Tezukayama RIEB Discussion Paper Series No. 25

The choice of collaboration to engage in exploration and exploitation

Masayo Kani

Faculty of Economics and Business Management, Tezukayama University

May 2019

Preliminary version

Tezukayama University

Research Institute for Economics and Business

7-1-1 Tezukayama, Nara 631-8501, Japan

The choice of collaboration to engage in exploration and exploitation

Masayo Kani[a]

Abstract

Using a Japanese patent database, this paper provides empirical analyses to enhance understanding about how firms choose collaborative research at the level of an individual patent technology. To assess whether the technology field belongs to the balance between exploration and exploitation, we measure the technological distance between a focal patent technology and a patent portfolio of a firm. We find that a firm is likely to undertake collaborative research in the more explorative technology field when it is especially dissimilar from the company's existing patent portfolio. Furthermore, using the U-curve model, findings suggest that a firm has an incentive to collaborate in the cases of balancing between exploration and exploitation but remains likely to focus on exploration.

Keywords: collaboration; technological distance; patent; exploration-exploitation; firm dynamics.

JEL classification: O31; O32; L20

1. INTRODUCTION

Scholars in economics have been interested in resource allocation. Firm entry and exit and product switching within firms require resource reallocation, and entry and exit induces industry dynamics. Bernard et al. (2010) show that 54 percent of U.S. manufacturing firms

[a] Faculty of Economics and Business and Management, Tezukayama University, 7-1-1 Tezukayama, Nara 631-8501, Japan. E-mail address: mkani@tezukayama-u.ac.jp, tel: +81-742-48-7148.

engage in product switching. Specifically, they change their mix of five-digit Standard Industrial Classification categories by using U.S. census data. Efforts at product switching in Japanese manufacturing firms, though, are lower: 33 percent (Kawakami and Miyagawa, 2010).

The issue of product switching is related to dynamic capabilities discussed in management literature. Dynamic capabilities are capabilities "to create, deploy, and protect the intangible assets that support superior long-run business performance" (Teece, 2007, p.1319; Teece et al. 1997). In fact, capabilities facilitating renewal of competences to address changing environments achieve sustainable performance (Danneels, 2002). Teece (2012) indicates that Japan's unstable economy since the 1990s is a result of absence of dynamic capabilities. Indeed, empirical evidence shows that Japanese manufacturing firms are unlikely to switch products (Kawakami and Miyakawa, 2010). Seemingly, then, the lack of dynamic capabilities prevents resource integration, creation, and redeployment, thus not engendering product switching.

Considering firm dynamics, whether a firm integrates, creates, and redeploys internal and external resources is crucial. In this paper we investigate integration, creation, and redeployment of internal and external technology knowledge. Chiefly focusing on collaborative research as an activity of resource reallocation, we examine two major issues: (1) what type of technology leads a company to engage in collaborative research and (2) whether the choice of collaborative research depends on organizational characteristics.

This remainder of this paper is structured as follows: Section 2 presents pertinent literature and develops the theoretical hypotheses. Section 3 describes the study's data and variables used for our empirical model. Section 4 discusses the results of an econometric analysis, and section 5 offers conclusions.

2. THEORETICAL DEVELOPMENT

2.1 Exploration-exploitation

As for the types of research activities, exploratory and exploitation are major concepts for understanding various behaviors of a firm. The concepts of exploration and exploitation are derived from March's (1991) framework in organizational learning. March (1991, p.85) addresses their essence. Exploration is "experimentation with new alternatives," and exploitation is "refinement and extension of existing competences." When considering knowledge management through the lens of exploration-exploitation, exploration is knowledge development used for changing the scope of an organization's existing knowledge base and skills; exploitation, alternatively, is knowledge utilization of the organization's existing knowledge base (Leivinthal and March, 1993).

2.2 Exploration-exploitation and alliance

Scholars have had interest in addressing the relationship between exploration-exploitation and strategic alliances. Koza and Lewin (1998) argue that the choice of entering an alliance is characterized in terms of the motivation to exploit an existing capability or to explore new opportunities. Rothaermel and Deeds (2004) discuss the new product development system integrated with several components: exploration alliances, products in development, exploitation alliances, and products on the market. In their framework, exploitation alliance is correlated with firm size. Beckman et al. (2004) indicate that a large firm is likely to engage in an exploration alliance owing to its internal resources. Santoro and Chakrabarti (2002) show that a large firm makes relationship with universities for knowledge transfer and research supports in non-core fields, while SME conduct collaboration with universities in core filed. Thus, we presume that a large firm tends to conduct collaborative research in the field of exploration.

Previous studies on alliances debate the issue of whether a firm is likely to participate in an alliance in exploration or exploitation. To date, though, virtually little published work has examined whether the individual technology is exploration or exploitation in the technology *portfolio* of a firm. Accordingly, we examine the relationship between a type of the individual technology and collaboration.

2.3 Balancing exploration-exploitation

Lavie et. al. (2010) proffers the exploration-exploration continuum, though some studies propose that they represent a dichotomy, not a continuum. We consider that the choice of collaboration is relevant to the degree of the exploration-exploitation. To assess the balance between exploration and exploitation, we use the measurement of technological distance between a focal technology and a patent portfolio.

3. EMPIRICAL METHODOLOGY

3.1 Data

In this study, we construct a dataset combining four data sources: Institute of Intellectual Property patent database (IIP-DB), Tamada DB, NISTEP Dictionary of Corporate Names, and the financial data from the Development Bank of Japan.

IIP-DB is an individual patent database that provides information about patent applications from 1964 to 2016, as derived from the Japan Patent Office standardized data (Goto and Motohashi, 2007; Nakamura, 2016). The IIP-DB contains five data tables: application, applicant, inventor, rights holder, and citation. Note that we use another database for citations, as the citation data in IIP-DB consist of information cited by patent examiners. Examiners provide reasons for rejecting applications and prior art that should take first priority and follow it. Although examiners' citations can be useful, we utilize inventors'/applicants' citations from another database: the Tamada DB from Artificial Life Laboratory (Tamada et al., 2006; Ikeuchi et al., 2017). We employ the inventor citation data published between 1993 and 2012.

During a company's duration, changes occur, such as a name change, merger, or restructuring. Therefore, we give a new identification code that tracks name changes using the NISTEP Dictionary of Corporate Names; it enables us to trace company history. Because this database also provides a security code, we can access financial data from the Development Bank of Japan that contain unconsolidated accounting data since 1960 and consolidated data since 1978.

3.2 Variables

Based on this dataset, we examine the relationship between collaborative research and technology position in a patent portfolio.

3.2.1 Technological distance

We assess technology position using methods from the field of economics and management that measure technological distance (Stellner, 2014). There are several types of technological distance: between firms (Jaffe, 1986; Benner and Waldfogel, 2008), between patents (McNamee, 2013), between technology fields (Bloom et al., 2013), and between a patent and a patent portfolio (Akcigit et al., 2016). This study measures technology distance employing technology propinquity from Akcigit et al. (2016). Although Akcigit et al. (2016) assess a distance between two technology classes utilizing IPC's first two digits, we apply the method for the primary IPC technology class at the time of the patent application, or the first three digits, such as A01. Note that we use the primary IPC at the time of patent application publication, which was introduced in 1971, as IPC data on patents prior to 1980 are not available. Let us consider a patent application citing patents from technology classes X and Y. The two technology classes cited simultaneously would be related with each other. Based on this idea, we define a distance between technology classes X and Y as follows:

$$\mathrm{d(X,Y)} = 1 - \frac{\#(X \cap Y)}{\#(X \cup Y)}$$

where $\#(X \cap Y)$ is the number of patents that cite patents from technology classes X and Y simultaneously, and $\#(X \cup Y)$ denotes the number of patents that cite patents from technology classes X and/or Y. The distance measure $\mathrm{d(X,Y)} = 0$ represents patents that always cite patents from both technology classes X and Y, whereas the distance measure $\mathrm{d(X,Y)} = 1,$ if there are no patent citing patents from both technology classes X and Y, then takes on the value from zero to one, $0 \leq \mathrm{d(X,Y)} \leq 1$. The number of technology classes is 126, so the symmetric distance metric consists of 15,876 distance measures.

Next, using the distance metric, we measure how similar a focal patent is to a firm's existing technology development. Let us consider that a firm files a patent p of technology class X_p. We can calculate the distance measures between technology classes X_p and $Y_{p'}$ using the above distance metric, where p' refers to the technology classes in the firm's patent portfolio before the focal patent P_f. The average distance of p to each patent in the firm's portfolio is as follows:

$$\mathrm{d(p,f)} = \frac{1}{\|\mathrm{P}_f\|} \sum_{\mathrm{p'} \in \mathrm{P}_f} d(X_p, Y_{p'}).$$ [1]

The distance measure of a patent p decreases, as the patent p is not close (or similar) to the existing technology of the firm; the measure takes on the value from zero to one, $0 \leq$

[1] Akcigit et al. (2016) define the distance as follows:

$$\mathrm{d(p,f)} = \left[\frac{1}{\|\mathrm{P}_f\|} \sum_{\mathrm{p'} \in \mathrm{P}_f} d(X_p, Y_{p'})^{\iota}\right]^{1/\iota}, 0 \leq \mathrm{d(p,f)} \leq 1.$$

Akcigit et al. (2016) examine three values of ι, and then the value, $\iota = 2/3$, is chosen for their analysis.

$d(p, f) \leq 1$. The variable of the distance measure between a patent and a firm is referred to as *technological distance*.

'Insert Figure 1 here'

3.2.2 Dependent variables

The binary variable of joint application is referred to as *D_collaboration*. The variable takes on the value of one if the patent application is jointly filed.

3.2.3 Control variables

To control for size of a patent portfolio and firm, the following two variables are used:

Ln(Number of patents): This represents the logarithm of the number of patent applications prior to the patent.

Ln(Asset): This is the logarithm of the firm's total assets in the year filing the patent.

Our dataset consists of patent applications filed between 1980 and 2012, as the IPC data on patents prior to 1980 are not available. Shown in Table 1 are the descriptive statistics and the correlation matrix. Aside from the descriptive statistics for the entire sample (ALL), we present subsamples we create by dividing by 10 years (1980s, 1990s, 2000s, and 2010s).

'Insert Table 1 here'

We note two dataset biases. First, the dataset has truncation bias, owing to using patent applications filed after 1980. The technological distance of patent applications filed in early 1980s are prone to bias, as there can be no existing patent applications in the technology class. Second, the dataset has selection bias, as the sampled firms are limited by the NISTEP Dictionary of Corporate Names: listed firms and firms that have filed more than 100 patent applications. Furthermore, when connecting the financial data from the Development Bank of Japan, the dataset only includes listed firms. To address these biases, we conduct additive analyses.

4. RESULTS

Shown in Table 2 are the parameter estimates of a probit model using a binary variable *D_collaboration* as a dependent variable. The technological distance is positively correlated with collaboration, as shown in model (1) in Table 2. Therefore, we find that a firm is likely to conduct collaborative research when exploring a technology field. To examine whether the likelihood is linear, we add a square term of the technological distance in model (2). The result indicates a U-curve of collaboration for the technological distance, which has a positive sign for the second-order term and a negative sign for the first-order term. Using the parameter estimates in model (2), we dispute the predicted probability of collaboration by the technological distance portrayed in Figure 2. When the patent is the first application of the technology filed, i.e., the most explorative field, of which the technological distance is one, the probability of choosing collaboration is 0.14. Conversely, when a firm develops patents in only one technology field, i.e., the most exploitative field, which means the technological distance is zero, the probability of collaboration is 0.08. A patent with the technological distance of 0.4 indicates the lowest probability of collaboration. These results suggest that a firm has incentive to collaborate with external organizations in the cases of balancing between exploration and exploitation but has a slight propensity to engage in exploration.

'Insert Table 2 here'

'Insert Figure 2 here'

Next, we estimate model (3) and (4) by adding an interaction term of technological distance with firm size to examine whether a U-curve of collaboration for technological distance depends on firm size (as measured by total asset at the time of filing a focal patent). Using estimated parameters in model (4), we present the predicted probabilities by firm size in Figure 3: 10th percentile, 25th percentile, 50th percentile, 75th percentile, and 90th percentile. We find that the higher likelihood of collaboration in a more explorative field increases with firm size.

'Insert Figure 3 here'

Because analyses shown in Table 2 use the dataset of listed companies, the results could have sample selection biases that do not include SME, as mentioned in section 3. We confirm whether the findings are consistent when extending the coverage of firms. The NISTEP Dictionary of Corporate Names includes information on the size of capital stock in a survey year. Instead of utilizing total assets as a measure of firm size, we use a categorical variable for capital stock. Note that the most frequently-listed firms (82.96%) in the previous analyses' categories have capital stock of more than one billion Japanese yen. Portrayed in Table 3 are parameter estimates of a probit model using a binary variable D_collaboration as the dependent variable with a category variable of capital size. The category variable of capital size 10, 100, 1000, and 9999 represents capital size of greater than ¥10M, ¥100M, and ¥1B, as well as an unknown amount, respectively. The reference is under ¥10M. We find the U-curve of collaboration for technological distance, which has a positive sign for the second-order term and a negative sign for the first-order term in model (2). We also depict the results of models that include the interaction term of the category variable of capital size in models (3) and (4). Using the parameter estimates of model (4), shown in Figure 4 is the predicted probability of collaboration by technological distance, divided into capital size. The predicted probabilities increase with technological distance; as such, a firm is likely to engage in collaboration in the field of exploration, though the probabilities have a U-curve in all categories of capital size. Thus, the probability of collaboration is higher for the more explorative field. The lowest probability, however, is not the case when the technological distance is zero.

‘Insert Table 3 here’

‘Insert Figure 4 here’

Shown in Figure 5 is the predicted probability of collaboration by technological distance based on the parameter estimates using data from 1990 to 2012 to address the truncation bias. Recall that this bias is likely to occur because of our using patent applications filed after 1980, as discussed in section 3. Although we find an upward shift in the group of firms possessing under 10M yen, the previous results could have a downward bias. The other groups have similar curves in previous analyses. Consequently, a large firm (capital stock is greater than one billion yen) has a reduced probability of collaboration at each technological distance.

‘Insert Figure 5 here’

To summarize, we find that a firm is likely to undertake collaborative research in a more explorative technology field: that is, when that field is especially dissimilar from the company’s patent portfolio of previous technology development. Furthermore, the results of the U-curve model suggest that a business has incentive to collaborate with external organizations when balancing between exploration and exploitation, but it is still likely to have a preference for exploration. When considering firm size, a large firm with more than one billion yen in capital stock has a reduced probability of collaboration at each technological distance. However, when using data limited to a group of listed large firms, we find a higher likelihood of collaboration in more explorative fields, and the probability increases with firm size.

5. DISCUSSION AND CONCLUSION

In this study, we provide empirical analyses that enhance understanding of how firms choose collaborative research at the level of an individual patent technology. The data are derived from a Japanese patent database. Our interest is on whether the choice of collaboration is relevant to the degree of exploration-exploitation. To assess the balance between exploration and exploitation, we employ the measure of technological distance between a focal patent technology and a patent portfolio of a firm.

In the analysis, we find that a firm is likely to undertake collaborative research in the more explorative technology field: one that is more dissimilar from its current patent portfolio from previous technology development. Furthermore, utilizing the U-curve model, we observe that a firm has incentive to collaborate when balancing between exploration and exploitation, but it still has a preference for exploration. When considering firm size, a large company (one with more than one billion yen in capital stock) has a reduced probability of collaboration at each technological distance. However, when using data limited to listed firms, we find a greater probability of collaboration in the more explorative field, and that likelihood increases with firm size.

A major empirical finding from our analysis is that the choice of collaboration in technological position is correlated with the size of a firm. In this paper, however, we employ crude measures, the size of total assets and capital stock, for firm-size variables. To examine the relationship with other characteristics, such as industry and intensity of R&D, subsequent research is recommended.

Acknowledgements

This research was supported by Grants-in-Aid for Scientific Research JP16K17128 of the Ministry of Education. The author acknowledges helpful comments from the seminar participants at the IIPR workshop.

References

Akcigit, U., Celik, M.A., Greenwood, J. 2016. Buy, keep, or sell: Economic growth and the market for ideas. Econometrica 84(3), 943-984.

Beckman, C.M., Haunschild, P. R., Philips, D.J. 2004. Friends or strangers? Firm-specific uncertainty, market uncertainty, and network partner selection. Organization Science 15(3), 259-275.

Bernard, A.B., Redding, S.J. and Schott, P.K. 2010. Multiple-product firms and product switching. American Economic Review 100(1), 70-97.

Benner, M., Waldfogel, J. 2008. Close to you? Bias and precision in patent-based measures of technological proximity. Research Policy 37(9), 1556-1567.

Bloom, N., Schankerman, M., Van Reenen, J. 2013. Identifying technology spillovers and product market rivalry. Econometrica 81(4), 1347-1393.

Danneels, E. 2002. The dynamics of product innovation and firm competences. Strategic Management Journal 23(12), 1095-1121.

Goto, A., Motohashi, K. 2007. Construction of a Japanese patent database and a first look at Japanese patenting activities. Research Policy 36(9), 1431-1442.

Ikeuchi, K., Motohashi, K., Tamura, R.,Tsukada, N. 2017. Measuring science intensity of industry using linked dataset of science, technology and industry. RIETI Discussion Paper Series 17-E-056.

Jaffe, A.B. 1986. Technological opportunity and spillovers of R&D: Evidence from firms' patents, profits, and market value. American Economic Review 76(5), 984-1001.

Kawakami, A., Miyagawa, T. 2010. Product switching and firm performance in Japan. RIETI Discussion Paper Series 10-E-043.

Koza, M.P., Lewin, A.Y. 1998. The co-evolution of strategic alliances. Organization Science, 9(3), 255-264.

Lavie, D., Steener, U., Tuchman, M.L. 2010. Exploration and exploitation within and across organizations. *Academy of Management Annuals* 4(1), 109-155.

Levinthal, D.A., March, J.G. 1993. The myopia of learning. *Strategic Management Journal* 14(S2), 95-112.

March, J.G. 1991. Exploration and exploitation in organizational learning. *Organization Science* 2(1), 71-87.

McNamee, R.C. 2013. Can't see the forest for the leaves: Similarity and distance measures for hierarchical taxonomies with a patent classification example. Research Policy 42(4), 855-873.

Nakamura, K. 2016. Development, complication and use of IIP Patent Database. Journal of economics & business administration 214(2), 75-90. (in Japanese).

Rothaermel, F.T., Deeds, D.L. 2004. Exploration and exploitation alliances in biotechnology: a system of new product development. Strategic Management Journal 25(3), 201–221.

Santoro, M.D., Chakrabarti, A.K. 2002. Firm size and technology centrality in industry-university interactions. Research Policy 31(7), 1163-1180.

Steller, F. 2014. Technological distance measures: Theoretical foundation and empirics. DRUID Society Conference 2014, CBS, Copenhagen, 16-18 June 2014.

Tamada, S., Naito, Y., Komada, F., Gemba, K., Suzuki, J. 2006. Significant difference of dependence upon scientific knowledge among different technologies. Scientometrics 68(2), 289-302.

Teece, D.J. 2007. Explicating dynamic capabilities: The nature and microfoundations of (sustainable) enterprise performance. Strategic Management Journal 28(13), 1319-1350.

Teece, D.J. 2012. Dynamic Capabilities and Strategic Management: Organizing for Innovation and Growth (Japanese Edition). Oxford University Press, New York.

Teece D.J., Pisano, G., Shuen, A. 1997. Dynamic capabilities and strategic management. Strategic Management Journal 18(7), 509-533.

Tables and Figures

Table 1. Descriptive statistics and correlation matrix

		D_collaboration	Technological Distance	Number of patents	Asset
1980	n	1912022	1912022	1,912,022	1,912,022
	mean	0.0933	0.856	56,067	1,217,304,295
	median	0	0.91	23,986	859,851,000
	sd	0.291	0.149	63,892	1,255,907,611
1990	n	2365494	2365494	2,365,494	2,365,494
	mean	0.111	0.846	76,813	1,664,813,905
	median	0	0.895	28,099	1,013,654,000
	sd	0.314	0.157	97,476	1,840,701,844
2000	n	2224848	2224848	2,224,848	2,224,848
	mean	0.107	0.829	94,225	1,792,071,794
	median	0	0.883	34,711	949,547,000
	sd	0.309	0.178	121,150	2,138,340,629
2010	n	467452	467452	467,452	467,452
	mean	0.0979	0.821	107,547	1,892,817,820
	median	0	0.875	38,534	1,029,066,000
	sd	0.297	0.187	135,828	2,307,309,371
Total	n	6969816	6969816	6,969,816	6,969,816
	mean	0.104	0.842	78,741	1,597,963,091
	median	0	0.894	29,565	952,888,000
	sd	0.305	0.165	102,672	1,859,674,302

	1	2	3	4
1 D_collaboration	1			
2 Technological Distance	0.056	1		
3 ln(Number of patents)	−0.087	0.322	1	
4 ln(Asset)	0.006	0.327	0.837	1

Table 2. Choice on collaboration for listed firms by probit model

Dependent variable: D_collaboration	Base Model	Model (1)	Model (2)	Model (3)	Model (4)
Technological Distance		0.873***	−0.938***	−4.746***	−3.725***
		(0.005)	(0.020)	(0.053)	(0.267)
(Technological Distance)^2			1.296***		0.008
			(0.015)		(0.193)
Technological Distance*Ln(Asset)				0.291***	0.192***
				(0.003)	(0.014)
(Technological Distance)^2*Ln(Asset)					0.032***
					(0.010)
Ln(Number of patents)	−0.220***	−0.233***	−0.230***	−0.236***	−0.234***
	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)
Ln(Asset)	0.256***	0.243***	0.243***	−0.001	0.058***
	(0.001)	(0.001)	(0.001)	(0.002)	(0.005)
Constant	−4.308***	−4.654***	−4.114***	0.052	−0.826***
	(0.012)	(0.013)	(0.014)	(0.046)	(0.093)
N	6969816	6969816	6969816	6969816	6969816
Log likelyhood	−2243794.5	−2223972.5	−2220557.7	−2218059.92	−2217480.9
Pseude-R-squared	0.035	0.044	0.045	0.046	0.046

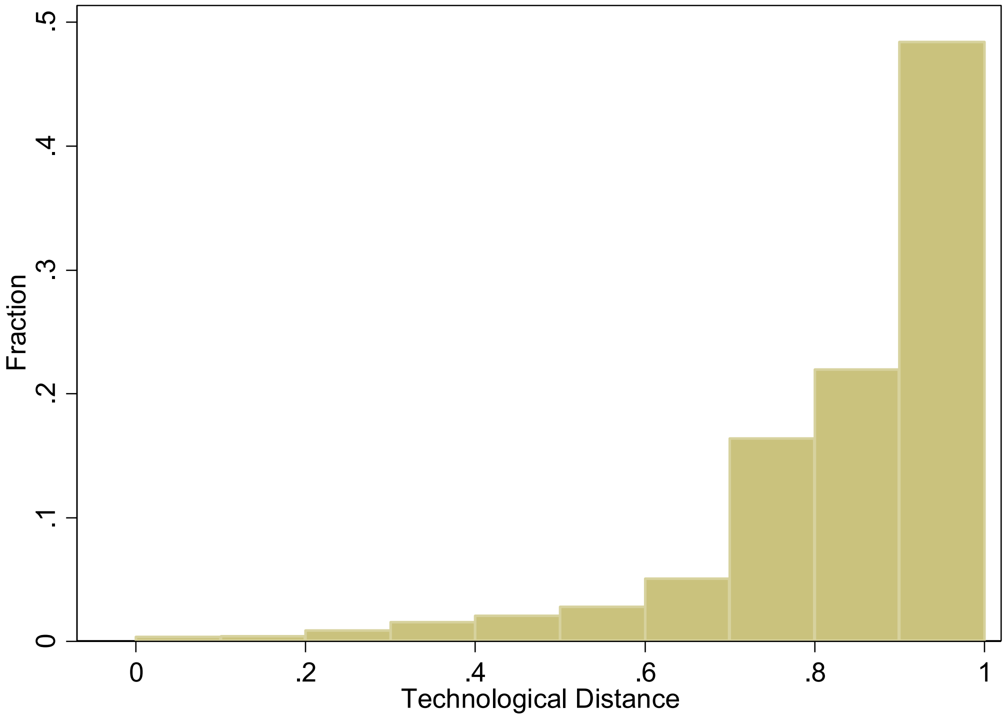
Note: The values indicate parameter estimates in a probit model of choosing collaboration. The values in parentheses are robust standard errors. *, **, and *** denote significance at the 10%, 5%, and 1% levels, respectively.

Table 3. Choice on collaboration for extended samples by probit model

Dependent variable: D_collaboration	Base Model	Model (1)	Model (2)	Model (3)	Model (4)
Technological Distance		0.696***	−0.135***	0.138	1.057**
		(0.003)	(0.011)	(0.125)	(0.495)
(Technological Distance)^2			0.664***		−0.815*
			(0.009)		(0.423)
Ln(Number of patents)	−0.101***	−0.121***	−0.121***	−0.121***	−0.119***
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
Capital size=10 * TD				0.727***	0.481
				(0.125)	(0.497)
Capital size=100 * TD				0.553***	1.044**
				(0.125)	(0.496)
Capital size=1000 * TD				0.775***	−1.689***
				(0.125)	(0.495)
Capital size=9999 * TD				0.141	−1.566***
				(0.125)	(0.496)
Capital size=10 * TD^2					0.177
					(0.425)
Capital size=100 * TD^2					−0.441
					(0.424)
Capital size=1000 * TD^2					1.979***
					(0.424)
Capital size=9999 * TD^2					1.450***
					(0.424)
4 dummy variables of capital size	Yes	Yes	Yes	Yes	Yes
N of obs.	9149679	9149679	9149679	9149679	9149679
N of firms	7551	7551	7551	7551	7551
Log likelyhood	−3376334.8	−3343182.6	−3340637.3	−3337477.1	−3331989.9
Pseude−R−squared	0.035	0.045	0.046	0.047	0.048

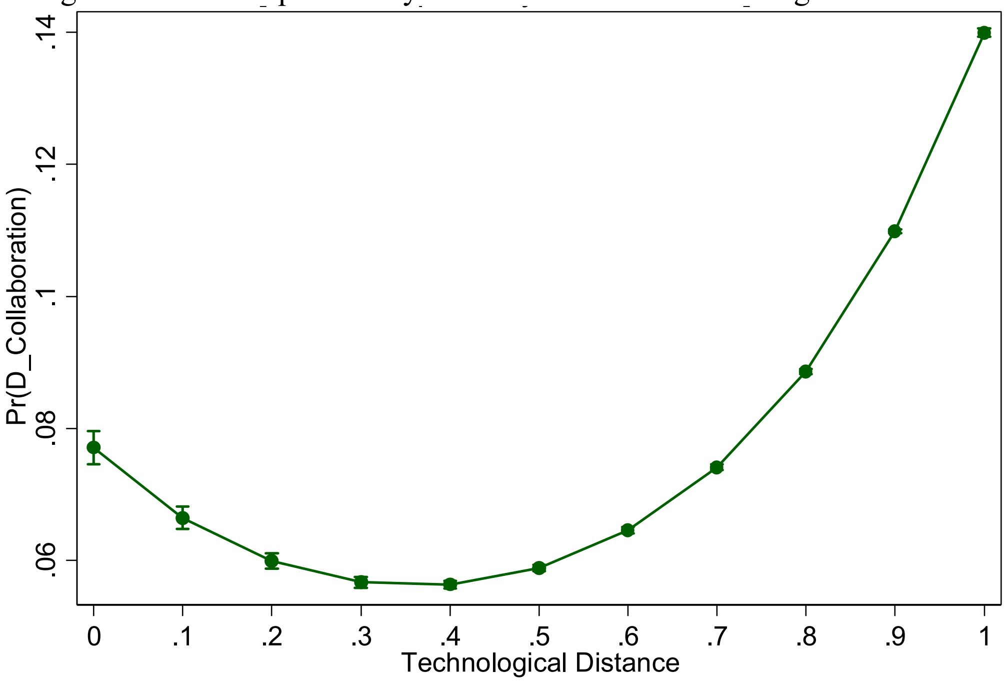
Note: The values indicate parameter estimates in a probit model of choosing collaboration. The values in parentheses are robust standard errors. *, **, and *** denote significance at the 10%, 5%, and 1% levels, respectively. The category variable of capital size 10, 100, 1000, and 9999 represent more than ¥10M, ¥100M, ¥1B, and an unknown amount, respectively. The reference is under ¥10M.

Figure1. Distribution of technological distance



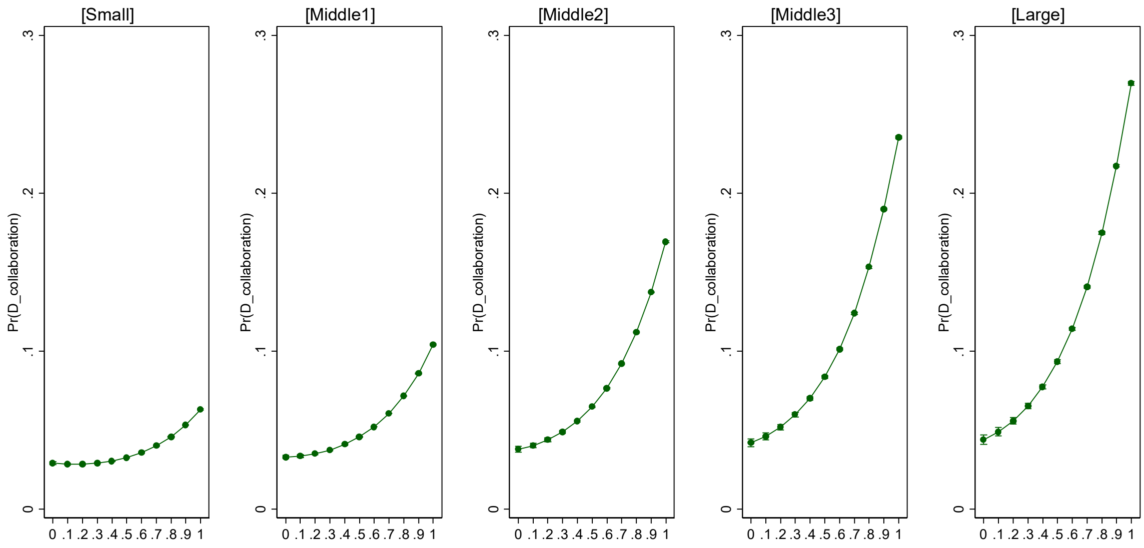
Note: The value shows the share of patents with the technological distance. N = 6,969,816.

Figure2. Predicted probability of collaboration for technological distance



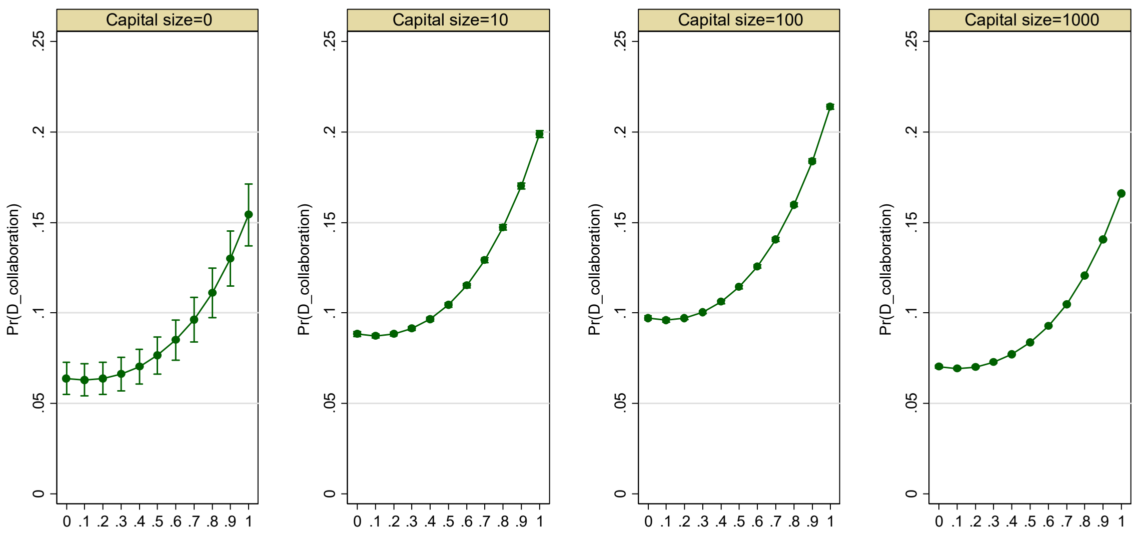
Note: The value is the average predicted probability of collaboration when the focal patent has the technological distance. The lower/upper bounds of 99 percent confidence are shown. Parameters estimated in model (2) of Table 2 are used.

Figure 3. Predicted probability of collaboration for technological distance by firm size



Note: The value is the average predicted probability of collaboration when the focal patent has the technological distance. Small, Middle1, Middle2, Middle3, and Large refer to the size of total assets at 10th, 25th, 50th, 75th, and 90th percentile, respectively. Parameters estimated in model (4) of Table 2 are used.

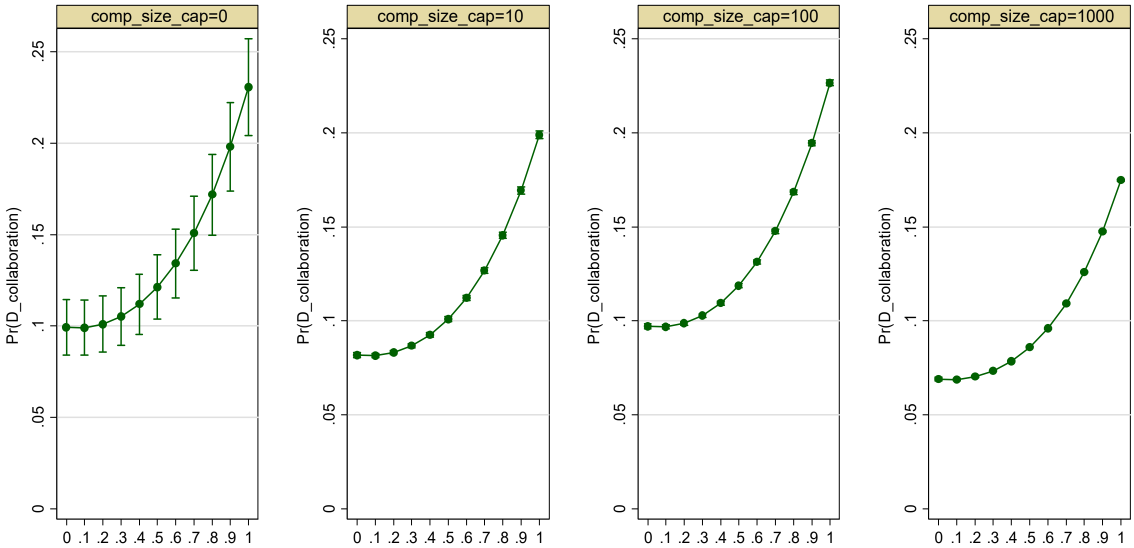
Figure 4. Predicted probability of collaboration for technological distance by firm size



Note: The value is the average predicted probability of collaboration when the focal patent has the technological distance. The category variable of capital size 0, 10, 100, 1000, and 9999 represent under ¥10M, more than ¥10M, ¥100M, ¥1B, and unknown amount, respectively. Parameters estimated in model (4) of Table 3 are used.

Figure 5. Predicted probability of collaboration for technological distance by firm size

(1990-2012)



Note: See figure 6.