outcomes
from Bilateral Inter-firm R&D Alliances**

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Abstract

This study investigates the relationship between the technological value of collaborative research and development (R&D) outcomes and technological diversity in inter-firm R&D alliances. We differentiate technological diversity into two types—relational technological diversity (RTD) and distributional technological diversity (DTD)—and relate them to distinct mechanisms. By empirically analyzing 18,575 granted U.S. patent applications from 1993 to 2002, we find that RTD and DTD is negatively associated and positively associated, respectively, with the technological value of R&D outcomes. In addition, we consider two hypothesized moderators—team size and exploratory degree—in order to examine the moderation effects. The results show that the negative effect of RTD becomes stronger when team size is larger, and the positive effect of DTD becomes greater when an alliance attempts to invent in a less familiar technological field where the exploratory degree is higher. Moreover, we find that RTD and DTD interact in their influences on outcomes.

Keywords: R&D alliance, Inter-firm collaboration, Technological diversity, Technological value, Absorptive capacity, Resource heterogeneity

JEL Classification: L24, O32

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INTRODUCTION

A number of studies have shown an increasing trend for the creation of R&D alliances (Hagedoorn, 2002); additionally, many further studies have attempted to establish theories, and to find empirical evidence, on how various factors influence the outcome or performance of such alliances. From the perspectives of the resource-based view (RBV) and the knowledge-based view (KBV), technological diversity in R&D alliances is deemed significantly important. For example, Sampson (2007) found an inverted-U relationship between overall R&D performance and partner technological diversity in the telecommunications equipment industry. Further, Phelps (2010) found that partner technological diversity increased a telecommunications equipment manufacturer's exploratory innovation.

Studies have stressed the importance of relation-based, or network-based, technological diversity but few have considered another type of technological diversity that is simultaneously manifested in the context of inter-firm R&D alliances. We differentiate the two conceptually different types of technological diversity as relational technological diversity (RTD) and distributional technological diversity (DTD). The former reveals the *relational* dissimilarity or distance between partnering firms with respect to their technological profiles, whereas the latter captures the *distributional* heterogeneity or variety of technological knowledge in their technological profiles. The present study focuses on the differentiation of these two conceptually different types of technological diversity that are related to technological resources and knowledge base, and accordingly examines their distinct influence on the technological value of collaborative R&D outcomes when we relate them to distinct mechanisms. Further, we consider the possibility of the impacts of the two types of technological diversity interacting by virtue of the underlying mechanisms.

In addition, the two types of technological diversity may respond differently to certain conditions in accordance with corresponding mechanisms. The first condition we examine is R&D team size, which reflects the participation of inventors. A number of empirical studies have addressed the influence of team size. For example, following tests, Dailey (1978) stated that a larger team size decreases team cohesiveness and collaborative problem solving. Elsewhere, Singh and Fleming (2010) found that a patent with more inventors appeared to be associated with more citations. However, studies regarding the interaction of team size with technological diversity have fallen short of expectations. The second condition of interest is the direction of R&D strategy in a particular inventive collaboration. The R&D for an invention can follow either an exploitative (and incremental) or an exploratory (and radical) direction. The former focuses on the refinement of existing technologies, whereas the latter is concerned with the risky development of new alternatives (March, 1991). Each direction or goal may influence inventing. For example, Nooteboom, Van Haverbeke, Duysters, Gilsing, and Van den Oord (2007) found a stronger positive effect of cognitive distance for exploration than for exploitation regarding a firm's innovation performance in terms of the number of output patents. In addition, Li, Eden, Hitt, and Ireland (2008) found that a close partnership is positively associated with the direction of the pursuit of radical inventions. Therefore, such a directional issue attracts our interest in hypothesizing the effects that accompany the two differentiated technological diversities. Besides, and importantly, by relating to distinct mechanisms, the two types of technological diversity may respond differently to team size and R&D direction. We expect the following theory development and evidence can help to establish in-depth understanding.

Further, we are more concerned about the *quality* rather than *quantity* of collaborative R&D outcomes in the scope of the present study. In particular, we emphasize the technological value

that is related to technological usefulness, importance, and novelty of a collaborative invention. Therefore, the present study can fill the gap left in prior studies, such as that of Nootboom et al. (2007), where the novelty of innovation was represented by the quantity of inventions.

CONCEPTUAL BACKGROUND AND HYPOTHESES

Relational Technological Diversity and the Technological Value of Collaborative R&D

Outcomes

Although R&D collaboration has proved beneficial to outcomes (Belderbos, Carree, & Lokshin, 2004; Miotti & Sachwald, 2003), it does not suggest an arbitrary partnership. For example, Sampson (2007) found an inverted-U relationship between overall R&D performance and partner technological diversity in the telecommunications equipment industry. Our proposed concept, RTD, is equivalent to such partner-specific diversity in the present study. Specifically, it captures the *knowledge distance* between the two collaborating firms in an R&D alliance with regard to their respective technological knowledge bases and can be linked to the well-known concept, relative absorptive capacity (also known as partner-specific absorptive capacity). Relative absorptive capacity refers to the ability of a firm to acquire, assimilate, transform, and exploit new knowledge and skills from a particular partner, and resides in the area of knowledge-sharing routines (Cohen & Levinthal, 1990; Dyer & Singh, 1998; Zahra & George, 2002).

Empirical evidence has suggested that relative absorptive capacity might be negatively associated with RTD. By narrating in terms of similarity, which is the opposite of terminology diversity, Lane and Lubatkin (1998) found that knowledge-processing similarity was positively relevant to absorptive capacity for pharmaceutical-biotechnology R&D alliances, most noticeably in the area of learning. Further, Mowery, Oxley, and Silverman (1996) reported that a firm's absorption of technological capabilities from its alliance partners was positively related to its technological overlap with such partners. In this regard, the collaborating firms first need to stand on common ground and reach a mutual understanding; thus, communication and learning can then be initiated smoothly among them. Consequently, common knowledge is widely

believed to play a vital role in collaboration, necessitating knowledge integration by enabling members in order to share and integrate external knowledge which is not common in the group (Clark & Marshall, 2002; Clark & Wilkes-Gibbs, 1986; Dixon, 2000; Grant, 1996). Accordingly, a structurally dissimilar dyad of technological knowledge bases can affect the firms' absorptive capacity to acquire and assimilate external knowledge, and transform and exploit the internalized external knowledge. First, the dissimilar collaborating firms may fail to recognize efficiently the value and utility of the external knowledge from their partners and to comprehend the knowledge effectively. The lack of relevant knowledge and skills prior to acquiring, assimilating, transforming, and exploiting the external knowledge is the most important cause of failure. Second, the firms may encounter a further obstacle in the form of internalizing and utilizing the learned knowledge. Latent incidental conflicts are more likely to be induced between partners with limited commonality of knowledge bases because of the reduced cohesiveness. As a result, RTD is thought to impede knowledge spillover and eventually hinder the partnering firms from achieving a promising invention with considerable technological value. Hence, we hypothesize the following:

Hypothesis 1a. RTD is negatively associated with the technological value of a collaborative R&D outcome.

Further, we deem that this type of technological diversity pervasively and consistently enforces a negative impact on the technological value of a collaborative R&D outcome regardless of various conditions, except for those that can affect the collaborators' relative absorptive capacity.

Team size is one possible condition that can affect relative absorptive capacity. Very likely, it has a double-edged influence. On one hand, a larger team was found to invent better quality

patents that were more frequently cited (Singh & Fleming, 2010); on the other, a larger team was shown to lead to a complicated knowledge environment with conflicting attitudes, thus impeding problem-solving (Dailey, 1978). It is not hard to deduce that a larger team implies a greater number of individual partners with whom each participating inventor collaborates. Therefore, in accordance with theories on absorptive capacity, a larger team can leverage potential incidental conflicts and thus further exacerbate ineffectiveness and inefficiency in all four dimensions of absorptive capacity: acquisition, assimilation, transformation, and exploitation (Zahra & George, 2002). This suggests the following hypothesis:

Hypothesis 1b. The negative effect of RTD on the technological value of a collaborative R&D outcome is significantly greater as team size becomes larger.

Distributional Technological Diversity and the Technological Value of Collaborative R&D Outcomes

Another type of technological diversity influences R&D. With or without R&D collaboration, a firm possesses a set of technological resources and capabilities. These can reflect the knowledge base of the firm. The *variety* that exists among all kinds of technological knowledge regarding the structure and composition of the firm's technological profile is defined as its DTD.

In diversification literature, a diverse resource profile was usually believed to have a positive relationship with performance (Rumelt, 1974; Varadarajan & Ramanujam, 1987; Wernerfelt & Montgomery, 1988). As technological knowledge has become increasingly endowed with more importance than other resources, it is natural to derive a similar hypothesis from the relationship between technological knowledge profile and innovative performance. Specifically, a diverse technological profile increases the variety of technological knowledge; thus, it broadens cross-technology combinatorial chances among heterogeneous knowledge and therefore yields a great

number of new combinatorial ideas and consequential inventions. Such variety remains influential on collaborative R&D performance when extended to cases of R&D alliance.[†] Therefore, as we deduce, an invention's novelty and importance, the combined underlying basis for technological value, from an R&D outcome would also benefit from such Schumpeterian combinations because the chance to obtain a potential quality idea is higher when considerable variety exists among the technological knowledge bases. This leads to the following hypothesis:

Hypothesis 2a. DTD is positively associated with the technological value of a collaborative R&D outcome.

Further, we deem that such a positive influence of DTD can be moderated by factors that affect realization of the combinational advantages. On most occasions when firms collaborate on an exploitative R&D project, which focuses on refining existing technological knowledge and implementing very incremental inventions, the demand for cross-technology combinatorial ideas created by a diverse set of knowledge would be insufficient, and the utilization of the ideas would be ineffective, because most of the combinations are useless for exploitation. Alternatively, when an exploratory invention is targeted, it is more likely that the resulting combinations created by variety among the technological knowledge will contribute to the eventual R&D outcome. Besides, a more diverse technological profile procures preemptive chances of having specialized resources and capabilities in the solution domain when the collaborating firms seek to explore an unfamiliar and unrelated field. This suggests the following hypothesis:

[†] Since a firm in collaboration still operates independently, its technological knowledge remains primarily within the firm boundary because such knowledge is difficult to transfer among the partners. Nevertheless, one can attain a certain degree of access to the partnering firms' knowledge when they collaborate with each other.

Hypothesis 2b. The positive effect of DTD on the technological value of a collaborative R&D outcome is significantly higher when an alliance attempts to invent in a less familiar technology field where the exploratory degree is higher.

Based on the theoretical differentiation of the two types of technological diversity and empirical evidence, we summarize the issue and conceptually propose Figure 1 for a better and more in-depth demonstration of the four types of R&D collaboration implied in our study. As shown in the figure, we divide the collaboration space into four quadrants according to two dimensions, RTD and DTD, and name the four quadrants as, counterclockwise, I) dissimilar-diverse, II) similar-diverse, III) similar-concentrate, and IV) dissimilar-concentrate. The two square waves in each quadrant refer to two collaborating firms, the peaks represent the existence of technological resources in the relevant categories of a firm, and the valleys represent the absence of such resources.

 Insert Figure 1 about here

Hypotheses 1a and 2a imply that the technological value of outcome increases along a path from quadrant IV to quadrant II. Although complementary capability is often emphasized, the type of similar-diverse collaboration still outperforms the rest, especially dissimilar-concentrate collaboration. These two types of collaboration (i.e., II and IV) to some extent resemble *pooling alliance* and *complementary alliance* as proposed by Lavie (2006), who stated that the former pursues a greater scale and enhanced competitive position whereas the latter seeks synergies from distinct resources that are difficult to accumulate alone. Lavie's (2006) argument was primarily built upon the RBV rather than the KBV. Knowledge can be counted as one part of a bundle of resources possessed by firms; however, it differs from other resources to a significant

degree in dimensions such as transferability and appropriability (Grant, 1996). Since explicit knowledge is revealed by communication and tacit knowledge is revealed through application, neither explicit nor tacit knowledge could possibly remain unchanged after either process. Therefore, we suggest that, in general, knowledge is a resource that has greater idiosyncrasy than others. Technological knowledge also inherits such a characteristic; thus, heterogeneity remains between two structurally similar firms in terms of their technological knowledge (i.e., type II collaboration). Such a technological similarity does not violate Barney's (1991) resource heterogeneity assumption. On the contrary, when type IV collaboration occurs, far fewer combinatorial chances are available. To make matters worse, relative absorptive capacity is also remarkably low when the collaboration is type IV.

Interaction between the Two Types of Technological Diversity

From the perspective of dynamic capability, firms need to pay considerable attention to “appropriately adapting, integrating, and reconfiguring internal and external organizational skills, resources, and functional competences to match the requirements of a changing environment” (Teece, Pisano, & Shuen, 1997). Therefore, because we treat partners as part of the “changing environment” and absorptive capacity as a type of “dynamic capability,” one's relative absorptive capacity with regard to different partners can elicit differential effects, as we posited earlier.

Further, this capability may also respond to the knowledge base “environment” of the alliance. When heterogeneous technological knowledge preexists for innovating firms, the relative absorptive capacity of such firms may be strengthened. Specifically, heterogeneous knowledge allows collaborating firms that have dissimilar technological knowledge bases to acquire external knowledge efficiently and assimilate it effectively. Firms with heterogeneous knowledge have

usually experienced diversification; thus, they are likely to have experienced considerable exposure to diverse and complementary external sources of knowledge. As a result, the firms can be enriched by greater opportunity to develop absorptive capacity (Zahra & George, 2002).

The impact of heterogeneous knowledge may also be leveraged by RTD. When collaborating firms are structurally similar to each other in terms of technological knowledge (and in extreme instances we may imagine that they are identical), the benefit of collaboration merely comes from economies of scale. In contrast, when firms are structurally dissimilar in terms of technological knowledge, more combinatorial opportunities emerge from the firms' prior knowledge bases. This situation can enhance synergies from technological resources and knowledge with regard to R&D output. Hence, we hypothesize the following:

Hypothesis 3. RTD positively interacts with DTD: the negative impact of RTD becomes less pronounced as DTD increases; the positive impact of DTD becomes more pronounced as RTD increases.

METHOD

Sample and Data Collection

The data used to test the hypotheses come from utility patents from the U.S. Patent and Trademark Office (USPTO). A patent is a direct outcome of innovative activities and represents an asset or resource of the assignee or assignees. Although it does not directly indicate technological capability that is tacit (Amit & Schoemaker, 2006), a patent can be taken for an approximation of the owner's technological capability because explicit knowledge such as a patent can reflect tacit knowledge (Mowery et al., 1996; Patel & Pavitt, 1997).

We select granted utility patents from the application years 1993 to 2002. R&D collaboration is recognized by the co-occurrence of identical assignee identifiers provided in the data set. The data of citation linkages are likewise obtained for utility patents applied for during 1993 to 2007.[‡] Three types of patent were excluded from the data set: (1) single assignee patents; (2) patents with more than two assignees involved because we focus only on bilateral R&D collaboration on the grounds that multilateral alliances might differ from bilateral ones in terms of the complexity of knowledge absorption;[§] and (3) patents invented by non-firm assignee(s). As a result, the sample consists of 18,575 observations with each one representing a granted patent.

Measures and Statistical Method

Dependent variables. Citations. This variable is measured by the number of forward citations an observed patent had received by the end of the fifth successive year after the patent was applied for. For example, if an observed patent was applied for in 2000, all citations received from 2000 to 2005 are counted. Patent citation is widely applied in the literature for measuring

[‡] Because the number of forward citations is counted by the end of the fifth year after the observed patent was applied for and the latest application year in the sample is 2002.

[§] Nearly 90 percent of multi-assignee patents have two assignees.

patent quality and patent importance; indeed, a number of studies have validated the correlation between forward citations and the importance of an invention (Albert, Avery, Narin, & McAllister, 1991; Hagedoorn & Cloudt, 2003; Harhoff, Narin, Scherer, & Vopel, 1999; Jaffe, Trajtenberg, & Henderson, 1993; Trajtenberg, 1990). Therefore, we employ it to act as a proxy for the technological value of a collaborative R&D outcome.

Independent variables. *RTD*. This variable is measured by the relatedness-weighted cosine index of diversity that was proposed by Huo and Motohashi (2014). Strategic management scholars often apply the original cosine index to measure partner technological diversity (Sampson, 2007), technological proximity (Jaffe, 1986), and technological relatedness (Petruzzelli, 2011). In addition, this recently proposed index incorporates the relatedness of non-independent categories (i.e., technological fields in the present study) in computation. The formal mathematical definition is given below:

$$RTD = 1 - \frac{v_A^T M v_B}{\sqrt{v_A^T M v_A * v_B^T M v_B}}$$

where the vectors $v_A(k_{A1}, \dots, k_{Ai}, \dots, k_{An})$ and $v_B(k_{B1}, \dots, k_{Bi}, \dots, k_{Bn})$ are defined as technological profiles for the two collaborating firms. The k_{Aj} in vector v_A represents the number of patents in field j to which firm A was assigned in the five-year period before the observed patent was applied for. By following the proposed approach, the relatedness matrix M is derived from all U.S. utility patent applications from 1988 to 2002, in which each entry refers to a relatedness score between two technological fields.

DTD. This variable is measured using the Herfindahl index. Scholars have adopted the Herfindahl index in strategic management research contexts such as diversification (Hitt, Biermant, Shimizu, & Kochhar, 2001), and functional or expertise diversity (Bunderson & Sutcliffe, 2002; Tihanyi, Ellstrand, Daily, & Dalton, 2000; Van Der Vegt & Bunderson, 2005).

To be consistent in measuring technological profile, the Herfindahl index also adopts patents applied for in the five years prior to a given year. When we apply this approach to a specific alliance, we compute relatedness-weighted Herfindahl diversity for each member firm separately and then take the average as the proxy. The weighting-relatedness matrix M is the same as the one used in the computation of RTD. This suggests the following expression, where, in vectors p_A and p_B , each element refers to a proportion of the patents assigned to a correspondent technological field for firms A and B in an alliance:**

$$DTD = \frac{(1 - p_A^T M p_A) + (1 - p_B^T M p_B)}{2}$$

Exploratory degree. We measure this R&D strategy choice with the assistance of the primary technological field to which each observed patent was assigned. Specifically, this variable is generated by subtracting the average of the relatedness scores among the primary technological fields of each member firm and the field of the observed patent from one. For example, assume a collaborating firm dyad $\langle A, B \rangle$, with firm A innovating primarily in *biotechnology* and firm B in *telecommunications* and *optics* (these two fields account for the two identical largest shares in firm B). Firms A and B then collaborate on a patent in *control*. The exploratory degree will be $1 - \frac{1}{2} \left[r_{bio-control} + \frac{1}{2} (r_{tele-control} + r_{optics-control}) \right]$, where $r_{bio-control}$ represents the relatedness between the *biotechnology* and *control* technologies. Such relatedness scores are obtained from the same relatedness matrix M employed to weigh the two types of technological diversity. Hence, this proxy reflects the degree to which the technological field of the observed patent departs from the most competitive fields of collaborating firms. In other words, a low

** This weighted index was also proposed by Huo and Motohashi (2014) and was proved to be equivalent to the concentric index (Caves, Porter, & Spence, 1980) in its nature despite the different methods of generating the relatedness matrix M .

value indicates that the collaboration is exploitative with a low R&D risk, and a high value implies that it is exploratory with a high risk.

Team size. We count the number of inventors recorded in the observed patent in order to proxy this variable. Of course, there are cases in which not all recorded people are the actual inventors. For example, perhaps because of an organization's convention, managing executives' names may need to appear in a patent even if such executives have not contributed de facto to the process of the invention. However, this proxy still plausibly represents the participation of team members because most of the time, non-inventors' participation potentially increases the complexity of the team's knowledge environment. Similar measures that are relevant to the documented inventors in patents have also been widely used in prior studies (Balconi, Breschi, & Lissoni, 2004; Singh & Fleming, 2010).

Control variables. Claims. Patent claims demonstrate the exclusive property right that an observed patent claims in order to protect the invention (Lanjouw & Schankerman, 2004). Studies have shown a positive relationship between the number of claims and patent quality (Tong & Frame, 1994) because a broad "protection scope" for a patent probably excludes potential competitors and thus raises its value.

References. A reference is also called a "backward citation," and the number of references reflects the external technological sources (i.e., the prior patents and non-patent technical documents) used in an observed patent. It has been suggested that a greater number of references reflects greater absorptive capacity when firms use external knowledge (Rothaermel & Thursby, 2005).

International alliance. This is a dummy variable that measures whether an observed patent is the result of international collaboration. Specifically, when the headquarters of collaborating

firms are in different countries, the value is one. The present study includes this variable because some research has suggested that there might be systematic differences between the performance of international collaboration and that of domestic collaboration (Barkema, Shenkar, Vermeulen, & Bell, 1997; Hagedoorn, 2002).

Prior patents. This is the number of patents applied for in the past five years for a member firm in an alliance. This variable has been suggested in order to reflect R&D capability or the firm's technological capital (Nooteboom et al., 2007; Silverman, 1999).

Same alliance experience. This is a dummy variable designed to indicate whether the collaborating firms collaborated in the past five years. It has been suggested that the experience of collaboration with the same partners may impede R&D performance because such repeat collaboration suppresses idea generation (Skilton & Dooley, 2010).

Other alliance experience. This is measured by counting the distinct number of alliances in which a firm has participated in the past five years, excluding the partner for a given observation. Such firms may benefit from collaboration in many alliances in order to acquire a variety of external resources.

Experience years. We measure this variable by counting the years that have elapsed since a firm first applied for a patent. A firm with more years of experience may possess more resources and management skills.

Year and technology field dummies. In order to control for the fixed effect introduced by time (Judge, 1985), the analysis also includes nine year dummies from 1993 to 2001. In addition, the fixed effect of the technology field is controlled by including 36 dummy variables in accordance with the subcategories in the HJT categorization scheme (Hall, Jaffe, & Trajtenberg, 2001).

In summary, among all these control variables, the first two, *claims* and *references*, and the two types of fixed effect dummy variable are applied to control for the *patent characteristics* of an observation, while the rest control for the *firm characteristics* for each firm in an alliance.

The characteristics of the data used show that the dependent variable is a non-negative integer count. As a result, we apply the negative binomial model to all hypothesis tests. This econometric model is able to account for a large portion of zero and small count values, and is therefore suitable for the analyses (Hausman, Hall, & Griliches, 1984).

When testing the moderation effects of team size and exploratory degree, correspondent interaction variables are generated. For example, *RTD X team size* represents the interaction variable between RTD and team size; and *DTD X exploratory degree* refers to the interaction variable between DTD and exploratory degree, and so on.

RESULTS

Before running the regression models, the consistency of the technological value for one alliance is checked first. If the number of forward citations of each patent applied for by an alliance in a specific year has considerably low variance, we would confidently trust the predicted relationship between the technological value and the technological diversities of the alliance. In other words, an alliance that has a given technological profile (defined by the two technological profiles of the partnering firms) would yield inventions with almost equal technological values.

We employ a variation coefficient, defined as the ratio of the standard deviation to the mean, to evaluate whether variance is considerably low. We compute the variation coefficient of the forward citations of patents produced by each alliance in a given application year and a given technological field, and then test whether the variation coefficients are low enough. A value smaller than one is commonly acknowledged to imply a low level of variance. Hence, a *t*-test is used to check whether the mean of the variation coefficient equals one. Finally, the result shows that this null hypothesis is rejected and the resulting one-tailed *p*-value reveals that the mean of the variation coefficient is significantly smaller than one.^{††} Therefore, we can confidently claim that an R&D alliance performs steadily and the technological value of its patents and inventions in the same period can be considered consistent.

Table 1 presents the descriptive statistics for all dependent, independent, and control variables.

 Insert Table 1 about here

^{††} The result of the *t*-test is briefly given here: $t = -12.6001$, $\Pr(T < t) = 0.0000$ (Ha: mean < 1), $\Pr(|T| > |t|) = 0.0000$ (Ha: mean \neq 1), and $\Pr(T > t) = 1.0000$ (Ha: mean > 1).

Impact of Relational Technological Diversity

We first examine the extent to which RTD influences a patent's technological value. The estimates are presented in Table 2.

 Insert Table 2 about here

In models (1)–(7), as we incrementally add variables of interest, the main effect of RTD remains negative, although in models (5) and (7) it is not significant at the 0.10 level. The variable *team size* exhibits a strong positive impact on the dependent variable. On average, when there is one more inventor participating in the collaboration, the expected log count of forward citations will increase by about 0.04 according to model (7). Despite this, the participation of more inventors also results in a greater negative effect of RTD on forward citations with the interaction term significant at the 0.10 level.^{‡‡} In addition, if we examine and compare the estimates of the moderator *team size* and the interaction term *RTD X team size*, it can be observed that their signs are opposite and that the magnitude of the former is a little smaller than that of the latter (0.04 versus -0.05). This implies that the predicted curves at different levels of *team size* intersect at a very high level of RTD. To make this clearer, we plot Figure 2 to demonstrate the predicted curves at three levels of *team size*: large, medium, and small. The numbers of inventors at these three levels are 7, 4, and 2, corresponding to mean+S.D., mean, and mean–S.D. of *team size*, respectively.^{§§} As shown in Figure 2, the curve with large *team size* decreases faster than the other two curves as RTD increases. Three curves intersect when RTD

^{‡‡} One may argue that the significance for the estimate of the interaction term is not enough. So we further consider *team size* as a dummy variable that differentiates two groups: no more than five individual members, and more than five individual members. With such an alternative proxy, we find a much stronger significance that has a *p*-value of 0.008.

^{§§} We generate three new variables to re-center the moderator, by subtracting mean+S.D., mean, and mean–S.D. from *team size*, and then re-estimating three models with the three new variables, respectively. Figure 2 is plotted based on these new estimates.

becomes 0.87. At the greater value end of RTD, an R&D team with smaller size is a little more beneficial than one with larger size;*** however, when RTD lies in $[0, 0.87)$, a team with larger size generally outperforms one with smaller size. Hence, hypotheses *1a* and *1b* are corroborated.

Impact of Distributional Technological Diversity

The estimates of the relationships between DTD and the technological value of patents are presented in Table 3.

 Insert Table 3 about here

Without considering the hypothesized moderator exploratory degree, models (1)–(5) show a significantly positive influence of DTD on technological value. Because we include the interaction term of exploratory degree in models (6) and (7), the estimate implies a strong moderation effect on the relationship between technological value and DTD. Specifically, this suggests that when an alliance attempts inventions in an unfamiliar and distant technological field, a more diverse technological knowledge profile is more helpful than a less diverse one. Similarly, by following the method used in Figure 2, we plot Figure 3 to demonstrate further the extent to which DTD affects technological value at three levels of exploratory degree: high, mean, and low. These levels are defined as mean+S.D., mean, and mean–S.D., with three values of 0.78, 0.49, 0.20, respectively. Accordingly, the coefficients of DTD can be re-estimated for the three levels of exploratory degree. We can distinctly observe from Figure 3 that a diverse technological knowledge profile substantially increases forward citations when collaborating firms attempt a highly exploratory invention compared to inventions with mean and low exploratory degrees. For example, when collaborating firms attempt an invention involving a

*** Because there are only five observations with diversity greater than 0.87 in the sample, this effect is not strong. For this reason, the estimate of team size from models (1)–(7) is consistently significant at the 0.001 level.

high exploratory degree, a very diverse technological profile (i.e., with a maximum DTD that equals 0.72 in the sample) enables an additional 0.04 forward citations compared to when they attempt a mean degree invention, and an increase of 0.07 citations compared to when the invention is low degree. Seemingly, these are not considerable upturns; but if the alliance has a very concentrated technological knowledge profile, and assuming that this applies to only one technological field (i.e., with a minimum DTD that equals zero in the sample), the R&D attempt that involves a high exploratory degree will result in 0.22 and 0.44 fewer forward citations compared to the mean and low degree attempts. In other words, holding a diverse technological profile significantly curtails inhibition caused by a risky, unrelated, and exploratory R&D attempt.

Insert Figure 3 about here

Interestingly, if we adopt an alternative perspective when examining Figure 3, we might find a better R&D strategy choice according to the given technological profile of an alliance. If the alliance has a very diverse profile that exceeds the crossing point (i.e., DTD is greater than 0.62), a high exploratory degree strategy is probably preferable. However, the technological value of the collaborative R&D outcome from the alliance would be better if the collaborating firms are in favor of a low level of exploratory degree.

Finally, we include both RTD and DTD at the same time in order to examine their influence. Table 4 presents the results. The significances of the estimates of RTD and DTD differ little to those reported in Tables 2 and 3. Hence, hypotheses 2*a* and 2*b* are corroborated.

Insert Table 4 about here

Interaction between the Two Types of Technological Diversity

We estimate the interaction effect between RTD and DTD by including the interaction term *RTD X DTD* into the regression models. Table 5 presents the estimates. As shown in models (1) and (2), the estimate of the interaction is statistically significant at the level of 0.05 when team size and exploratory degree are not considered, whereas its significance decreases a little to the level of 0.10 when team size and exploratory degree are included.

Insert Table 5 about here

To verify the hypothesis with more confident evidence, we refine the sample further and only consider a subset of observations. The experience of collaborating with a familiar partner can potentially cause creative abrasion (Skilton & Dooley, 2010). In this scenario, we may expect a stronger interaction effect between the two types of technological diversity since the familiar partners may be more susceptible to heterogeneous knowledge when developing their absorptive capacity. Therefore, we select the observed patents that were co-patented by a pair of firms that collaborated with each other within the past five years (i.e., same alliance experience = 1) and re-estimate. Models (3) and (4) in Table 5 show the results. The estimate of the interaction terms becomes more significant, reaching the 0.05 level in model (4) when team size and exploratory degree are included. In this regard, hypothesis 3 is accepted.

DISCUSSION AND CONCLUSION

The RBV and KBV provide integrated theories explaining how firms utilize and extend knowledge (as a resource) to gain competitive advantage. The present study discusses the influence of technological knowledge profiles on the technological value of R&D outcomes in the context of inter-firm bilateral collaboration. In this regard, we differentiate two types of technological diversity involved in R&D alliances: RTD and DTD.

RTD reflects the knowledge distance between the collaborating firms. In the context of inter-firm collaboration, considering one firm as a basic unit, this type of technological diversity is an inborn characteristic along with collaboration. Importantly, we relate absorptive capacity to RTD. The absorptive capacity is considered partner-specific (Dyer & Singh, 1998; Lane & Lubatkin, 1998); therefore, the conceptual construct of RTD is inherently consistent to the “dyadic” nature of relative absorptive capacity. As a result, a theoretical proposition concerning the impact of RTD on R&D outcomes can be clearly established: first, RTD impedes absorptive capacity because of potential cognitive obstacles and the accompanying conflicts in knowledge acquisition, assimilation, transformation, and exploitation; in addition, a low absorptive capacity for each partner in an R&D alliance hinders the alliance from achieving a superior invention with potential technological value.

In other words, using an analogy from research findings in cognitive science and psychology, RTD’s involvement is such that the higher the diversity between the collaborating firms, the stronger the cognitive disadvantage for them (Cohen & Levinthal, 1990). This disadvantage is universal, insusceptible, and regardless of various conditions except for one where such cognitive disadvantage can be leveraged. We argued that team size meets the characteristic of such a condition because the greater the number of individuals participating in a group, the more

complicated the communication pattern becomes. Further, as we hypothesized, team size was found to significantly moderate the relationship between RTD and the technological value of the R&D outcomes in the reported results.

Of course, beyond the scope of the present study, the literature has proposed other factors that are possible determinants of absorptive capacity. One example is the organizational form of an alliance (e.g., bilateral contract or equity joint venture). This has been found to influence the relationship between performance and partner technological diversity (Sampson, 2007). If we incorporate the theoretical perspective of KBV that knowledge is difficult to transfer and is easier to share within a firm than among firms (Kogut & Zander, 1992), then the organizational form of an alliance is expected to be prone to RTD. The form of the joint venture may facilitate communication, learning, and knowledge transfer among the partners; therefore, the cognitive disadvantage due to RTD may be reduced for a joint venture compared to a bilateral contract.

The construct of DTD, however, represents another concept that has little connection to cognitive characteristics and absorptive capacity. It measures compositional variety among all kinds of technological knowledge and is the difference induced by the distribution of this technological knowledge rather than the difference formed through a comparison of the knowledge holders. The impact of this type of technological diversity originates from the mechanism that combinations of knowledge (as a resource) can facilitate synergy. Because an R&D alliance possesses richly diverse technological knowledge, the effect of this synergy upon different technological knowledge fields should be high.

In addition, exploratory degree was found to significantly moderate the influence of DTD in the reported results. Specifically, when an alliance seeks an exploitative invention, little is gained from a diverse technology portfolio; on the contrary, when an alliance attempts to invent

exploratively in a less familiar field, a diverse technological profile can help to achieve a better technological value for the R&D outcome. In short, the exploratory degree of a planned invention leverages the synergy of heterogeneous resource combinations. Moreover, we also included the variable team size and the corresponding interaction term *DTD X team size* in Table 3 to check whether this variable can moderate the influence of DTD. Unlike our finding for exploratory degree, the estimate for team size was insignificant, implying that little evidence exists to suggest such an effect. Although we cannot confidently deduce causality from the fact that team size does not moderate the relationship merely by using this insignificant estimate, it is logically plausible that the way in which synergy occurs among heterogeneous technological resources is unlikely to be affected by the number of inventors involved in a collaboration.

We also found that RTD and DTD interacted in terms of their influence on the technological value of R&D outcomes. In short, a diverse technological profile can ease the negative effect of RTD while the dissimilarity between firms' technological profiles can enrich them with potential opportunities to innovate. This may conform to a recently raised discussion on rethinking diversity through a view of positive organizational scholarship (POS), although this has been mainly considered in the field of international business (Cameron, Dutton, & Quinn, 2003; Stahl & Tung, 2013; Stevens, Plaut, & Sanchez-Burks, 2008). Analogously, the present study's results provide evidence to support the POS view in R&D strategy literature. Such an extension may enable business strategy and international business scholars to comprehend a full picture of various diversities in a range of dimensions.

The results from the present study have important practical implications. First, the choice of partnering firm significantly affects the quality of the outcome from an alliance. For example, a large RTD impedes an alliance from achieving a quality invention. To reduce such disadvantages,

care must be taken when lowering the cognitive cost of inter-firm acquisition and assimilation as well as intra-firm transformation and the exploitation of knowledge. Maintaining a small team could be a plausible approach because this can constrain the possible cognitive obstacles and conflicts due to the dissimilar technological profiles of the partnering firms. Second, technological resource variety also benefits the quality of the outcome from an alliance. Having a diverse technological profile is especially important to alliances that pursue exploratory inventions because it can greatly boost the generation of quality inventions.

However, this study has limitations. First, the two types of technological diversity are constructed from patent portfolios; thus, the accuracy of measurement depends on the extent to which the patent portfolios reflect the real technological resources of firms. Nonetheless, RBV and KBV research acknowledges that patent data are a credible source to evaluate the technological capability of firms. Second, there might be an additional need for further theoretical development and empirical evidence on the possible distinct influence of RTD on the *quantity* and *quality* of R&D outcomes. (Nooteboom et al., 2007) found that cognitive distance had an inverted U-shaped effect on the quantity of output patents.^{†††} They attributed the rising half of the predicted curve to “novelty value” that originates from the enlarged cognitive distance. However, in the present study we found little novelty value contribution to the quality, as opposed to the quantity, of outcomes. Moreover, the possible benefits or novelty value from enlarging the number of inventors, which was assumed to facilitate rigorous idea selection in teamwork (Singh & Fleming, 2010), were not manifested in the reported results either; instead, weakened cohesiveness due to more participants provided a better explanation of the

^{†††} The cognitive distance in the literature mentioned here was measured by the average of the correlations between the focal firm’s technological background and that of each of its alliance partners. Unlike this measure, the focal RTD in the present study reflects cognitive distance for a specific dyad of firms.

strengthened negative effect of RTD. In addition, in the aforementioned study by Nooteboom et al. (2007), a stronger positive association of cognitive distance with the quantity of the outcomes was found for exploration rather than exploitation. The authors explained that such cognitive distance can yield problems that are unnecessary for exploitation but probably needed for exploration. Similarly, we did not find plausible evidence to support a significant moderation effect for exploration.^{†††} Future work in the development of theory is expected to provide persuasive explanations. Third, unlike the results that we found between type II and type IV collaboration, as revealed in Figure 1, it is difficult to determine confidently the superiority between type I and type III. In addition, we extracted observations of types I and III, and regressed *citations* on *distance* from the point of an observation to the origin (i.e., the median or mean of the sample) in the space illustrated in Figure 1.^{§§§} The result revealed a positive but insignificant estimate of the distance. This might imply that an alliance with both moderate RTD and DTD underperforms to some extent compared to an alliance with both extremely high/low RTD and DTD. This issue remains unexplored and the aforesaid primitive finding is an encouragement for further theoretical explanations in future studies.

Even with these limitations, this study offers greater understanding of inter-firm R&D collaboration. Hopefully, it can be a useful guide for managers and policymakers so that they can make suitable strategies and decisions when facing relevant issues.

^{†††} When we included the variable *exploratory degree* in Table 2, to examine whether this variable has a moderation effect, the estimate of the interaction term *RTD X exploratory degree* from models (6) and (7) was insignificant.

^{§§§} The values of RTD and DTD form a two-dimensional point for an observation in the space plotted in Figure 1, and the distance to the origin reflects the extent to which the observed collaboration is with both extremely high (or low) RTD and DTD (i.e., upper-right or bottom-left in Figure 1).

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Table 1. Descriptive Statistics

VARIABLES	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)	(14)	(15)
(1) Citations															
(2) RTD	-0.03 (0.00)														
(3) DTD	0.05 (0.00)	-0.11 (0.00)													
(4) Team size	0.02 (0.01)	0.01 (0.13)	0.01 (0.06)												
(5) Exploratory degree	0.01 (0.24)	0.26 (0.00)	0.39 (0.00)	-0.02 (0.01)											
(6) Claims	0.14 (0.00)	-0.05 (0.00)	-0.05 (0.00)	0.05 (0.00)	-0.03 (0.00)										
(7) References	0.15 (0.00)	0.01 (0.13)	-0.03 (0.00)	0.01 (0.47)	-0.00 (0.48)	0.19 (0.00)									
(8) International alliance	0.07 (0.00)	-0.19 (0.00)	-0.05 (0.00)	-0.11 (0.00)	-0.06 (0.00)	0.13 (0.00)	0.14 (0.00)								
(9) Prior patents 1	0.08 (0.00)	-0.05 (0.00)	0.39 (0.00)	-0.01 (0.17)	0.14 (0.00)	0.06 (0.00)	0.06 (0.00)	0.15 (0.00)							
(10) Prior patents 2	0.02 (0.01)	-0.04 (0.00)	0.24 (0.00)	-0.01 (0.04)	0.10 (0.00)	0.00 (0.71)	-0.01 (0.09)	0.05 (0.00)	0.12 (0.00)						
(11) Same alliance experience	-0.07 (0.00)	-0.19 (0.00)	0.11 (0.00)	-0.01 (0.30)	-0.02 (0.00)	0.03 (0.00)	0.04 (0.00)	0.03 (0.00)	0.29 (0.00)	0.12 (0.00)					
(12) Other alliance 1	-0.04 (0.00)	-0.02 (0.00)	0.25 (0.00)	0.03 (0.00)	0.09 (0.00)	-0.00 (0.72)	0.02 (0.01)	-0.04 (0.00)	0.55 (0.00)	0.09 (0.00)	0.55 (0.00)				
(13) Other alliance 2	-0.06 (0.00)	-0.04 (0.00)	0.18 (0.00)	0.02 (0.00)	0.09 (0.00)	-0.04 (0.00)	-0.03 (0.00)	-0.08 (0.00)	0.04 (0.00)	0.60 (0.00)	0.25 (0.00)	0.17 (0.00)			
(14) Experience year 1	0.01 (0.26)	-0.00 (0.97)	0.34 (0.00)	0.05 (0.00)	0.10 (0.00)	-0.02 (0.00)	0.00 (0.99)	-0.01 (0.62)	0.47 (0.00)	0.09 (0.00)	0.16 (0.00)	0.33 (0.00)	0.09 (0.00)		
(15) Experience year 2	-0.04 (0.00)	-0.02 (0.00)	0.32 (0.00)	0.10 (0.00)	0.09 (0.00)	-0.06 (0.00)	-0.06 (0.00)	-0.07 (0.00)	0.05 (0.00)	0.51 (0.00)	-0.00 (0.52)	0.04 (0.00)	0.29 (0.00)	0.16 (0.00)	
Mean	4.92	0.21	0.52	4.36	0.49	15.48	9.00	0.24	2514.92	477.74	0.30	17.67	3.42	24.16	11.69
S.D.	8.29	0.17	0.16	2.33	0.29	12.82	15.82	0.42	3322.09	1309.43	0.46	37.76	12.69	11.80	9.57
Min	0.00	0.00	0.00	2.00	0.00	1.00	0.00	0.00	1.00	1.00	0.00	0.00	0.00	1.00	1.00
Max	170.00	1.00	0.72	28.00	1.00	259.00	275.00	1.00	20806.00	20806.00	1.00	199.00	199.00	99.00	96.00

$n = 18,575$. Significance levels appear below correlations.

Table 2. Negative Binomial Estimates for Technological Value and RTD

VARIABLES	(1)	(2)	(3)	(4)	(5)	(6)	(7)
RTD	-0.33*** (0.07)	-0.34*** (0.07)	-0.32*** (0.07)	-0.33*** (0.07)	-0.14 (0.14)	-0.27† (0.16)	-0.07 (0.19)
Team size		0.03*** (0.01)		0.03*** (0.01)	0.04*** (0.01)		0.04*** (0.01)
RTD X team size					-0.05† (0.03)		-0.05† (0.03)
Exploratory degree			-0.05 (0.04)	-0.04 (0.04)		-0.04 (0.06)	-0.02 (0.06)
RTD X exploratory degree						-0.08 (0.27)	-0.10 (0.27)
Claims	0.01*** (0.00)						
References	0.01*** (0.00)						
International alliance	0.02 (0.03)	0.04 (0.03)	0.02 (0.03)	0.04 (0.03)	0.05 (0.03)	0.02 (0.03)	0.05 (0.03)
Prior patents 1	0.00*** (0.00)						
Prior patents 2	0.00*** (0.00)						
Same alliance experience	-0.10** (0.04)	-0.10* (0.04)	-0.11** (0.04)	-0.10* (0.04)	-0.10* (0.04)	-0.11** (0.04)	-0.10* (0.04)
Other alliance 1	0.00* (0.00)	0.00† (0.00)	0.00* (0.00)	0.00† (0.00)	0.00† (0.00)	0.00* (0.00)	0.00† (0.00)
Other alliance 2	-0.00*** (0.00)						
Experience year 1	-0.00 (0.00)						
Experience year 2	-0.01*** (0.00)						
Constant	0.62*** (0.08)	0.50*** (0.08)	0.65*** (0.08)	0.51*** (0.08)	0.46*** (0.08)	0.64*** (0.08)	0.47*** (0.08)
Year fixed effect	Include						
Tech fixed effect	Include						
Chi ²	2615	2678	2624	2686	2692	2625	2699
df	56	57	57	58	58	58	60

Robust standard errors are in parentheses. $n = 18,575$.

† $p < 0.10$

* $p < 0.05$

** $p < 0.01$

*** $p < 0.001$

Table 3. Negative Binomial Estimates for Technological Value and DTD

VARIABLES	(1)	(2)	(3)	(4)	(5)	(6)	(7)
DTD	0.35*** (0.09)	0.34*** (0.09)	0.44*** (0.09)	0.43*** (0.09)	0.54*** (0.16)	-0.05 (0.14)	0.11 (0.18)
Team size		0.03*** (0.01)		0.03*** (0.01)	0.06** (0.02)		0.05** (0.02)
DTD X team size					-0.05 (0.03)		-0.03 (0.03)
Exploratory degree			-0.14** (0.04)	-0.13** (0.04)		-0.81*** (0.15)	-0.76*** (0.14)
DTD X exploratory degree						1.31*** (0.26)	1.23*** (0.26)
Claims	0.01*** (0.00)						
References	0.01*** (0.00)						
International alliance	0.04 (0.03)	0.06* (0.03)	0.03 (0.03)	0.06* (0.03)	0.06* (0.03)	0.04 (0.03)	0.06* (0.03)
Prior patents 1	0.00** (0.00)	0.00** (0.00)	0.00*** (0.00)	0.00*** (0.00)	0.00** (0.00)	0.00** (0.00)	0.00** (0.00)
Prior patents 2	0.00*** (0.00)						
Same alliance experience	-0.07† (0.04)	-0.07† (0.04)	-0.08* (0.04)	-0.07† (0.04)	-0.07† (0.04)	-0.09* (0.04)	-0.09* (0.04)
Other alliance 1	0.00 (0.00)	0.00 (0.00)	0.00† (0.00)	0.00 (0.00)	0.00 (0.00)	0.00† (0.00)	0.00† (0.00)
Other alliance 2	-0.00*** (0.00)						
Experience year 1	-0.00 (0.00)						
Experience year 2	-0.01*** (0.00)						
Constant	0.37*** (0.08)	0.25** (0.08)	0.41*** (0.08)	0.28*** (0.08)	0.15 (0.11)	0.66*** (0.10)	0.45*** (0.11)
Year fixed effect	Included						
Tech fixed effect	Included						
Chi ²	2567	2646	2583	2659	2663	2639	2708
df	56	57	57	58	58	58	60

Robust standard errors are in parentheses. n = 18,575.

† p < 0.10

* p < 0.05

** p < 0.01

*** p < 0.001

Table 4. Negative Binomial Estimates for Technological Value and Two Types of Technological
Diversity

VARIABLES	(1)	(2)	(3)	(4)	(5)	(6)	(7)
RTD	-0.29*** (0.07)	-0.30*** (0.07)	-0.24** (0.07)	-0.26*** (0.07)	-0.08 (0.14)	-0.11 (0.16)	0.10 (0.20)
DTD	0.26** (0.10)	0.25** (0.10)	0.34*** (0.10)	0.32** (0.10)	0.44** (0.16)	-0.05 (0.13)	0.12 (0.18)
Team size		0.03*** (0.01)		0.03*** (0.01)	0.07*** (0.02)		0.06** (0.02)
RTD X team size					-0.05† (0.03)		-0.05† (0.03)
DTD X team size					-0.04 (0.03)		-0.04 (0.03)
Exploratory degree			-0.10* (0.05)	-0.09† (0.05)		-0.71*** (0.18)	-0.64*** (0.17)
RTD X exploratory degree						-0.05 (0.27)	-0.08 (0.27)
DTD X exploratory degree						1.17*** (0.28)	1.08*** (0.28)
Claims	0.01*** (0.00)						
References	0.01*** (0.00)						
International alliance	0.02 (0.03)	0.05† (0.03)	0.02 (0.03)	0.05† (0.03)	0.05† (0.03)	0.03 (0.03)	0.06† (0.03)
Prior patents 1	0.00*** (0.00)	0.00*** (0.00)	0.00*** (0.00)	0.00*** (0.00)	0.00*** (0.00)	0.00** (0.00)	0.00** (0.00)
Prior patents 2	0.00*** (0.00)						
Same alliance experience	-0.10* (0.04)	-0.10* (0.04)	-0.10** (0.04)	-0.10* (0.04)	-0.10** (0.04)	-0.11** (0.04)	-0.10** (0.04)
Other alliance 1	0.00† (0.00)						
Other alliance 2	-0.00*** (0.00)						
Experience year 1	-0.00 (0.00)						
Experience year 2	-0.01*** (0.00)						
Constant	0.50*** (0.09)	0.38*** (0.09)	0.51*** (0.09)	0.39*** (0.09)	0.25* (0.12)	0.68*** (0.10)	0.43*** (0.12)
Year fixed effect	Included						
Tech fixed effect	Included						
Chi ²	2630	2697	2636	2703	2725	2673	2749
df	57	58	58	59	60	60	63

Robust standard errors are in parentheses. $n = 18,575$.

- † $p < 0.10$
- * $p < 0.05$
- ** $p < 0.01$
- *** $p < 0.001$

Table 5. The Interaction Effect between Two Types of Technological Diversity

VARIABLES	(1)	(2)	(3)	(4)
RTD	-0.62*** (0.17)	-0.53** (0.17)	-1.42** (0.49)	-1.32** (0.49)
DTD	0.12 (0.12)	0.20 (0.13)	-0.06 (0.24)	-0.05 (0.26)
RTD X DTD	0.80* (0.37)	0.65† (0.37)	2.23* (1.00)	1.99* (1.00)
Team size		0.03*** (0.01)		0.04*** (0.01)
Exploratory degree		-0.08† (0.05)		0.03 (0.09)
Claims	0.01*** (0.00)	0.01*** (0.00)	0.01*** (0.00)	0.01*** (0.00)
References	0.01*** (0.00)	0.01*** (0.00)	0.01*** (0.00)	0.01*** (0.00)
International alliance	0.03 (0.03)	0.05† (0.03)	-0.11* (0.06)	-0.09 (0.05)
Prior patents 1	0.00*** (0.00)	0.00*** (0.00)	0.00 (0.00)	0.00 (0.00)
Prior patents 2	0.00*** (0.00)	0.00*** (0.00)	0.00*** (0.00)	0.00*** (0.00)
Same alliance experience	-0.10* (0.04)	-0.10* (0.04)		
Other alliance 1	0.00† (0.00)	0.00† (0.00)	0.00 (0.00)	0.00 (0.00)
Other alliance 2	-0.00*** (0.00)	-0.00*** (0.00)	-0.01*** (0.00)	-0.01*** (0.00)
Experience year 1	-0.00 (0.00)	-0.00 (0.00)	0.00 (0.00)	0.00 (0.00)
Experience year 2	-0.01*** (0.00)	-0.01*** (0.00)	-0.01*** (0.00)	-0.01*** (0.00)
Constant	0.56*** (0.09)	0.44*** (0.09)	0.48** (0.17)	0.31† (0.17)
Year fixed effect	Included	Included	Included	Included
Tech fixed effect	Included	Included	Included	Included
Observations	18,575	18,575	5,374	5,374
Chi2	2644	2713	906.3	908
df	58	60	51	53

Robust standard errors are in parentheses.

† p < 0.10

* p < 0.05

** p < 0.01

*** p < 0.001

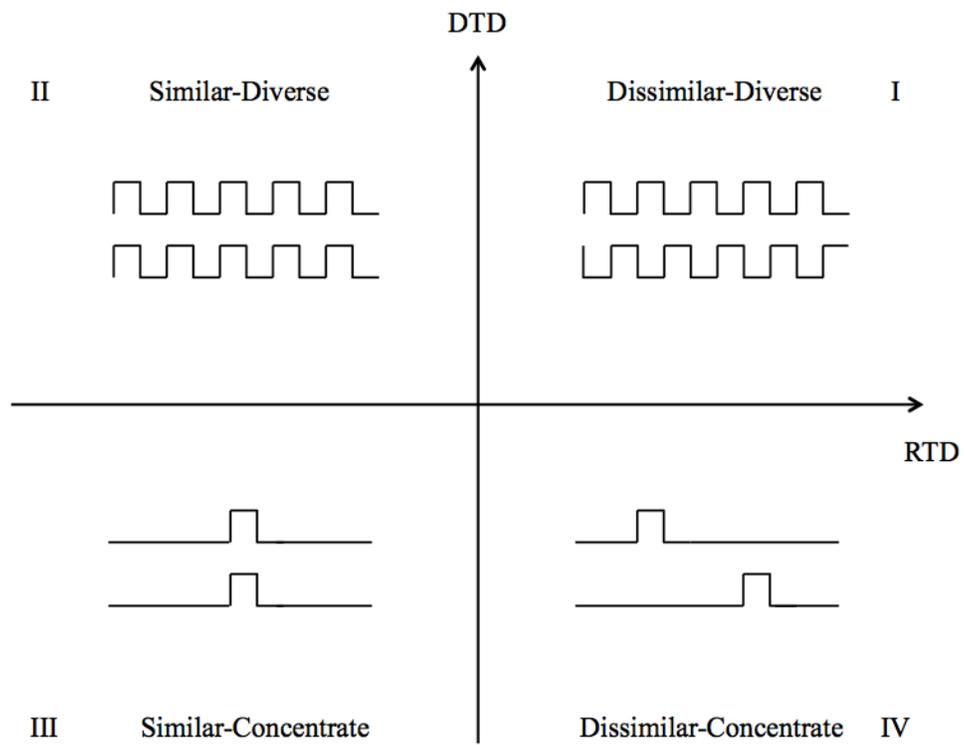


Figure 1. Four Types of R&D Collaboration

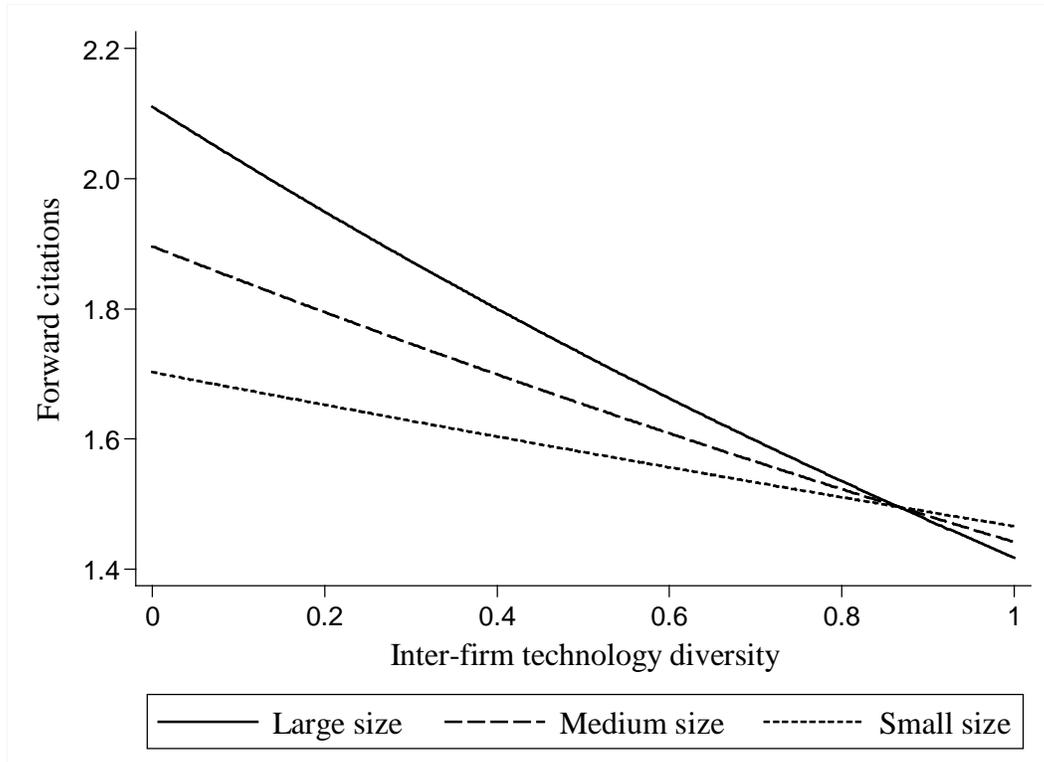


Figure 2. Moderation Effect of Team Size on RTD

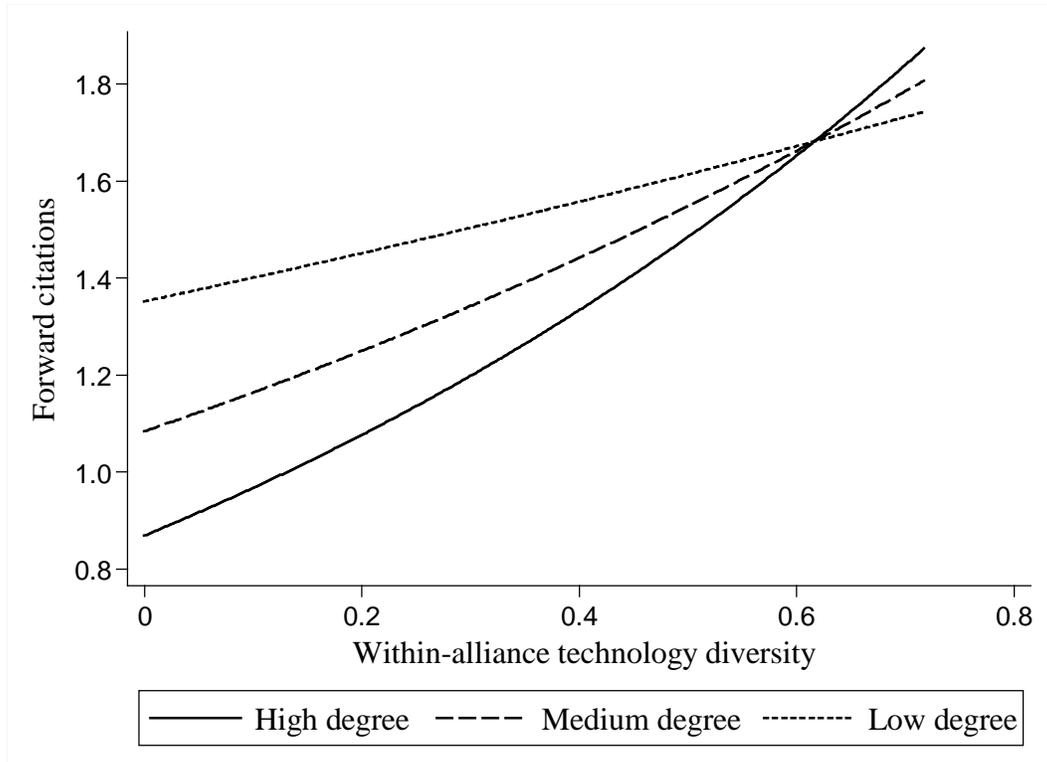


Figure 3. Moderation Effect of Exploratory Degree on DTD