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University spillovers into small technology-based firms: channel, mechanism, and geography

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Abstract This study examines how university knowledge spills over into small technology-based firms in Japan. Estimated Heckman selection models taking into account the timing of university-industry research collaboration and geographical proximity to spillover pools reveal that cooperative research with universities positively affects R&D productivity of small technology-based firms with a three-year lag. Among small technology-based firms that collaborate with universities in research, firms with local ties have a greater advantage in improving the quality of their R&D personnel through the acquisition of complementary knowledge. Theoretical and policy implications of empirical results are discussed.

Keywords Spillover · University · Small firms · Cooperative research · Japan

JEL Classification L25 · O33 · M21

1 Introduction

Universities play three important roles in national innovation systems (Mowery and Sampat 2005). First, they educate and provide society with excellent human resources that are critical for economic growth. Second, they engage in basic research that, while not directly associated with any industrial use, can be applied and developed in various technological categories, thereby fostering economic growth in the long run. Third, they act as a source of knowledge for firms that encounter problems in R&D. Recently, the third role of universities in the promotion of economic growth has received a great deal of attention. Empirical studies in Western countries show that small technology-based firms receive significant knowledge spillovers from university research, measured by the rate of return to R&D (Link and Rees 1990), innovation counts or new product development (Acs et al. 1994; Piergiovanni et al. 1997; Rothaermel and Deeds 2004), patents (Audretsch and

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Vivarelli 1996), novel innovations (Romijn and Albaladejo 2002), and sales (Baum et al. 2000).

In Japan, national (ex-imperial) universities[1] have historically been research universities significant enough to act as sources of industrial innovations. However, formal university-industry interactions were limited because of the regulations that scientists at national universities were civil servants, and thus not allowed to consult for private firms (Collins and Wakoh 2000; Kneller 2007a, b). Until the incorporation of national universities, most of university patents were held by the government or by individual academic inventors, neither of whom were motivated to commercialize the outcomes of publicly-funded research. Such institutional obstacles hampered efficient university-industry knowledge transfer (Zucker and Darby 2001). As a result, an informal and long-term relationship between prestigious national universities and large firms, such as the recruitment of competent graduates and voluntary transfer of university inventions, became a significant conduit for transferring university knowledge. Under such circumstances, it was difficult for small technology-based firms to exploit university knowledge for innovation. Despite a series of reforms of the national innovation system since the late 1990s,[2] legal and organizational factors recreate the strong relationship between large firms and leading research universities (Kneller 2007a, b). Thus, small firms continue to have difficulty in accessing university knowledge.

The aim of this study is to quantitatively evaluate the actual impact of university-industry collaborations on small technology-based firms under the reform of national innovation systems (1997–2007) in Japan. The extensive literature reviews identified important research questions on university-industry knowledge transfer, such as the recipients, geographical range, and channel of university spillovers, and determinants of the technology transfer productivity, such as characteristics of firms, universities, technology transfer offices (TTOs), and innovation policies (Bozeman 2000; Agrawal 2001; Breschi and Lissoni 2001; Rothaermel et al. 2007). This study specifically examines the channel, mechanism, and geographical range of university spillovers. The empirical contributions of this study to technology transfer literature can be summarized as follows. First, despite the concern over the effectiveness of cooperative research as a spillover channel in the legal environment, cooperative research is found to act as a spillover channel from academic research to R&D resources of small technology-based firms. Second, indirect effects of research collaborations with universities (i.e., the improvement of the quality of R&D personnel by learning from external sources of knowledge), which is considered to be particularly important for R&D of small technology-based firms, is found to become visible within 3 years and last for at least 5 years. Third, localized university linkage is found to provide small technology-based firms with greater opportunities to benefit from indirect effects more efficiently.

[1] Imperial universities in prewar Japan were Hokkaido University, Kyoto University, Kyushu University, Nagoya University, Osaka University, Tohoku University, and University of Tokyo.

[2] Kneller (2007b) highlights the following important changes in innovation policy. The Technology Licensing Organization (TLO) Act of 1998 legitimized contractual transfers of university inventions to industry. The Japan Bayh-Dole Act (Act on Special Measures for Industrial Revitalization) of 1999 had the same effect as the U.S. Bayh-Dole Act, except that it did *not* apply to *national* universities until they obtained legal status as semi-autonomous administrative entities in 2004. The Industrial Technology Enhancement Act of 2000 established procedures under which university-based scientists can consult for, establish, and manage companies. The National University Corporation Act of 2004 gave national universities independent legal status, allowing them to apply Article 35 of Japan Patent Law, which enables employers to require assignment to them of employee inventions.

The remainder of this paper is organized as follows. Section 2 reviews the previous literature on R&D collaboration and hypothesizes how university-industry collaborations affect R&D productivity of small technology-based firms. Section 3 introduces the econometric model, variables, and data set used for regression analysis. Section 4 presents estimation results and Section 5 discusses the theoretical and policy implications of the key findings.

2 Hypotheses

This section discusses the relationship between R&D cooperation and R&D productivity in general and then proposes hypotheses regarding the impact of university-industry collaborations on R&D productivity of small technology-based firms.

R&D collaborations can be understood as a means of correcting market failure, that is, underinvestment stemming from externalities. Firms are not motivated to invest in R&D when spillovers are large (Arrow 1962). R&D collaborations enable participating firms to internalize externalities and encourage them to invest in R&D (Katz 1986). They also provide participating firms with opportunities to gain complementary knowledge from others, which implies that firms may increase R&D investment to exploit technological opportunities. This skill-sharing in R&D collaborations is particularly effective when participating firms are heterogeneous in terms of technological and commercial capabilities (Sakakibara 1997). The quality of their R&D personnel improves through the acquisition of complementary technological knowledge in R&D collaborations (Branstetter and Sakakibara 1998; Anand and Khanna 2000; Sakakibara 2003). In this sense, skill-sharing has positive implications for both R&D input and R&D productivity. However, firms may participate in R&D cooperation in order to garner knowledge from other firms as much as possible while concealing their own. The concerns about such an asymmetric flow of knowledge are serious when participating firms compete in the same product market (Katz 1986).[3] Thus, opportunistic behavior in R&D collaborations could decrease R&D and deteriorate R&D productivity of participating firms (Khanna et al. 1998; Baum et al. 2000; Branstetter and Sakakibara 2002; Dickson et al. 2006). R&D collaborations also enable firms to conduct product development that otherwise could not have been initiated through cost-sharing. Together, participating firms exert scale economies. R&D collaborations involving cost-sharing are typically formed by a large number of organizations that are homogenous in terms of technological and commercial capabilities (Irwin and Klenow 1996). This cost-sharing has positive implications for R&D productivity of participating firms as individual R&D investment is saved.

University-industry collaborations are more common in basic research than in applied research (Link and Bauer 1989; Link et al. 2002). In basic research, serious conflicts of commercial interest in the product market are rarely a problem, and concerns about the leakage of technological information are not as serious as in interfirm R&D collaborations (Veugelers and Cassiman 2005).[4] These characteristics of university-industry research collaborations suggest that negative implications of skill-sharing are unlikely, which would enable firm scientists to acquire complementary (basic) knowledge from university-based

[3] Relational assets, such as trust, mitigate the dilemma between sharing and appropriating knowledge (Kale et al. 2000).

[4] The risk of leaking valuable knowledge could be serious for a firm whose university partners are the research partners of competitors in a product market.

scientists.[5] Therefore, among the several channels through which R&D collaborations affect R&D productivity, skill-sharing in research collaborations with universities is considered to have an important impact on R&D productivity of participating firms. Although university-industry knowledge interactions do not necessarily have direct outcomes, such as the commercial success of product development, firms can make their R&D personnel more productive by having their scientists acquire complementary knowledge from university-based scientists (Link and Bauer 1989; Link and Rees 1990; Sakakibara 1997; Odagiri and Kato 1998; Sakakibara 2003). Since the improved knowledge resources can be assigned to other R&D projects as well, research collaborations with universities *indirectly* improve R&D productivity of participating firms (Arvanitis et al. 2008).

The inherent difficulties of learning through university-industry collaborations must be mentioned here. First, the efficient transfer of university knowledge requires close interactions between industry- and university-based scientists because of the nature of academic inventions (this will be discussed in more detail later in this section). Second, in a cooperative research contract, it is often difficult to design incentive mechanisms, such as cost share and output distribution. In fact, R&D alliances between universities and biotechnology startups engaged in drug discovery sometimes entail legal disputes on the ownership of intellectual property rights (Rothaermel and Deeds 2004). Third, the coordination between university and industry can be difficult because of the cultural gap between the open science and proprietary technology (Siegel et al. 2003). University-based scientists generally attempt to share their research widely through publication, and as promptly as possible. Firms, however, seek to appropriate knowledge output from research collaborations for as long as possible to secure monopoly profit in the market.

If the quality improvement of R&D personnel through learning offsets the potential difficulties of university-industry collaborations, university-industry collaborations will have a positive effect on R&D productivity of small technology-based firms. It should be emphasized that this study does not focus on the direct outcomes of research collaborations with universities, such as revenue from new products developed through the cooperative research project, which may not appear or may appear after a long period of time (Mansfield 1991). It is assumed that knowledge spillovers through university-industry collaborations improve the quality and usage of knowledge resources that are assigned to other research projects, which may elicit the effect of university-industry research collaborations within a relatively *short* period of time.

On appropriability conditions, small technology-based firms have less complementary assets, such as distribution channels, service networks, and reputation, than their larger counterparts, which means that they do not have the advantage of embodying the outcome of R&D in products and appropriating the return to R&D investment by exploiting complementary assets (Cohen and Klepper 1996). Thus, it would be inappropriate to measure the *indirect* effect of research collaborations with universities by using an indicator such as sales growth (Kollmer and Dowling 2004). In this regard, firms can use strategies other than embodying the outcome of R&D in products, for example R&D-related services and licensing (Stankiewicz 1994; Libaers et al. forthcoming), to commercialize technology.

[5] Although the benefits received by small technology-based firms through cooperative research with universities are highlighted in this study, university-based scientists also learn about the applied technological field from their research partners, which means that the flow of knowledge in collaborative relationships is not unilateral. The impacts of industry engagement on academic productivity significantly vary according to the types of knowledge interactions (Perkmann and Walsh 2008).

Specifically, small biotechnology firms that do not have complementary assets recognize patent licensing as an important mode of commercialization (Kollmer and Dowling 2004). Based on the aforementioned arguments, it is hypothesized that

H1: Research collaborations[6] with universities positively affect R&D productivity of small technology-based firms, measured as the number of patents per R&D personnel, with a relatively short lag.

University-based scientists compete globally, and their achievements are evaluated through the publication of academic papers and number of forward citations received by the paper. Their goal is for their research outcomes to be published in international journals as promptly as possible so that the results will be widely disseminated and cited in the scientific community. Therefore, if university knowledge were to spill over into private R&D, the geographical range of its impact would not be localized. However, previous studies show that the flow of university knowledge is *localized* (Jaffe 1989; Acs et al. 1992; Acs et al. 1994; Mansfield 1995; Audretsch and Feldman 1996; Audretsch and Vivarelli 1996; Anselin et al. 1997; Piergiovanni et al. 1997; Feldman and Audretsch 1999; Autant-Bernard 2001; Acs et al. 2002). In other words, university knowledge spills over into private R&D in a region through some channel, but firms in remote regions will not receive such benefits. This implies that for university research to have positive effects on industrial innovations, the transfer of not only codified knowledge via scientific papers, but also tacit knowledge, is important. One of the main reasons for this lies in the characteristics of university knowledge. Technological knowledge developed at universities tends to be in the embryonic stage (Jensen and Thursby 2001). Therefore, firms attempting to industrialize university inventions need to communicate closely with the academic inventor in order to identify practical applications of the invention (Mansfield 1995). This implies that the geographical distance between universities and firms can be a key factor in the promotion of industrial innovations because, other things being equal, active face-to-face communication and transfer of tacit knowledge are more likely to occur when there is geographical proximity.

Since the seminal work of Jaffe (1989), researchers have paid particular attention to the geographical relationship in university-industry research collaborations. Empirical studies in Western countries show that localized university spillovers are particularly important for the innovative activities of small technology-based firms (Acs et al. 1994; Audretsch and Feldman 1996; Audretsch and Vivarelli 1996; Piergiovanni et al. 1997; Varga 1998; Feldman and Audretsch 1999; Acs et al. 2002; Romijn and Albaladejo 2002). Although no econometric analysis has been conducted on the geographically contingent nature of university spillovers to small technology-based firms in Japan, it is said that university-industry collaborative networks are divided into (1) networks among prestigious research universities and large firms in geographically broader areas and (2) networks among other research universities and small firms in localized areas (NISTEP 2003; Fukugawa 2005). Based on these arguments, it is hypothesized that

H2: Among small technology-based firms that collaborate with universities in research, firms with local ties receive more knowledge spillovers, resulting in higher R&D productivity.

[6] Among the various channels of university spillovers, this study analyzes whether cooperative research acts as an effective channel through which university knowledge spills over into R&D of small technology-based firms.

3 Method

3.1 Model

The econometric models to test H1 and H2 are:

$$Y_{it} = aU_{it-q} + bX_{it} + u_{it} \tag{1}$$

and

$$P^*_{it} = cZ_{it} + v_{it}, \tag{2}$$

where Y is R&D productivity, measured as the log of the number of patents applied for by the firm divided by the number of full-time scientists[7]; U is a binary dummy indicating cooperative research between firms and universities (in order to test H2, UL, a binary dummy indicating cooperative research between the firm and universities located in the same prefecture,[8] is alternatively included[9]); X represents the control variables, which consist of firm age, firm size (measured as the number of employees), the quadratic term of firm size, industry dummies, and time dummies; P^* is a latent variable of patent application and Y can be observed if P^* exceeds a particular threshold; Z represents the determining factors in patent propensity, which consist of R&D intensity (measured as the ratio of scientists to employees), firm age, the number of non-R&D employees,[10] the quadratic term of non-R&D employees, industry dummies,[11] and time dummies; and u and v are error terms. The quadratic term of firm size is included to test the non-linear relationship between R&D productivity and firm size (Cohen 1995). Suffixes i, t, and q denote a firm, time, time lag required for the effect of university-industry collaborations to become visible, respectively. Tables 1 and 2 show sample means by industry and correlation coefficients between variables, respectively.

Since a dependent variable, Y, cannot be observed for firms that do not apply for a patent, a Heckman selection model (Heckit) is introduced to control for the sample selection (Heckman 1976). Forty-six percent of the firms listed in the data set applied for at least one patent, as shown in Table 1. Heckit first estimates the probability of firms' applying for a patent, using a probit model (Eq. 2), and then estimates Eq. 1, incorporated with the inverse Mills ratio computed by probit estimation, using ordinary least squares (OLS).

7 The Heckman selection model requires the error term of the outcome equation (Equation 1) to be normally distributed. Log transformation of the dependent variable is performed to meet this condition.

8 A prefecture is a local unit of governance in Japan. There are 47 prefectures. No finer geographical classification is available from the survey.

9 When the firm collaborates with several universities, UL takes a value of one if there is a local research partner.

10 Since patent application requires firms to possess not only knowledge resources but also administrative resources, the number of non-R&D employees is considered to affect patent propensity. However, the size of administrative resources is uncorrelated to R&D productivity. Therefore, this variable is expected to act as an exclusion restriction in a Heckman selection model.

11 The effectiveness of patents as a means to appropriate the return to R&D investment varies significantly across the industry, which affects patent propensity at the sectoral level (Levin et al. 1984; Arundel et al. 1995; Cohen et al. 2000).

Table 1 Sample mean by industry

Industry	Freq.	Proportion	Age	Employment	R&D intensity	Patents	Patent application	University linkage
Analysis	52	2.0	19	28	0.58	2.5	0.40	0.86
Ceramics	66	2.6	37	65	0.20	1.0	0.28	0.64
Chemical	193	7.6	36	84	0.21	3.7	0.59	0.55
Electronics	577	23.0	26	66	0.31	3.4	0.47	0.54
Food	114	4.5	41	123	0.16	1.6	0.37	0.70
Information	181	7.2	15	30	0.43	1.2	0.29	0.62
Machinery	459	18.2	39	73	0.20	4.6	0.51	0.56
Metal	155	6.1	40	107	0.12	2.8	0.49	0.61
Other manufacturing	250	9.9	31	50	0.24	2.5	0.41	0.45
Other than manufacturing	110	4.3	24	32	0.38	1.0	0.32	0.50
Precision	270	10.7	34	78	0.24	4.5	0.55	0.68
Textile	82	3.2	52	106	0.08	3.4	0.52	0.82
Total	2,509	100.0	32	69	0.26	3.2	0.46	0.58

R&D intensity = the number of scientists/the number of employees; Patent application = proportion of firms applying for at least one patent; University linkage = proportion of firms conducting cooperative research with universities

It takes time for the impact of university-industry collaborations on R&D output to become visible. Several types of lagged structures are introduced to assess how cooperative research with universities affects R&D productivity of small technology-based firms.[12] In a once-lagged model, for instance, if a firm participated in cooperative research with universities in 2001 (note that U indicates the involvement in cooperative research in 2001 and not the initiation of cooperative research in 2001), the number of patents that the firm applied for at the Japan Patent Office (JPO) in 2002 is regarded as R&D output that corresponds to the effect of university-industry cooperative research. In a twice-lagged model, if a firm participated in cooperative research with university-based scientists in 1999 (note that the data set of this study is based on a biannual survey and taking one lag of 2001 means going back 2 years), the number of patents that the firm applied for in 2002 is regarded as R&D output corresponding to university-industry collaborations. It should be borne in mind that this study does not focus on the direct outcomes of cooperative research with universities, which may not appear or may appear after a long period of time. It is assumed that knowledge spillovers through university-industry collaborations improve the quality and usage of knowledge resources that are assigned to other research projects as well, which may elicit the indirect effect of university-industry cooperative research within a relatively short period of time. To capture the timing of the appearance of such indirect effects, the year of patent filing is used to measure R&D productivity because not all the

[12] The contemporary model entails endogeneity (i.e., the significant correlation between the probability of participating in cooperative research with universities and the error term, u). If this is the case, it is difficult to identify causality from the results of the contemporary model. For cross section analysis, an instrumental variable method or treatment regression would be employed to address the endogeneity problem. With panel data, endogeneity is not a problem here.

Table 2 Descriptive statistics and correlation matrix

	N	Mean	SD	Min	Max	1	2	3	4	5	6	7
1. R&D productivity	1,132	−0.90	1.15	−4.74	2.89	1.00						
2. Cooperative research with universities	1,230	0.59	0.49	0	1	−0.01	1.00					
3. Cooperative research with local universities	659	0.59	0.49	0	1	0.07		1.00				
4. The number of employees	2,509	70.93	69.83	1	300	−0.17	0.08	0.13	1.00			
5. Non-R&D employees	2,429	59.73	63.50	0	294	−0.08	0.07	0.14	0.98	1.00		
6. Firm age	2,493	32.55	18.63	0	126	−0.07	0.01	0.10	0.48	0.51	1.00	
7. R&D intensity	2,430	0.26	0.22	0.004	1	−0.16	−0.01	−0.13	−0.45	−0.53	−0.47	1.00

R&D productivity = log(the number of patents applied for by the firm/the number of scientists of the firm); R&D intensity = the number of scientists/the number of employees patents applied for were granted and patent registration can be greatly delayed for many reasons.[13]

3.2 Data

An unbalanced panel, consisting of 10 years (1997–2007) and 723 small technology-based firms, was established using the Institute of Intellectual Property's (IIP) Patent Database[14] and Lattice's Nationwide Research Institutes Directory (NRID). NRID is a biannual survey which provides information on approximately 500 small technology-based firms that Lattice chose.[15] The definition of small technology-based firms in this study has two major components. The first is that the firm must perform R&D, defined as employing at least one full-time scientist. This criterion signifies that the firm invests in R&D since most R&D costs are fixed costs paid to scientists as salaries. The second is that the firm must be small in size, defined according to the Small and Medium-sized Enterprise (SME) Basic Law. In the manufacturing industry, firms with 300 or fewer employees (100 or fewer employees before the amendment of the SME Basic Law in 1999), or firms with a capitalization of 300 million JPY or less, are regarded as small firms. The threshold applied varies according to industry. Since the empirical period (1997–2007) of this study encompasses the amendment of the SME Basic Law, different criteria were used according to time. Information on small technology-based firms from biannual surveys conducted in 1997, 1999, 2001, 2003, 2005, and 2007 was collected.

4 Results

Table 3 shows estimation results of Heckman selection models. The main findings from the estimation results are threefold. Implications of the first and second findings are discussed in detail in Section 5. First, the results show that cooperative research with universities positively affects R&D productivity of small technology-based firms, which supports H1. It takes 3 years for the effect to become visible, as shown in Model 2, and the effect lasts at least 5 years, as shown in Model 3 (note that a once-lagged structure means going back 2 years since the data set is based on a biannual survey). A significantly positive correlation between error terms indicates that unobservable factors encouraging firms' patent filing positively affect R&D productivity.

Second, as shown in Model 4, there is a significant difference in the impact of university-industry collaborations on R&D productivity between small technology-based firms with local research partners and those without local research partners. The results of Model 5 also show a positive but less significant ($p = .07$) effect of localized university spillovers. The same is not true of Model 6, which partially supports H2.

[13] Potential drawbacks of patents as a measure of R&D output will be discussed in Section 5.

[14] IIP, an external body of the JPO, compiles and discloses the comprehensive data set of all the patents applied for at the JPO.

[15] Since it is impossible to identify the population of small technology-based firms, it is difficult to confirm the representativeness of the sample used in this study. However, it should be noted that the presence of firms in life science-based sectors (such as biotechnology) in the sample are relatively small. In Table 1, the proportion of small technology-based firms in chemicals (including drugs) is 7.6% and that in foods is 4.5%, which is even lower than that in physical science-based sectors such as electronics (23.0%) and machinery (18.2%).

Table 3 Estimated Heckman selection model

Model	1		2		3		4		5		6	
Lagged structure	1		2		3		1		2		3	
N	1,888		1,725		1,584		1,629		1,535		1,449	
	Coef.	SE	Coef.	SE	Coef.	SE	Coef.	SE	Coef.	SE	Coef.	SE
Dependent variable: R&D productivity (the outcome equation)												
Cooperative research with universities	0.049	0.094	0.221*	0.105	0.287*	0.123						
Cooperative research with local universities							0.270*	0.136	0.283†	0.157	0.210	0.194
Employees	0.260	0.303	0.268	0.336	0.260	0.407	0.628	0.478	0.513	0.478	0.550	0.557
Employees^2	−0.035	0.100	−0.061	0.109	−0.013	0.131	−0.167	0.151	−0.148	0.153	−0.081	0.183
Firm age	−0.006†	0.004	−0.001	0.043	0.004	0.005	−0.007	0.005	0.001	0.005	−0.003	0.007
Constant	−2.888**	0.459	−3.319**	0.503	−3.777**	0.640	−3.801**	0.698	−4.426**	0.752	−4.429**	0.813
Correlation between u and v	0.808**		0.810**		0.830**		0.797*		0.814**		0.865**	
	dy/dx	SE	dy/dx	SE	dy/dx	SE	dy/dx	SE	dy/dx	SE	dy/dx	SE
Dependent variable: patent application dummy (the selection equation)												
R&D intensity	0.530**	0.056	0.464**	0.055	0.389**	0.051	0.424**	0.052	0.352**	0.047	0.261**	0.040
Non-R&D employees	0.071**	0.006	0.059**	0.006	0.047**	0.005	0.060**	0.005	0.047**	0.005	0.032**	0.004
Non-R&D employees^2	−0.207**	0.025	−0.169**	0.023	−0.140**	0.021	−0.176**	0.022	−0.134**	0.019	−0.092**	0.016
Firm age	−0.029**	0.007	−0.012†	0.006	−0.004	0.062	−0.027**	0.006	−0.010†	0.005	−0.028	0.049
Log likelihood	−1,993		−1,544		−1,129		−1,272		−977		−690	

Coefficients in the selection equation represent the marginal effects. All regressions include year and industry dummies

R&D productivity = log(the number of patents applied for by the firm/the number of scientists of the firm); cooperative research with (local) universities = a binary dummy indicating cooperative research with (local) universities; patent application dummy = a binary dummy indicating the firm's applying for at least one patent; R&D intensity = the number of scientists/the number of employees

The level of significance: ** $p < .01$; * $p < .05$; † $p < .1$

Third, the results of Eq. 2 (the lower part of Table 3) show that more R&D-intensive firms tend to apply for patents more positively. This implies that, among small technology-based firms that have less complementary assets, patents act as an important method to appropriate innovative returns as they invest more in knowledge resources. The results also show that the relationship between firm size and patent application is non-linear (Lotti and Schivardi 2006). Model 1 shows that the probability of applying for a patent continues to increase until the number of non-R&D employees reaches 171, and then declines. However, the decreasing portion of the inverse U-shaped curve is narrow, since 171 is beyond the 90th percentile of the distribution of this variable. Similar results are found in the other models. Therefore, it can be said that the patent propensity of small technology-based firms increases as firm size, measured by non-R&D employees, increases. The results imply that smaller firms have difficulty in applying for patents because they lack administrative resources (Brouwer and Kleinknecht 1999). As firms grow, they can afford to retain the administrative resources required for patent filing, which increases the probability of applying for patents.

5 Discussions

The actual impact of university-industry cooperative research networks is quantitatively evaluated, focusing on the innovation advantage of small technology-based firms. This section reports several implications, derived from key empirical findings, for the design and evaluation of policies to promote university spillovers and concludes with an agenda for future research.

5.1 Channel of university spillovers

Previous studies have identified several university spillover channels, such as joint supervision of Ph.D. students (Schartinger et al. 2001), coauthorship (Cockburn and Henderson 1998), labor mobility (Odagiri et al. 1997), licensing of university patents (Shane 2002), academic startups (Markman et al. 2004), and consultation as a scientific adviser (Audretsch and Stephan 1996). Among the various channels of university spillovers, this study finds that cooperative research acts as an effective channel through which university knowledge spills over into R&D of small technology-based firms. This evidence has peculiar implications in the Japanese context. From a legal perspective, cooperative research has been considered as a means for large firms to preempt outcomes of publicly-funded research (Kneller 2007a, b).[16] Unlike US Patent Law, Japan Patent Law (Article 73) does not allow a co-owner (in this case the university) to transfer or license jointly-owned patents to other firms without the permission of other co-owners (in this case the industry partner). This legal environment offers large firms a great advantage to preempt the outcomes of university research through cooperative research (Kneller 2007a, b). The industry partner may not intend to use a joint invention internally.[17] Given the legal environment, the industry partner may exploit a channel of cooperative research as a means

[16] The number of university-industry cooperative research projects rapidly increased since the 1980s, which also increased the number of jointly-owned patents between universities and firms (Collins and Wakoh 2000).

[17] A university cannot commercialize the joint invention through internal use. In addition, the legal environment makes it difficult for the university to license the jointly-owned patents to other firms.

to block competitors, to use its own patents (defensive patenting), or to expand the patent portfolio in preparation for negotiations with other firms (cross licensing),[18] which suggests the *absence* of knowledge spillovers, rather than the acquisition of complementary knowledge from academic research.

Despite the concern about the effectiveness of cooperative research as a spillover channel in the legal environment, the results show that small technology-based firms effectively exploit cooperative research networks to university-based scientists as a source of knowledge. First, small technology-based firms have difficulty in doing the same as large firms due to their limited social capital, such as personal connections to university-based scientists and experience in research collaborations with them. Second, and more importantly, patent strategies significantly vary according to firm size, with smaller firms more likely to patent their inventions to enhance their reputation in the business community rather than to block their competitors (Giuri 2005; Nagaoka and Walsh 2009). Therefore, for small technology-based firms engaged in research collaborations with universities, it seems that the acquisition of complementary knowledge is more important than preemption. The implication for this finding is that policy initiatives to mediate between universities and small technology-based firms in the conduct of cooperative research will have positive effects on small technology-based firms through improving their knowledge resources. In this regard, previous studies conducted in various regions suggest that nurturing gatekeepers connecting different realms is the key for the promotion of knowledge interactions between industry and science (Westhead and Batstone 1999; Frisch and Lukas 2001; Santoro and Chakrabarti 2002; Balconi et al. 2004; Cassi et al. 2008; Molina-Morales and Martínez-Fernández 2010). Considering the relative disadvantage of small firms in establishing personal connections to university-based scientists, policy instruments to strengthen intermediation between the two, undertaken by coordinators at regional cooperative R&D centers (Collins and Wakoh 2000), business incubators, and local public technology centers (Fukugawa 2005), is of high importance.

5.2 Mechanism of university spillovers

Since university-industry collaborations are more common in basic research than in applied research, it may take some time for university knowledge to spill over into private R&D. In this regard, the results show that the impact of cooperative research on R&D productivity of small technology-based firms becomes visible within 3 years, which is consistent with the findings of a previous study in Japan (Motohashi 2005). This evidence is also consistent with the findings that forward citations of university patents reach the peak in 2 or 3 years from the registration of patents (Bacchiocchi and Montobbio; 2009). As prior studies suggest (Link and Bauer 1989; Odagiri and Kato 1998), the involvement of university-industry cooperative research encourages small technology-based firms to gain complementary technological knowledge, and the knowledge resources improved through such collaborations can be assigned to other R&D projects as well, eventually increasing R&D productivity of the firm as a whole. The results further indicate that the indirect effect lasts at least 5 years, which is a long period of time in relation to the average firm age of this sample (32 years). Small technology-based firms are likely to engage in cooperative research with universities when seeking an immediate solution to a clearly defined problem in their core technological field (Santoro and Chakrabarti 2002; Perkmann

[18] Note that smaller firms are unlikely to patent their inventions for the purpose of blocking (Giuri 2005). Such strategic behavior to maintain the market power is typically observed in larger firms.

and Walsh 2008). In this respect, the results suggest that cooperative research also acts as a knowledge transfer channel, contributing to longer-term R&D capability building of small technology-based firms.

Considering that the survival and growth of small technology-based firms with less complementary assets rely heavily on the quality of knowledge resources (Teece 1986; Kollmer and Dowling 2004), such indirect and long-term effects of research collaborations with universities are important even in the absence of direct outcomes, such as commercial success of product development. Therefore, in the program evaluation of university-industry collaborations, it is important to take into account the indirect and long-term effects of research collaborations. Focusing exclusively on direct impacts can be misleading because revenue from new products developed through the cooperative research project may appear after a long period of time, or may never appear at all.

5.3 Significance of geography

Previous studies find localized spillover from academic research (Jaffe 1989; Acs et al. 1992; Mansfield 1995; Autant-Bernard 2001), and many studies identify small technology-based firms as significant recipients of localized university spillovers (Acs et al. 1994; Audretsch and Feldman 1996; Audretsch and Vivarelli 1996; Piergiovanni et al. 1997; Feldman and Audretsch 1999; Acs et al. 2002; Gittelman 2007). Among channels through which tacit knowledge is transferred, academic spinoffs and labor mobility are considered as typical drivers of localized knowledge spillovers (Almeida and Kogut 1997; Almeida and Kogut 1999; Almeida et al. 2003). In this regard, the results show that among small technology-based firms engaged in cooperative research with university-based scientists, the firms with localized linkages have greater advantages in improving the quality of their knowledge resources, than firms without local ties. Furthermore, this advantage of geographical proximity in university-industry knowledge transfer seems to become visible immediately (i.e., within 1 year, as shown in Model 4 in Table 3).

The significance of geographical proximity in knowledge transfer between small technology-based firms and universities depends on the nature of innovation that the firm pursues through cooperative research. The results may reflect that the cognitively distant knowledge that is required for novel innovations can be transferred by close communications. The geographical proximity to spillover pools facilitates face-to-face communications with university-based scientists, promoting the efficient transfer of tacit knowledge, which is essential for successful industrial applications of research (von Hippel 1994; Nooteboom 1999; Jensen and Thursby 2001). Another interpretation is that small technology-based firms might have pursued incremental innovations through cooperative research, which implies that the nature of knowledge pursued by the firm is not novel. In this case, localized knowledge spillover might have resulted from limited searching capabilities of firms for external sources of knowledge. Small technology-based firms might have selected the most accessible source of knowledge and searched for the second best only when the first selection was deemed a failure (Beise and Stahl 1999). Since information on the types of innovation that small technology-based firms aim for in their cooperative research projects could not be obtained from the data set, it is difficult to identify the mechanisms underlying geographically constrained university spillovers. However, the relative advantage of having local ties suggests that policy instruments forming research agglomerations would enhance the innovativeness of small technology-based firms through knowledge interactions with universities in the cluster (Nishimura and Okamuro 2011).

5.4 Limitations and future research

This study has several limitations that call for future study. First, a program level data is required for more detailed research. It is difficult to effectively design output distribution in collaborative organizations. R&D productivity of a firm is affected not only by the presence of university-industry collaborations but also by the management of collaborative relationships. For instance, incentive mechanisms designed for the firm, university, faculty, and university-based scientists would have a significant effect on the success of the cooperative research. Second, there are many unpatented inventions, and patents are highly heterogeneous in their value or quality (Levin et al. 1984; Griliches 1990; Trajtenberg 1990; Cohen et al. 2000). For future research, it is necessary to develop an alternative means of capturing the indirect effects of university-industry collaborations with more accuracy. Third, the data set does not provide information on managers' individual backgrounds. Since the innovative activities of small firms heavily rely on the entrepreneur's characteristics, future study should control for manager characteristics, such as educational background. Fourth, the type of recipients may affect the efficiency of university-industry collaborations. For instance, firms with more absorptive capacity (Cohen and Levinthal 1990; Mowery et al. 1996; Kamien and Zang 2000; Fontana et al. 2006; Muscio 2007) are able to exploit university knowledge more efficiently through cooperative research with universities, or firms that establish relational assets, such as mutual trust, may receive spillovers from universities efficiently through research collaborations (Dyer and Nobeoka 2000; Kale et al. 2000; Izushi 2003). Finally, future study should test whether the impacts of university-industry collaborations have changed since the reform of the national innovation system, represented as the incorporation of national universities in 2004. This was not possible in the present study, which used data up until 2007.

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