Chapter 12

International R&D Collaboration in Asia: A First Look at Their Characteristics based on Patent Bibliographic Data

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CHAPTER 12

International R&D Collaborations in Asia: A First Look at Their Characteristics based on Patent Bibliographic Data

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This paper has analyzed whether and how international research collaboration in terms of co-inventions and co-ownership may affect invention performance in three Asian countries: Korea, China, and Taiwan. We focused on the patents which have been applied to the patent offices of a focused country (Korea / China / Taiwan) and also applied to the US Patent Office. Our major findings are the following. First, international collaboration is rare both in terms of co-invention (around 1% or less) and also co-application (less than 1%) in the three countries. Second, internationally co-owned patents tend to be more associated with international co-inventions in all three countries. In addition, more international co-inventions are realized under pure foreign ownership than international co-ownership in China and Taiwan. Third, international co-inventions are strongly associated with more science linkage, that is, more references to scientific literature in Korea and Taiwan, perhaps reflecting the strong absorptive power of these economies, but not in China. Fourth, international research collaborations are associated with higher patent quality, in terms of forward citation, in China and Taiwan, even after we control for the number of inventors and the literature cited.

Keywords: Research collaboration, International co-invention, Patent, Inventors, Research productivity

JEL Classification: O31, O32, O34

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1. Introduction

International research collaborations have become important, as more countries in the world, including East Asian countries such as Korea, China, and Taiwan have significantly strengthened their research capability and as firms globalize their research operations. They may also have become more important as R&D tasks have become more complex, so that they now often require a combination of diverse knowledge input and inventive capability (Jones, 2009).

This research analyzes how international research collaborations have become important and what their consequences are in East Asian countries, based on patent data. An important question is whether and how international research collaborations affect research performance. The combination of inventors from different countries would allow a firm to undertake research which might not have been possible if only the resources of a single-nation inventor could be used and would enlarge the pool of technological or scientific knowledge available for research. It might also facilitate better consideration of local market needs in R&D. Co-ownership by firms with different nationalities might be important for creating incentives for such firms to contribute various resources to the collaborative R&D, including their inventors and their tacit knowledge, even though co-ownership might create a free rider problem or an adverse selection problem.

There is a great deal of literature on research collaboration, focusing on the incidence of co-ownership (for an example, Cassiman and Reinhilde (2002), Hagedoorn, Link and Vonortas (2002) and Hagedoorn (2002)) and on the effects of such research cooperation on the economic performance of a firm (see, for example,

Cockburn and Henderson (1998), Sakakibara (1997), Branstetter and Sakakibara (1998), Lerner and Merges (1998) and see a survey by Siegel (2002)). However, most studies are at firm level (One exception is Mowery, Oxley and Silverman (1996)). This makes it very difficult to assess how research collaboration actually affects the process of knowledge production, such as the scope of the knowledge used for the research.

Our research makes an attempt to grasp the incidence of international research collaborations and their effects in Asia, focusing on the effects on the scope of the use of existing knowledge as well as on the productivity of using such knowledge. Nagaoka and Tsukada (2011) examined international collaborations, using the triadic patent families from Japan, US, and three major European countries (Germany, France, and Great Britain). The major findings are as follows. First, international co-inventions have become increasingly important in recent years, especially in the high tech sectors with strong science linkage. Second, internationally co-applied patents are associated with significantly larger inventor size, except for Japan, indicating that international inter-firm alliances facilitate firms to undertake larger and more complex R&D. Third, international co-inventions are strongly associated with more science linkage per patent, although not with more backward patent citations (large number and lee time lag), indicating that going beyond a border in order to organize an international inventor team is especially important for science-driven inventions.

This research project makes another attempt to assess the effects of international research collaborations on invention performance at patent-family level, focusing on internationally co-invented and/or co-owned patents of the major Asian countries (Korea, Taiwan, Mainland China etc). The driving force for international collaborations may be different in these countries, since there is a fairly large international cost

difference between these countries and the triadic countries. In addition, they may have different market requirements. International investment rather than international alliance may play an even more important role in the engagement of international research collaborations in these countries.

The channels of the effects of international research collaborations are similar to those for the major OECD countries: International collaborations might expand the size of a research team, and therefore the human capital available for research. They might also expand the scope of the knowledge used for invention by enhancing the absorptive capability of the research team and increasing the speed of research. Finally, they might also have a synergy or productivity enhancement effect, that is, they might enhance the productive combination of the knowledge used. The patent level study allows us to examine the effects of research collaborations through these various channels, in order to help us understand how international research collaboration may or may not work.

The paper is organized as follows. Section 2 provides the construction of data set and the description of the structure of invention and ownership of patents. Section 3 provides analysis of the effect of international collaboration on the size of research teams. Section 4 provides analysis of knowledge exploitation. In Section 5, performance of international collaboration is examined. And Section 6 concludes.

2. Structure of International Co-Invention and Co-Ownership

2.1. Data

For this objective, we have developed the data set, using the following patent

database: EPO Worldwide Patent Statistical Database[2] (PATSTAT September 2009 version) released by the European Patent Office. Patent data provides important information: the addresses of the inventors and the owners (or assignees). If inventors of more than two different national addresses work together (international co-invention), it implies that the inventive human resources of different nations are combined. If firms of more than two different national addresses share the ownership of the patent (international co-ownership), it would typically imply that these firms collaborated on the R&D in term of finance, human resources or in another manner. Although co-invention or co-ownership does not cover all research collaborations[3], they would cover an important part of the research collaborations involving the combination of significant resources. Research collaboration defined in these terms has become important in recent years (Nagaoka, Motohashi, and Goto (2010), OECD (2009)).

The unit of analysis in this study is patent family. A new invention often has applications for patent protections in several countries[4]. The set of patent applications share one or more priority filings and is known as a patent family. There are several definitions of a patent family[5]. The difference mainly depends on how far the priority

[2] PATSTAT database are compiled by the trilateral patent offices (European Patent Office, United States patent and Trademark Office, and Japanese Patent Office) and released from the European patent Office. The database contains patent bibliographic data of about 170 countries/regional patent offices.

[3] It is important to note that co-ownership significantly under-represents actual collaborations especially in the US (see Walsh and Nagaoka, 2009). See Hagedoorn (2003) for motivations for co-ownership or joint patenting. Since we use both international co-invention and international co-ownership as measures of international collaborations, our coverage of research collaborations is wider than that based only on international co-ownership.

[4] In addition, multiple patent applications derived from a single earlier patent application are filed to one patent office by using a priority claim based on domestic applications. For example, there is a system of continuing application (continuation application, continuation-in-part application, and divisional application) in the US, divisional application and priority claim based on Japanese application in Japan. There are similar application procedures in the other countries. An invention is often protected by multiple patents, derived by using these application procedures, even in one country.

[5] Martinez (2010) summarized many kinds of definition of patent family.

links among family members are stretched (OECD, 2009). We use the INPADOC patent family. The definition of INPADOC patent family is the following; "all the documents which are directly or indirectly linked via a priority document belong to the same patent family" (OECD, 2009). A patent family of this definition contains all patent application documents from D1 to D5 and priority documents P1, P2, P3 as a family shown in Table A1 of the Appendix.

The PATSTAT database covers the records of patents applied for at many Asian patent offices. It provides information on the patents, such as application number, application date, grant number, grant date, the priority relations, code identifying INPADOC family, although a lot of information is missing in some countries, such as the country code of inventors/applicants. By using INPADOC family as the unit of analysis, however, we can fill in such missing information by using that of corresponding foreign patents in the same family.

We focus on the patent families which have both at least one inventor and one assignee of the patent in one of the East Asian countries. We also extract the detailed citation information from the PATSTAT database, including the citation of non-patent literature (mainly scientific literature), available for US patents in each family (Duplications in forward and backward patent citation have to be removed). Thus, we have to restrict our sample to the patent families which include both the applications to the Patent Office of an Asian country and those to the US Patent & Trademark Office (See the following section for the share of such families). We use the technology classification and the earliest application year of the patents of the family. These patent data provide information both on the structure of inventors and owners, including whether a particular invention involves international co-inventions or whether it

involves international co-ownership. In addition, the extensive citation information available for US patents allows us to assess the quality of the patent as well as the scope of knowledge relevant to the invention process. In particular, the number of forward citations, that is, the frequency by which a particular patent is cited, will tell us the quality of the patent, once we control for the technology and the length during which the citations can be made. The backward citation to the patent and non-patent literature indicates the level of exploitation of prior knowledge in the invention process, although it is an imperfect measure, given that the bulk of citations (especially backward citation to patent literature) are made by an examiner (not by an inventor himself).

2.2. Patent Applications to the Asian Countries

Table 1 shows the total number of patent applications to each Patent Office of all Asian countries, recorded in the PATSTAT database. The four East Asian countries (Japan, China, Korea, Taiwan) have received the largest number of patent applications in the region. The South East Asian countries (Singapore, the Philippines, Indonesia, Malaysia, Thailand and Vietnam) are second in terms of the number of patent applications, if excluding Israel, India, and Turkey. Table 2 shows the time trend of patent applications in 10 countries in East Asia and South East Asia. While most countries experienced a growth in patent applications, there are some exceptions. Malaysia received many patent applications in the 1950s, while the number of patent applications declined in the second period of the 1980s. This is because Malaysia used the *confirmation patent system*, which confirmed the patents granted in the UK, although it was abolished in 1986 (see Table 3 for a summary of a brief history of the patent system). Similarly, the Philippines experienced a decline in patent applications

as recorded in the PATSTAT since the middle part of the 1980s.

Table 1. Total Number of Applications to Asian Countries Included in The EPO PATSTAT Database

Area	Country	appln_auth code	Num. of applications	Focus in the paper
ASEAN	Brunei Darussalam	BN	0	
ASEAN	Cambodia	KH	0	
ASEAN	Indonesia	ID	12,408	*
ASEAN	Lao People's Democratic Republic	LA	0	
ASEAN	Malaysia	MY	10,774	*
ASEAN	Myanmar	MM	0	
ASEAN	Philippines	PH	20,098	*
ASEAN	Singapore	SG	47,518	*
ASEAN	Thailand	TH	189	*
ASEAN	Vietnam	VN	148	*
East Asia	China (HongKong)	HK	68,829	
East Asia	China (Macao)	MO	1	
East Asia	China (Mainland)	CN	1,493,780	*
East Asia	Japan	JP	11,362,260	(*)
East Asia	Korea	KR	1,374,200	*
East Asia	Mongolia	MN	233	
East Asia	North Korea	KP	29	
East Asia	Taiwan	TW	191,114	*
Central Asia	Kazakhstan	KZ	346	
Central Asia	Kyrgyzstan	KG	12	
Central Asia	Tajikistan	TJ	353	
Central Asia	Turkmenistan	TM	1	
Central Asia	Uzbekistan	UZ	38	
South Asia	Afganistan	AF	1	
South Asia	Bangladesh	BD	5	
South Asia	Bhutan	BT	0	
South Asia	India	IN	61,813	
South Asia	Iran	IR	74	
South Asia	Maldives	MV	0	
South Asia	Nepal	NP	0	
South Asia	Pakistan	PK	33	
South Asia	Sri Lanka	LK	122	
West Asia	Armenia	AM	82	
West Asia	Azerbaijan	AZ	62	
West Asia	Bahrain	BH	1	
West Asia	Cyprus	CY	2,591	
West Asia	Georgia	GE	63	
West Asia	Iraq	IQ	14	
West Asia	Israel	IL	146,540	
West Asia	Jordan	JO	9	

Table 1 (continued). Total Number of Applications to Asian Countries Included in The EPO PATSTAT Database

Area	Country	appln_auth code	Num. of applications	Focus in the paper
West Asia	Kuwait	KW	0	
West Asia	Lebanon	LB	108	
West Asia	Oman	OM	1	
West Asia	Qatar	QA	0	
West Asia	Saudi Arabia	SA	9	
West Asia	Syrian Arab Republic	SY	28	
West Asia	Turkey	TR	32,137	
West Asia	United Arab Emirates	AE	36	
West Asia	Yemen	YE	1	

Note: Extracted from table: tls201_appln. Only appln_kind = 'A' or 'T'.
Source: Authors constructed from PATSTAT database.

Table 2. Number of Applications by Application Year

Application Year	Japan	Korea	China	Taiwan	Indonesia	Malaysia	Philippines	Singapore	Thailand	Vietnam
before 1949	1,498	1	1	0	4	3	0	1	0	0
1950	62	0	0	0	0	0	0	0	0	0
1951	79	0	0	0	0	0	1	1	0	0
1952	96	0	0	0	0	0	0	0	0	0
1953	131	0	0	0	0	154	0	0	0	0
1954	145	0	0	0	0	58	0	0	0	1
1955	261	0	0	0	0	51	0	3	0	0
1956	325	0	0	0	0	47	0	0	0	0
1957	457	0	0	0	0	44	0	0	0	1
1958	772	0	0	0	0	48	1	0	0	0
1959	918	0	0	0	0	48	1	0	0	0
1960	1,180	0	0	0	0	74	1	0	0	0
1961	1,336	0	0	0	0	126	1	0	0	0
1962	2,065	0	0	0	0	106	2	0	0	0
1963	2,933	0	0	0	0	111	0	0	0	0
1964	3,527	0	0	0	0	140	2	0	0	0
1965	4,898	1	0	0	0	186	2	0	0	0
1966	7,090	4	0	0	0	144	10	0	0	0
1967	10,510	1	0	0	0	172	7	0	0	0
1968	21,645	2	0	0	0	119	38	0	1	0
1969	41,769	22	0	0	0	414	73	0	0	0
1970	68,247	66	0	1	0	169	143	1	0	1
1971	70,565	112	0	1	0	223	307	0	0	2
1972	120,279	143	1	0	0	129	486	2	0	0

Table 2 (continued). Number of Applications by Application Year

Application Year	Japan	Korea	China	Taiwan	Indonesia	Malaysia	Philippines	Singapore	Thailand	Vietnam
1973	141,876	266	0	2	0	496	716	1	1	0
1974	145,623	1,591	0	2	0	332	823	0	0	0
1975	152,819	889	0	7	1	301	871	1	0	0
1976	158,055	1,090	0	2	0	282	976	2	0	0
1977	158,149	1,417	0	3	0	328	918	1	0	0
1978	163,322	2,244	0	2	0	484	943	1	0	0
1979	172,845	2,803	0	5	1	244	1,020	1	0	0
1980	188,475	3,186	0	6	0	282	1,070	0	0	1
1981	215,281	3,328	0	7	0	378	1,086	3	0	0
1982	233,756	4,752	0	1	8	282	1,109	160	0	2
1983	252,428	6,030	0	4	4	253	1,182	592	1	5
1984	281,634	8,235	5	5	12	400	1,112	848	0	10
1985	300,383	7,396	8,113	6	7	1,125	1,056	675	0	9
1986	316,915	8,362	7,454	15	7	740	1,037	317	0	8
1987	337,285	10,778	7,797	5	9	950	1,040	964	1	3
1988	337,623	12,449	8,917	13	9	166	981	625	1	6
1989	348,518	13,900	9,034	10	15	7	867	831	1	11
1990	367,099	15,334	9,520	18	0	11	541	1,280	0	7
1991	369,831	17,336	10,400	10	58	13	215	1,503	1	0
1992	371,458	19,138	13,349	39	113	22	266	2,562	0	5
1993	366,850	20,757	18,781	175	38	21	438	2,866	3	22
1994	354,975	23,529	23,256	530	32	23	446	4,173	0	17
1995	371,453	34,256	26,902	1,427	43	27	171	2,576	1	5
1996	380,946	39,372	32,252	3,289	477	56	20	2,413	2	0
1997	393,110	39,257	36,861	6,563	4,325	28	10	2,447	7	0
1998	403,434	46,371	40,687	14,698	3,511	30	3	2,289	6	1
1999	405,703	64,580	44,476	18,557	2,737	56	9	2,313	19	1
2000	432,458	79,829	57,623	21,446	906	75	14	2,448	8	0
2001	435,456	83,554	68,738	25,574	50	46	13	2,391	17	2
2002	418,338	85,875	89,880	23,671	4	102	6	1,886	12	6
2003	412,674	96,121	119,311	22,082	5	94	14	1,763	32	4
2004	420,050	118,439	142,547	21,151	5	99	12	2,545	21	1
2005	420,431	144,249	176,492	17,615	8	125	17	2,571	16	7
2006	395,783	149,016	202,872	7,637	6	109	12	1,901	14	2
2007	326,709	145,075	197,912	5,886	13	210	9	1,662	21	8

Table 2 (continued). Number of Applications by Application Year

Application Year	Japan	Korea	China	Taiwan	Indonesia	Malaysia	Philippines	Singapore	Thailand	Vietnam
2008	47,065	56,230	131,271	628	0	11	0	899	3	0
2009	2,498	6,812	9,323	8	0	0	0	0	0	0
9999	164	2	5	13	0	0	0	0	0	0
Total	11,360,762	1,374,199	1,493,779	191,114	12,404	10,771	20,098	47,517	189	148

Source: Authors constructed from PATSTAT database.

Table 3. Intellectual Property Right in Asian Countries

	Establishment of patent law
Japan	The first act was published in 1871, but not enforced, and abolished the following year. The next action was taken in 1885. This is the basis of Japanese patent law. The present patent law is based on legislation from 1959, and has been revised several times.
Korea	Enforced in 1946.
China	Published in 1983, enforced in 1985.
Taiwan	Published in 1944, enforced in 1949.
Indonesia	(N/A)
Malaysia	Published in 1983, enforced in 1986.Under this law, the confirmation patents system, which confirms patents granted in UK, is abolished.
Philippines	Originally 1947. Reformed in 1968, 1998.
Singapore	(N/A)
Thailand	Originally 1979. Reformed in 1992, 1999.
Vietnam	In 1981 "Regulations on Innovations and Inventions". In 1989 "Ordinance on Protections of Industrial Property Rights". In 2006 "Law on Intellectual Property" enforced.

Source: Authors made based on information on the website of Japan Patent Office.

Table 4-(1) shows that the total number of families including applications to the Korean Patent Office, and the ratio of families with applications both to the Korean Patent Office and to the US Patent Office and other patent offices[6] relative to the total number of families including application to Korea. About 27% of families including a Korean patent are applied also to the US in 2005-2007. 20% of families are applied both to Korea and Japan, 22% both to Korea and China. In 1985-1989, larger shares of families were applied to both Korea and US/Japan (more than 60%). It is likely that the major part of these families were applied by US or Japanese firms, since US or Japanese firms considering patent applications to Korea are very likely to apply for patents in their home countries. Recently, the share of these two counties in Korean patents decreased. This might be due to two reasons; firms in many other countries come to apply to the Korean Patent Office, and, perhaps more importantly, Korean firms have increased the number of patent applications made both to the Korean Patent Office as well as to other foreign patent offices. Table 4-(2) provides similar data for China. The number of families including applications to the Chinese Patent Office has increased very significantly since 2000. During the period from 2005 to 2007, 30% of the families are applied to China and US, 25% to China and Japan, 22% to China and the European Patent Office. There are a rather large percentage of families applied to Australia. As shown in Table 4-(3), the share of families applied both to Taiwan and to the US is very large (68%). The families including an application to Singapore are applied not only to the US but also to many other countries (Table 4-(4)).

[6] US: United States, JP: Japan, EP: European Patent Office, KR: Korea, CN: China, TW: Taiwan, SG: Singapore, PH: Philippines, ID: Indonesia, MY: Malaysia, TH: Thailand, VN: Vietnam, AU: Australia.

Table 4. International Patent Applications

(1) Incidence of Families Which Applied to Both Korea and Each Patent Office

Earliest application year in family	Number of families including application to Korean Patent Office	US	JP	EP	CN	TW	SG	PH	ID	MY	TH	VN	AU
1985-1989	56,342	64.4%	69.1%	52.2%	13.8%	0.1%	3.6%	2.9%	0.1%	0.0%	0.0%	0.0%	22.3%
1990-1994	90,134	40.9%	44.0%	28.6%	12.1%	0.6%	2.5%	0.5%	0.1%	0.0%	0.0%	0.0%	9.8%
1995-1999	220,701	22.0%	21.8%	11.6%	10.8%	5.6%	1.2%	0.0%	0.8%	0.0%	0.0%	0.0%	2.9%
2000-2004	500,356	27.8%	24.7%	17.0%	21.5%	5.2%	0.8%	0.0%	0.0%	0.0%	0.0%	0.0%	6.1%
2005-2007	386,874	26.5%	19.9%	16.7%	21.6%	0.4%	0.5%	0.0%	0.0%	0.0%	0.0%	0.0%	4.5%

(2) Incidence of Families Which Applied to Both China and Each Patent Office

Earliest application year in family	Number of families including application to China Patent Office	US	JP	EP	KR	TW	SG	PH	ID	MY	TH	VN	AU
1985-1989	41,960	40.7%	42.5%	38.7%	18.5%	0.1%	2.5%	3.5%	0.1%	0.0%	0.0%	0.0%	21.2%
1990-1994	83,749	41.6%	42.4%	38.8%	13.1%	1.4%	4.3%	1.0%	0.2%	0.0%	0.0%	0.0%	17.4%
1995-1999	179,537	54.1%	55.8%	50.5%	13.3%	12.9%	2.9%	0.0%	4.4%	0.0%	0.0%	0.0%	17.0%
2000-2004	489,786	52.5%	47.2%	40.5%	21.9%	8.1%	1.2%	0.0%	0.0%	0.0%	0.0%	0.0%	15.2%
2005-2007	518,148	30.3%	24.7%	22.0%	16.1%	0.2%	0.5%	0.0%	0.0%	0.0%	0.0%	0.0%	5.0%

(3) Incidence of Families Which Applied to Both Taiwan and Each Patent Office

Earliest application year in family	Number of families including application to Taiwan Patent Office	US	JP	EP	KR	CN	SG	PH	ID	MY	TH	VN	AU
1985-1989	103	94.2%	0.1%	0.2%	0.1%	0.1%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.1%
1990-1994	2,081	90.1%	2.2%	2.0%	0.7%	1.4%	0.3%	0.1%	0.0%	0.0%	0.0%	0.0%	1.2%
1995-1999	55,846	74.6%	72.6%	52.5%	22.3%	41.3%	5.5%	0.0%	5.7%	0.1%	0.0%	0.0%	14.7%
2000-2004	101,296	66.2%	10.6%	6.2%	5.3%	8.1%	0.5%	0.0%	0.0%	0.0%	0.0%	0.0%	1.9%
2005-2007	25,741	67.9%	0.6%	0.1%	0.3%	0.2%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%

(4) Incidence of Families Which Applied to Both Singapore and Each Patent Office

Earliest application year in family	Number of families including application to Singapore Patent Office	US	JP	EP	KR	CN	TW	PH	ID	MY	TH	VN	AU
1985-1989	4,928	88.9%	81.5%	74.7%	41.3%	21.4%	0.4%	8.7%	0.3%	0.0%	0.0%	0.0%	43.0%
1990-1994	8,311	89.8%	86.7%	86.0%	27.3%	43.1%	3.5%	3.4%	0.5%	0.1%	0.0%	0.1%	38.3%
1995-1999	10,641	80.8%	77.7%	60.6%	24.2%	49.4%	28.7%	0.1%	8.1%	0.3%	0.1%	0.0%	18.4%
2000-2004	10,040	82.6%	66.5%	53.3%	40.4%	57.7%	25.3%	0.0%	0.1%	0.3%	0.0%	0.0%	19.6%
2005-2007	4,743	70.0%	56.2%	50.1%	41.1%	55.7%	1.9%	0.1%	0.1%	0.5%	0.0%	0.0%	17.3%

Source: Authors constructed from PATSTAT database.

2.3. Structure of Invention and Ownership

We focus on the patents which have both at least one inventor and one assignee of the patent in one of the three countries (Korea, China and Taiwan). We define international collaborative research to involve either foreign co-inventor, foreign co-owner or both. In this paper, we will analyze the effects of international collaborative research compared with purely domestic research. As shown in Table 5, we can classify inventor (ownership) structure by using patent bibliographic data into four types: domestic single-inventor invention, domestic co-invention, international co-invention, and invention by only inventor(s) residing in a foreign country. Ownership structure can be classified similarly. These bibliometric indicators are also used in Hagedoorn (2003), Hicks and Narin (2001). We do not focus on the patents invented by only foreigners and/or owned by only foreign firms. For example, the Korean sample consists of inventions with at least one Korean inventor and one Korean applicant (A+B+C+D in Table 5), which is applied both to the Korean Patent Office, and the US Patent and Trademark Office. The reason why we focus on the inventions with patent applications to the USPTO is due to the availability of extensive patent bibliographic information, such as citation information, country code of inventors/applicants. However, it should be noted that we have ignored a significant part of inventions for this selection. In addition, our analysis in this paper does not cover an important part of international research collaborations such as research outsourcing.

Table 5. Focus of the Sample

		Inventor structure			
		Domestic single inventor	Domestic co-invention	International co-invention	Invented by foreigner(s)
Ownership structure	Domestic single ownership	A: Purely domestic		B	-
	Domestic co-ownership				
	International co-ownership	C		D	-
	Owned by foreign firm(s)	-		-	-

Source: Authors.

Table 6 provides the percentage of the focus of this analysis; 33% of all the Korean and US patent offices' patents, only 2.7% of Chinese and US patent offices' patents, 31% of Taiwan and US patent offices' patents, for example in the year 2000-2006 in terms of the application year. Most of the rest of the patents were applications by foreign firms. Foreign firms owned 67% of these patents in Korea, 98% in China and 70% in Taiwan.

Table 6. The Incidence of Applications by Inventor and Ownership Structures (Application Year: 2000-2006)

Korea (Application year: 2000-2006)

	Single inventor	Domestic co-invention	International co-invention	Invention by foreigner(s)	Total
Single ownership	12.4%	18.0%	0.9%	0.5%	31.8%
Domestic co-ownership	0.2%	1.0%	0.0%	0.0%	1.2%
International co-ownership	0.0%	0.0%	0.1%	0.0%	0.2%
Owned by foreigner(s)	0.1%	0.1%	0.1%	66.6%	66.9%
Total	12.7%	19.1%	1.1%	67.2%	100.0%

Table 6. The Incidence of Applications by Inventor and Ownership Structures (Application Year: 2000-2006)

China (Application year: 2000-2006)

	Single inventor	Domestic co-invention	International co-invention	Invention by foreigner(s)	Total
Single ownership	1.4%	0.6%	0.0%	0.0%	2.1%
Domestic co-ownership	0.0%	0.1%	0.0%	0.0%	0.1%
International co-ownership	0.0%	0.0%	0.0%	0.0%	0.1%
Owned by foreigner(s)	0.1%	0.1%	0.2%	97.3%	97.7%
Total	1.5%	0.9%	0.3%	97.4%	100.0%

Taiwan (Application year: 2000-2006)

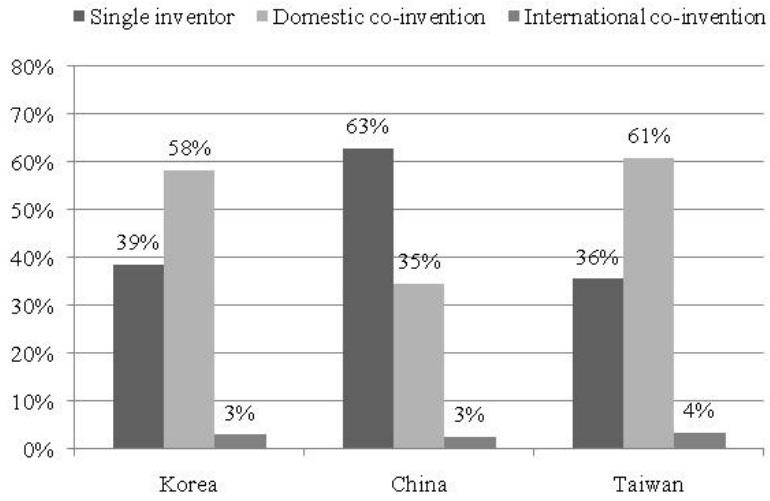
	Single inventor	Domestic co-invention	International co-invention	Invention by foreigner(s)	Total
Single ownership	10.4%	17.4%	0.9%	1.0%	29.7%
Domestic co-ownership	0.1%	0.5%	0.0%	0.0%	0.6%
International co-ownership	0.0%	0.1%	0.1%	0.2%	0.4%
Owned by foreigner(s)	0.2%	0.2%	0.2%	68.9%	69.3%
Total	10.6%	18.1%	1.2%	70.1%	100.0%

Source: Authors constructed from PATSTAT database.

Figure 1 shows the incidence of domestic or international co-inventions of three East Asian countries. Roughly speaking, one third of the patents in Korea and Taiwan involve single-inventors, while the rest are co-inventions involving more than two inventors in the years 2000-2006. In China, however, 63% of patents are invented by a single inventor. As to the percentage of international co-inventions, it is only 3% of patents in these three countries. These low ratios of international co-invention are similar to the invention structure of Japan (Figure 2). Moreover, more international co-inventions are realized under pure foreign ownership than international co-ownership in

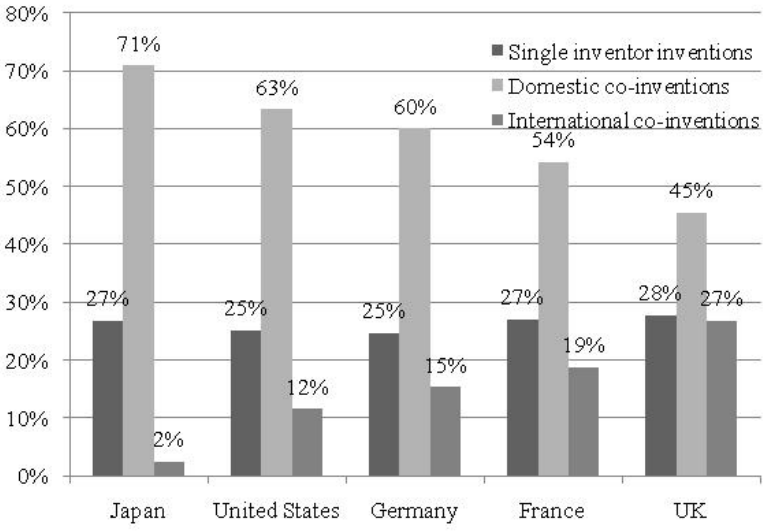
China and Taiwan. Thus, it can be said that international investment plays a more important role than international alliance when it comes to engaging in international co-invention collaborations in these countries.

Figure 1. Incidences of Co-Inventions of Three East Asian Countries (Application Year: 2000-2006)



Source: Authors constructed from PATSTAT database.

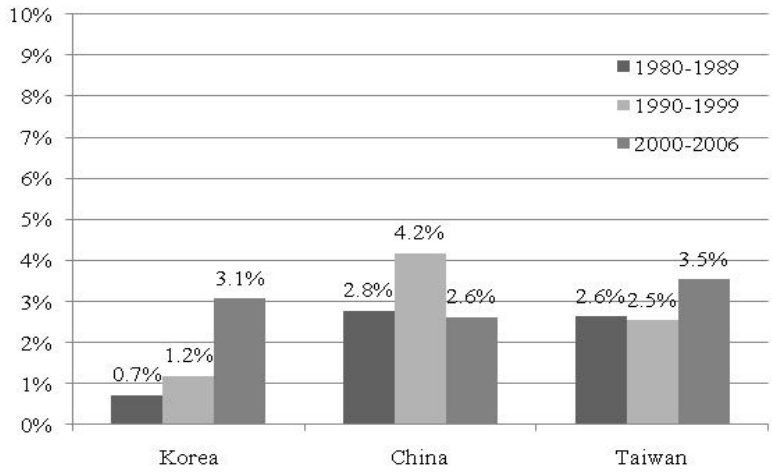
Figure 2. Incidence of Co-Inventions of The Five Industrialized Countries (Application Year: 2000-2006)



Source: Nagaoka and Tsukada (2011).

Figure 3 show the time trend of international co-inventions. In Korea, there is a significant increase from the 1980s to the 2000s; the incidence in the 2000s is 4.4 times greater than the incidence of the 1980s. But, it does not show any significant change in China and Taiwan.

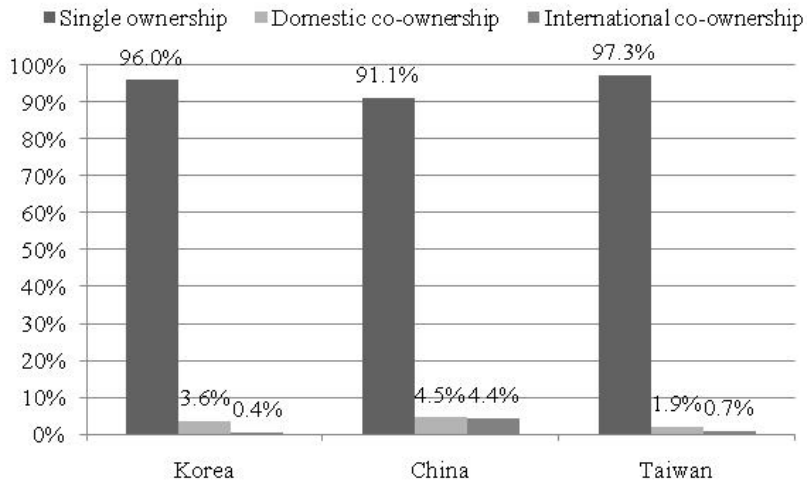
Figure 3. The Evolution of International Co-Inventions



Source: Authors constructed from PATSTAT database.

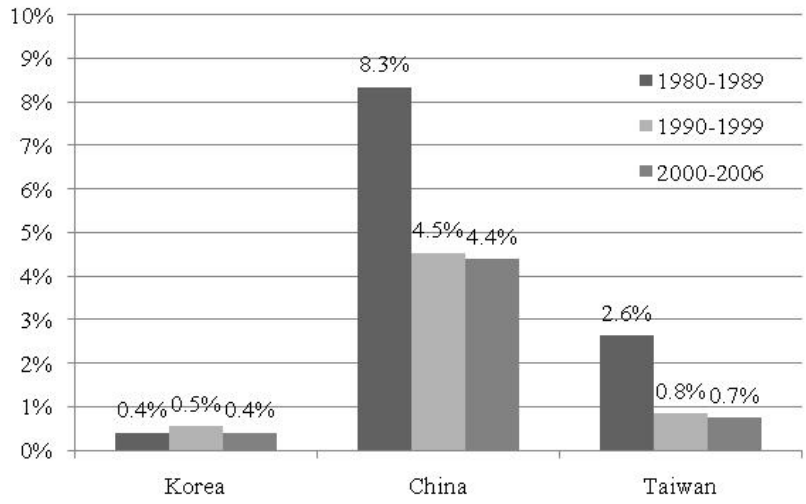
In these three countries, the share of international co-ownership is also small, as shown in Figure 4 and Figure 5. It is 0.4% for Korea, 4.4% for China and 0.7% for Taiwan for the period from 2000 to 2006.

Figure 4. Incidences of Co-Ownerships of Three East Asian Countries (Application Year: 2000-2006)



Source: Authors constructed from PATSTAT database.

Figure 5. The Trend of International Co-Ownerships



Source: Authors constructed from PATSTAT database.

3. International Co-Ownership and Size of Inventor Team

3.1. Framework[7]

In this section, we examine whether international collaboration in terms of co-ownership between national and foreign firms is associated with a larger number of inventors than purely domestic patents. We focus on the effect of international co-ownership on facilitating the expansion of the inventor team. We can examine this issue by looking at how international co-ownership is associated with a significantly larger number of inventors than purely domestic patents. The domestic inventive human resources would become more limiting as the research task becomes larger and more complex. That is, the marginal cost of hiring additional inventors increases more rapidly when the firm has to hire inventors only in the domestic labor market than when no such constraint exists[8]. Consequently, we would expect that especially as the size of the research task increases, it would become more efficient to hire foreign inventors and the incidence of international co-inventions would rise.

Since engaging a foreign firm as the co-owner of the invention would enable a domestic firm to gain better access to foreign researchers, we would expect a positive correlation between the size of the research team and the incidence of international co-ownership. Figure 6 shows the frequency distribution of the size of the inventor team by ownership type in the three countries (application year: 2000-2006). The horizontal axis is team size, and the vertical axis is the incidence of each size of inventor team by

[7] See Nagaoka and Tsukada (2011) for more details.
[8] Guellec and de la Potterie (2001) analyzed by using cross-county sample. They concluded that the degree of international collaboration is higher for small countries and for countries with lower R&D intensity. It implies that a firm in a small country needs to look for a collaborative partner in foreign countries.

ownership type. Inventions owned by a single firm are associated with smaller size of inventor team. A collaborative project of multiple firms tends more often to involve more than two inventors. In Korea, when the number of inventors is more than three, the possibility of collaborative projects with foreign firms tends to be higher than that of collaboration with domestic firms. We can observe a similar pattern in China too. Figure 7 shows that as the number of owners of the invention increases, the average size of the research team also increases. The patterns of the three countries are very similar to each other.

Figure 6. Incidence of Size of Inventor Team by Ownership Types (Application Year: 2000-2006)

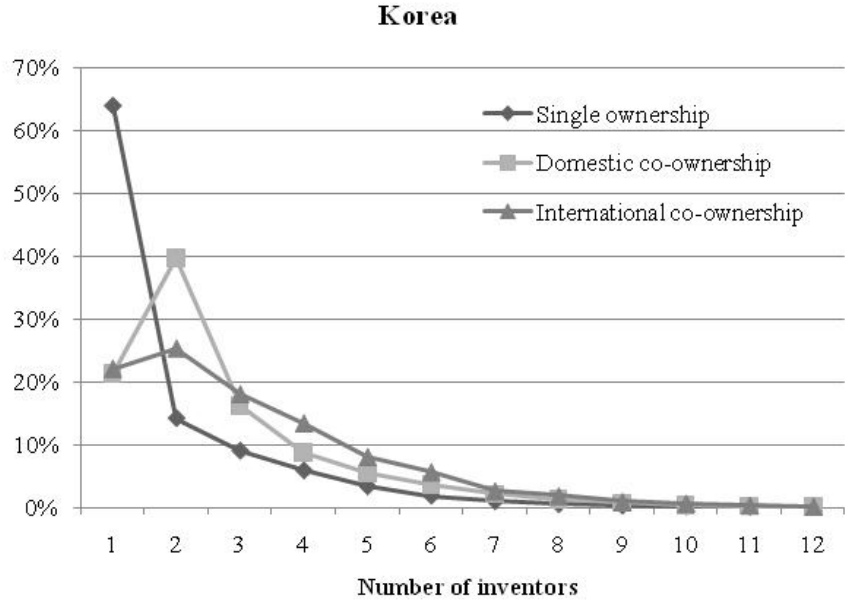
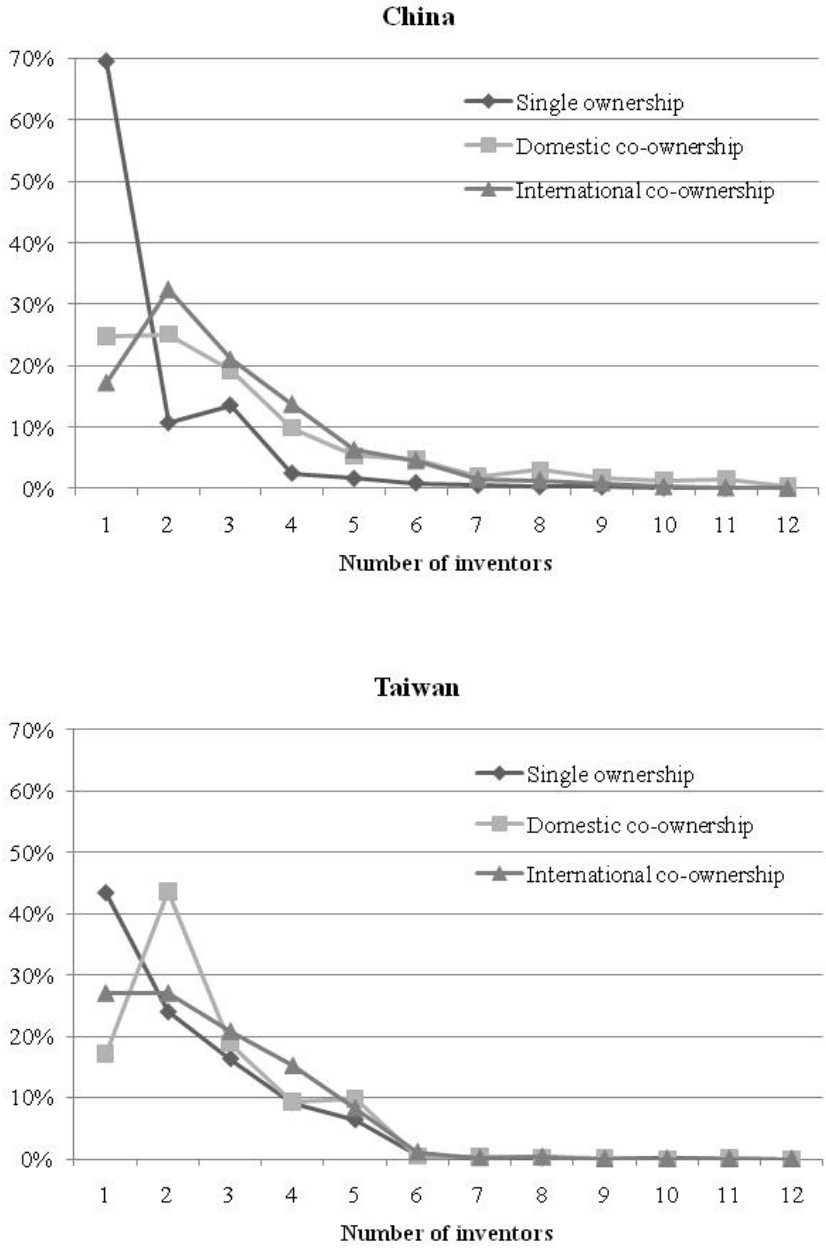
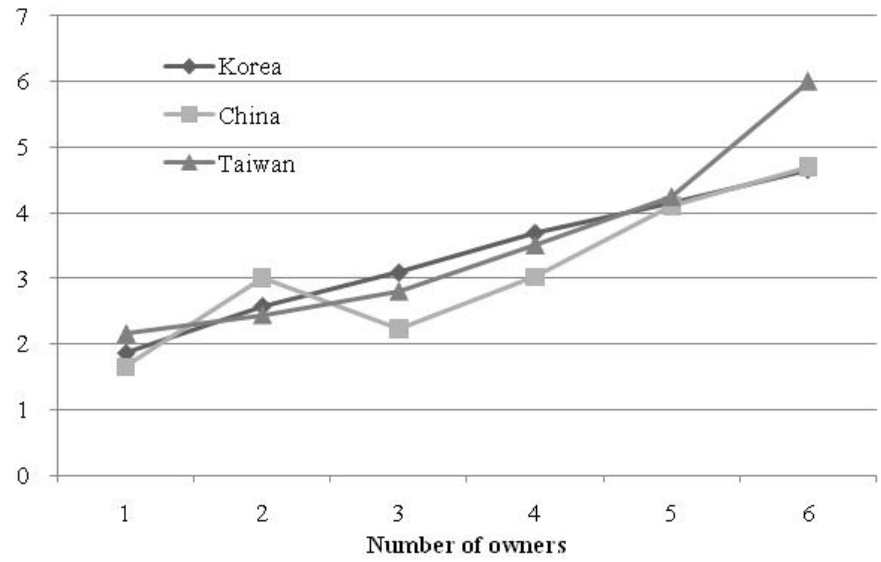


Figure 6 (continued). Incidence of Size of Inventor Team by Ownership Types (Application Year: 2000-2006)



Source: Authors constructed from PATSTAT database.

Figure 7. Number of Owners and Average Size of Inventor Team (Application Year: 2000-2006)



Source: Authors constructed from PATSTAT database.

3.2. Estimation

Figure 7 shows the results of the Probit estimation using the sample which consists of the patents with more than two inventors, according to the following model:

$$\begin{aligned}&\text{Dummy of international coinvention}\\&= f\left(\text{Num. of inventors, Dummy of domestic coownership, Dummy of international coownership}\right), \quad (1)\end{aligned}$$

$$\text{Dummy of international coinvention} = \begin{cases}1 & \text{if international coinvention}\\0 & \text{if domestic coinvention}\end{cases}$$

We also use the cross terms between the dummy variables of application year and those of the technology area to control for the variations of technological or demand characteristics over time.

The estimated coefficients of number of inventors are significantly positive in Korea and Taiwan. Thus, in a situation where a firm has to find a collaboration partner, as the project size proxied by number of inventors becomes larger, it is more likely that the project involves foreign inventors. The coefficient of international co-ownership

indicates the effects of international co-ownership relative to single ownership. It is significantly positive in all three countries. It shows that a patent internationally co-owned is positively associated with a research team consisting of both domestic and foreign inventors, while a patent co-owned domestically is not. These results imply that when a project is large and might be technically complex, the firm tends to seek foreign inventors as the research partners, and collaboration with a foreign firm facilitates the hiring of foreign inventors.

Table 7. Results of Probit Estimation (Sample: Number of inventors >= 2)

	Dummy: 1 if international co-invention, 0 if domestic co-invention					
	Korea		**China**		**Taiwan**	
	Probit	**Marginal Effect**	**Probit**	**Marginal Effect**	**Probit**	**Marginal Effect**
ln(Num. of Inventors)	0.513***	0.020***	0.027	0.005	0.339***	0.026***
	(0.053)	(0.002)	(0.151)	(0.027)	(0.072)	(0.006)
Dummy for International co-ownership	3.560***	0.901***	1.533***	0.387***	2.103***	0.572***
	(0.202)	(0.031)	(0.165)	(0.048)	(0.142)	(0.054)
Dummy for Domestic co-ownership	-0.146	-0.005	-0.250	-0.040	-0.777**	-0.031***
	(0.140)	(0.004)	(0.270)	(0.038)	(0.370)	(0.006)
Constant	-2.311***		-1.626***		-1.549**	
	(0.365)		(0.506)		(0.638)	
Observations	17073		859		7236	
Pseudo R-Squared	0.23		0.33		0.14	
Log Likelihood	-1581.88		-263.98		-1196.58	

Standard errors in parentheses.
*significant at 10%; ** significant at 5%; *** significant at 1%.
Dummy variables of application year and technology are included, but not reported.
Source: Authors.

Next, Table 8 provides the results of estimation, explaining the number of inventors, based on the following model:

$$\ln(\text{inventors}) = f(\text{Dummies of Num. applicants},\ \text{Dummy for international coownership}), \quad (2)$$

We introduce again the technology by time dummies to control for the variations of technological or demand characteristics over time in each technology area.

The estimated coefficients for the dummy of international co-ownership indicate the average additional effect of international co-ownership on the size of inventors for all levels of the number of owners or applicants (both single ownership and 4 categories of co-ownership). The dummy variables of number of applicants have significantly positive coefficients in the samples of all three countries and the coefficient size increases with the number of applicants monotonically, with the marginal effect being less than 1 (for example, the increase of the number of applicants from 2 to 3 is associated with 0.17), implying that the number of inventors increases but significantly less than proportionately with the number of co-owners. The dummy for international co-ownership has a significantly positive coefficient in Korea, implying that the inventions with international co-ownership, relative to domestic co-ownerships, are associated with a significantly larger number of inventors than purely domestic owned patents (around 20 %). On the other hand, international co-ownership, relative to domestic ownership, is not associated with a larger team size in Taiwan and China. In China, it has a significantly negative coefficient. That is, the patents of pure domestic ownership involve a larger sized research team than the patents of international co-ownership (such relationship between domestic and foreign co-ownership is clear in Figure 6 too).

Table 8. Estimation Results (1)

	ln(Num inventors)		
	Korea	**China**	**Taiwan**
Dummy for num. applicant == 2	0.327***	0.655***	0.164***
	(0.029)	(0.066)	(0.049)
Dummy for num. applicant == 3	0.237***	0.563***	0.362***
	(0.084)	(0.189)	(0.120)
Dummy for num. applicant == 4	0.413***	0.990**	0.724***
	(0.154)	(0.465)	(0.239)
Dummy for num. applicant >= 5	0.834***	0.821**	0.669***
	(0.144)	(0.377)	(0.177)
Dummy for International co-ownership	0.179***	-0.268***	0.033
	(0.064)	(0.081)	(0.072)
Constant	0.740***	0.930***	0.231
	(0.144)	(0.250)	(0.328)
Observations	29750	1483	11744
R-squared	0.11	0.44	0.10

Standard errors in parentheses.
*significant at 10%; ** significant at 5%; *** significant at 1%.
Dummy variables of application year and technology are included, but not reported.
Source: Authors.

4. Use of Prior Knowledge as Measured by US Patent References

An important reason for international research collaboration might be to gain access to the knowledge base of foreign inventors, in addition to using their inventive expertise and efforts. If international collaborations expand the scope of knowledge exploited, we would observe that the patents from international research collaborations are associated with a larger scope of knowledge used for the research, controlling for the number of inventors.

We use the following indicators as the extent of the knowledge used: the amount of prior non-patent literature cited (mainly science literature), the amount of prior US patent literature cited, and the median citation lag to the prior US patent literature (citation lag) as the indicators of how quickly the knowledge disclosed in the patent literature is used in the invention process. The econometric model we estimate has the following structure, with the dependent variable indicating the scope of the use of knowledge by an invention resulting in the patent in the technology area granted in year:

$$\begin{aligned}\text{Use of prior knowledge}_{i,k,t} \\ = f(&\text{Number of applicants, Number of inventors,} \\ &\text{Dummies for international collaborations (co-applicants, co-inventors),} \\ &\text{Dummies for technology by time})\end{aligned} \tag{3}$$

US patent law imposes strong disclosure requirements in patent applications with respect to prior literature, although the examiners are mainly responsible for identifying the relevant prior art in Japan and EPO. This is the reason why we use the US patent references as the index of knowledge exploitations, although it is a very noisy measure of knowledge flow, because it includes references by patent examiners, not by inventors themselves (Thomson (2006) and Thomson and Fox-Kean (2005)). A recent study based on an inventor survey indicates that the number of references to non-patent literature ("science linkage") is a good measure of knowledge flow (Nagaoka, Motohashi and Goto (2010)).

Table 9 shows the estimation results for each variable: science linkage (the number of non-patent literature references), backward patent citation (the number of patent literature references) and citation lag (median citation lag to the prior US patent literatures). For each dependent variable, we use two international collaboration dummies (one for international co-ownership and the other for international co-

invention), measuring the extent of international research collaboration, relative to domestic collaborations. The estimation method is negative binomial regression for the former two dependent variables, and ordinary least square for citation lag.

Table 9. Estimation Results of Negative Binomial Regressions

	Num. citations to non-patent literature			Num. citations to patent literatures		
	Korea	**China**	**Taiwan**	**Korea**	**China**	**Taiwan**
ln(Num. of Inventors)	0.456***	0.401***	0.436***	0.070***	-0.001	0.042***
	(0.022)	(0.104)	(0.066)	(0.008)	(0.037)	(0.014)
ln(Num. of Applicant)	0.358***	-0.406	-0.423	-0.188***	-0.076	0.034
	(0.120)	(0.287)	(0.335)	(0.043)	(0.106)	(0.073)
Dummy for International	0.510***	0.076	1.935***	0.072	0.306***	1.003***
co-inventions	(0.117)	(0.245)	(0.221)	(0.044)	(0.085)	(0.047)
Dummy for International	-0.237	-0.668**	-1.040**	0.562***	-0.198**	-0.468***
co-ownership	(0.240)	(0.265)	(0.484)	(0.087)	(0.099)	(0.099)
Constant	1.114***	1.104***	1.268	1.948***	1.690***	2.888***
	(0.276)	(0.408)	(0.811)	(0.110)	(0.178)	(0.186)
Observations	29750	1483	11744	29750	1483	11744
Pseudo R-Squared	0.04	0.11	0.05	0.01	0.04	0.02
Log Likelihood	-35495.22	-1863.27	-7823.91	-92417.43	-4585.75	-36064.31

Table 9 (continued). Estimation Results of Negative Binomial Regressions

	ln(Citation Lag)		
	Korea	**China**	**Taiwan**
ln(Num. of Inventors)	0.005	-0.059***	-0.034***
	(0.004)	(0.023)	(0.008)
ln(Num. of Applicant)	0.042*	0.066	0.112**
	(0.024)	(0.064)	(0.044)
Dummy for International co-inventions	0.013	0.039	0.010
	(0.025)	(0.054)	(0.030)
Dummy for International co-ownership	0.014	-0.181***	-0.121**
	(0.050)	(0.060)	(0.060)
Constant	2.147***	2.618***	2.293***
	(0.062)	(0.106)	(0.118)
Observations	29750	1483	11744
R-squared	0.16	0.28	0.12

Standard errors in parentheses.
*significant at 10%; ** significant at 5%; *** significant at 1%.
Dummy variables of application year and technology are included, but not reported.
Source: Authors.

As shown in Table 9, the number of inventors is highly significant when accounting for the variation of the number of non-patent literature citations (science linkage) for the sample of all three countries, controlling for the changes over time in each technology sector. It is also significant for backward citation of prior patent literature, except for China. It is significantly negative for the citation lag in China and Taiwan. A larger number of inventors are highly associated with more extensive use of the knowledge embodied in non-patent literature (in the three countries), exploitation of a greater amount of patent literature (in Korea and Taiwan) and utilization of more recent knowledge (in China and Taiwan). On the other hand, the number of applicants has a less significant coefficient or a coefficient with an opposite sign, although it is significantly positive for science linkage in Korea. The coefficient is significantly

negative for backward citation of patent literature in Korea and significantly positive for citation lag in Korea and Taiwan. Thus, the increase of co-ownership apparently is not strongly associated with more use of prior knowledge for research, unless it is accompanied with a significant increase of the number of inventors. This may be because co-ownership may create a free-rider problem in terms of ex-post incentive for invention or an ex-ante adverse selection problem for a project. That is, there are possibilities that some firms try to use the output of a collaborative research project without contributing it, since each firm can freely use the co-owned invention. And, a firm may not propose a high-quality research project as a collaboration target, if it is able to conduct research by itself even if inefficiently. As a result, only firms with a lesser ability to conduct research might participate in the collaborative research project.

Our main concern is whether the international co-invention or co-ownership has a significant relationship with the additional use of prior knowledge. As Table 9 shows, international co-invention has a positive and highly significant coefficient for science linkage in Korea and Taiwan. The coefficients imply that the participation of one or more foreign inventors is associated with significantly greater use of scientific literature in both samples, after controlling for the number of inventors. Thus, international co-invention significantly enhances the absorption of scientific knowledge in Korea and Taiwan. As for the model for backward citations to patent literature, the international co-invention has a positive significant coefficient in China and Taiwan. Participation of foreign inventors significantly promotes more use of prior knowledge disclosed in patent literatures. On the other hand, international co-ownership is significantly less associated with science linkage in the three countries, and also less associated with backward patent citations in China and Taiwan.

5. Quality of Patents

International research collaborations may improve the quality of inventions, controlling for the number of inventors as well as the scope of prior knowledge used. It may create a synergy between domestic and foreign inventors and may facilitate the exploitation of tacit knowhow, not captured by the number of inventors or the use of literature. We use the quality of patented inventions as a performance measure of an invention: the number of forward citations received from subsequent US patents per patent family. When the number of patents in a family is more than two, there are cases that the two (or more) patents in the family receive references from the same subsequent patent. In such a case, we counted the number of forward citations to the patent family from the subsequent patent as one. That is, we excluded the duplication of citations in constructing the number of forward citations per family. And we also excluded self-citations in a family. For example, when a family includes two US patents and one of the patents cites the other US patent in the family, we do not count it as forward citation, since it is a citation from the same invention.

We postulate the following estimation equation for the invention quality:

$$\begin{aligned}\text{Invention Quality}_{i,k,t} = f(&\text{Number of prior US patent literature cited,}\\ &\text{Science linkage, Citation lag,}\\ &\text{Number of applicants, Number of inventors,}\\ &\text{Dummies for international collaborations,}\\ &\text{Dummies for technology by time})\end{aligned} \tag{4}$$

If international co-invention or co-ownership are significant even if we control for its effects of the prior public knowledge used for invention and of the number of inventors and applicants, we can conclude that international collaborations matter for invention performance.

Table 10 shows the estimation results for the forward citations as the dependent variable. Models use two international collaboration dummies (one for international co-invention and the other for international co-ownership) measuring the effect of international research collaboration, relative to domestic projects. As shown in this Table, the estimated coefficients for backward patent citation, science linkage and citation lag have highly significant coefficients for the patent quality variables in Korea and Taiwan. An invention with more reference to prior patent literature, science literature and shorter citation lag tends to have significantly higher values proxied by forward citation, consistent with our expectation and with prior research at firm level (Nagaoka, 2007) and research at patent family level focusing on Japan, US, and three European countries (Naogaka and Tsukada, 2010). In China, although coefficients for backward patent citation and citation lag are significant, science linkage is not significant. Thus, science literature does not play a significant role in enhancing research productivity in China.

Let us turn to the effects of the number of inventors and that of applicants. Patent quality increases highly significantly with the number of inventors in Korea. However, international collaboration in terms of either co-inventions or co-ownership does not have significant coefficients in Korea. That is, there does not seem to exist any additional effects other than the effects on the number of inventors and the use of knowledge embodied in literature already identified for Korea. On the other hand, the dummy of international co-invention has a significant positive coefficient in China and Taiwan. Thus, in these two countries, there seem to be additional effects, after controlling for the effects of the number of inventors.

Table 10. Estimation Results of Negative Binomial Regressions

	Num. forward citations					
	Korea	**Korea**	**China**	**China**	**Taiwan**	**Taiwan**
ln(Num. of Inventors)	0.143***	0.124***	0.193**	0.160*	0.050*	0.021
	(0.014)	(0.014)	(0.085)	(0.083)	(0.026)	(0.025)
ln(Num. of Applicant)	-0.225***	-0.155**	0.126	0.096	-0.026	0.077
	(0.079)	(0.077)	(0.238)	(0.229)	(0.142)	(0.135)
Dummy for International co-inventions	0.107	0.055	0.416**	0.375**	0.548***	0.427***
	(0.078)	(0.076)	(0.186)	(0.181)	(0.084)	(0.081)
Dummy for International co-ownership	0.602***	0.369**	0.067	0.034	-0.162	-0.268
	(0.160)	(0.157)	(0.223)	(0.218)	(0.187)	(0.179)
ln(Num.citations to non-patent literatures)		0.035***		0.017		0.242***
		(0.013)		(0.062)		(0.026)
ln(Num. citations to patent literatures)		0.318***		0.382***		0.332***
		(0.012)		(0.065)		(0.020)
ln(Lag of citations to patent literatures)		-0.605***		-0.648***		-0.473***
		(0.019)		(0.099)		(0.028)
Constant	-0.059	0.580**	-0.679	0.299	0.966***	1.064***
	(0.247)	(0.247)	(0.435)	(0.513)	(0.356)	(0.352)
Observations	29750	29750	1483	1483	11744	11744
Pseudo R-Squared	0.08	0.09	0.09	0.11	0.08	0.10
Log Likelihood	-49109.89	-48307.00	-1722.97	-1687.99	-18934.37	-18534.77

Standard errors in parentheses.
*significant at 10%; ** significant at 5%; *** significant at 1%.
Dummy variables of application year and technology are included, but not reported.
Source: Authors.

6. Conclusions and Implications

This paper has analyzed whether and how international research collaboration in terms of co-inventions and co-ownership may affect invention performance in three Asian countries: Korea, China, and Taiwan. We have distinguished its potential effects

on the number of inventors used for the invention, on the scope and the speed of using the prior knowledge as measured by the US patent references and the other effects (productivity effect). We focused on the patents which have been applied to the patent offices of a focused country (Korea / China / Taiwan) and also applied to the US Patent Office.

Our major findings are the following. First, foreign firms owned the majority of these patents in each of the three countries: 67% of patents in Korea, 98% of patents in China, 70% of patents in Taiwan. On the other hand, international collaboration is rare both in terms of co-invention (around 1% or less) and also co-application (less than 1%) in the three countries. Focusing on the patents involving at least one inventor of each of the three countries, we have found that there is a large share of patents invented only by a single person; especially in China, 63% of the patents are invented by single person. The share is also higher in Korea and Taiwan than that of Japan, US, and European countries. These findings indicate that the domestic firms in these countries engage in relatively simple inventive tasks during this period.

Second, internationally co-owned patents tend to be more associated with international co-inventions in all three countries. And internationally co-owned patents are associated with a significantly larger size of inventor team than purely domestically-owned patents, controlling for the number of applicants, only in Korea, confirming our earlier study based on the largest OECD countries. This seems to indicate that capabilities or opportunities for engaging foreign inventors enable a domestic firm to undertake a larger scale R&D project. This effect, however, is weak for inventions in China and Taiwan. In addition, more international co-inventions are realized under pure foreign ownership than international co-ownership in China and Taiwan, indicating that

international investment plays a more important role in initiating international co-inventions in these countries than international alliance.

Third, international co-inventions are strongly associated with more science linkage, that is, more references to scientific literature in Korea and Taiwan. A research project with a high degree of science linkage is often based on basic research. Absorptive capability may be important for using the scientific knowledge, where international collaboration among inventors matters. This may indicate that Korea and Taiwan have stronger absorptive capabilities to exploit scientific knowledge than China for this period. Moreover, international co-invention is associated with more backward patent citation in China and Taiwan. Knowledge embodied in patent literature may be relatively well-known among the inventors of developed economies, since patent documents are completely disclosed. However, in these economies, collaboration with foreign investors may help local inventors exploit that knowledge too.

Fourth, international research collaborations are associated with higher patent quality, in term of forward citation, in China and Taiwan, even after we control for the number of inventors and the literature cited. Thus, the benefits of international research collaboration in terms of creating a synergy or exploitation of knowhow may be significant for these economies.

Although our study is still at an early stage, we can point out several policy implications of our study. First, it would seem important to enhance international collaborations in research by reducing the barriers to the collaboration. Our study shows that an international co-invention helps domestic inventors to undertake large and science-intensive research projects. Mobility of professionals and students across borders would be very instrumental in this regard. While the Internet provides very

effective communication channels across borders, direct contact among persons would be critical in identifying and designing a collaborative research project. International R&D collaboration among firms is also important, since sharing co-ownership can be an important mechanism to allow both the domestic and foreign firm to join their inventive forces, although co-ownership may have some inherent inefficiency due to divided-ownership. International investment plays a more important role for initiating international co-inventions (more than international alliance in China and Taiwan). Direct foreign investment thus plays an even more important role for organizing international collaborative research in less developed economies.

Our study also indicates that the effectiveness of international co-inventions depends on capability of domestic inventors. International co-inventions result in more exploitation of scientific findings in Korea and Taiwan, but not in China during our sample period. International co-inventions did not result in larger inventor teams in China either. These differences seem to be due to the differences of the capability of domestic inventors. Developing the capability of domestic inventors will not only enhance their direct inventive power but it also enhances their absorptive power and spillover from international co-inventions.

There are reservations and further issues to be addressed. First, our study does not distinguish between co-ownership by independent firms and that between related firms. Co-ownership between related firms may have less serious governance problems. Second, there is an endogeneity issue, even though we introduce technology by time dummies to control for the variations of technological or market opportunities in each technology area. Another potential source of endogeneity is the capability of firms. That is, a firm with strong capability in research management may make more use of an

international research team and also have high R&D performance. Introducing firm-fixed effects is effective to control for such endogeneity. However, the results of estimation with and without fixed effects using Japanese/European sample restricted to patents owned by single firm are almost the esame in Nagaoka and Tsukada (2011).

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Appendix

Table A1. Example of Relations of Patent Documents and the Priority Documents

Document D1	Priority P1		
Document D2	Priority P1	Priority P2	
Document D3	Priority P1	Priority P2	
Document D4		Priority P2	Priority P3
Document D5			Priority P3

Note: Document D1 claims the priority document P1. D2 claims P1 and P2.

Source: OECD (2009)

Table A2. Basic Statistics

Korea

Variable	Obs	Mean	Std. Dev.	Min	Max
Num. Inventors	29,750	2.517	1.820	1	27
Num. Applicants	29,750	1.030	0.233	1	10
Num. citations of non-patent literatures	29,750	1.089	4.449	0	266
Num. citations of patent literatures	29,750	8.460	13.124	0	820
Citation lag of patent literatures	29,750	6.926	5.133	0	80
Num. forward citations	29,750	1.917	4.073	0	120
Dummy: International co-invention	29,750	0.015	0.121	0	1
Dummy: International co-application	29,750	0.004	0.064	0	1

China

Variable	Obs	Mean	Std. Dev.	Min	Max
Num. Inventors	1,483	2.953	2.370	1	20
Num. Applicants	1,483	1.335	0.539	1	6
Num. citations of non-patent literatures	1,483	1.715	5.936	0	103
Num. citations of patent literatures	1,483	8.837	12.894	0	189
Citation lag of patent literatures	1,483	9.168	7.529	0.5	74
Num. forward citations	1,483	0.967	2.165	0	24
Dummy: International co-invention	1,483	0.102	0.303	0	1
Dummy: International co-application	1,483	0.200	0.400	0	1

Table A2. Basic Statistics

Taiwan

Variable	Obs	Mean	Std. Dev.	Min	Max
Num. Inventors	11,744	2.342	1.468	1	13
Num. Applicants	11,744	1.032	0.251	1	8
Num. citations of non-patent literatures	11,744	0.649	9.363	0	931
Num. citations of patent literatures	11,744	8.259	46.020	0	4,847
Citation lag of patent literatures	11,744	6.089	5.019	0	84
Num. forward citations	11,744	1.877	4.601	0	117
Dummy: International co-invention	11,744	0.029	0.169	0	1
Dummy: International co-application	11,744	0.009	0.097	0	1

Source: Authors.

Table A3. Correlation Coefficient Matrix

Korea

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
(1) **Num. Inventors**	1							
(2) **Num. Applicants**	0.1058	1						
(3) **Num. citations of non-patent literatures**	0.1141	0.0451	1					
(4) **Num. citations of patent literatures**	0.0166	-0.0034	0.2581	1				
(5) **Citation lag of patent literatures**	0.0157	0.0373	0.0155	0.0548	1			
(6) **Num. forward citations**	0.0043	-0.0068	0.0587	0.1625	-0.1172	1		
(7) **Dummy: International co-invention**	0.1345	0.1348	0.0589	0.0156	0.0076	0.0057	1	
(8) **Dummy: International co-application**	0.0556	0.3181	0.0194	0.0263	0.015	0.0038	0.4209	1

China

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
(1) **Num. Inventors**	1							
(2) **Num. Applicants**	0.3149	1						
(3) **Num. citations of non-patent literatures**	0.0597	-0.038	1					
(4) **Num. citations of patent literatures**	-0.042	-0.0444	0.1615	1				
(5) **Citation lag of patent literatures**	-0.0208	-0.0636	-0.0247	0.0329	1			
(6) **Num. forward citations**	0.0422	-0.0136	0.1504	0.2444	-0.0738	1		
(7) **Dummy: International co-invention**	0.0723	0.3098	-0.0115	0.0241	-0.0974	0.0298	1	
(8) **Dummy: International co-application**	0.0539	0.627	-0.0955	-0.0142	-0.1849	-0.0227	0.492	1

Table A3 (continued). Correlation Coefficient Matrix

Taiwan

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
(1) **Num. Inventors**	1							
(2) **Num. Applicants**	0.0735	1						
(3) **Num. citations of non-patent literatures**	0.0223	0.0045	1					
(4) **Num. citations of patent literatures**	0.0039	-0.0004	0.9351	1				
(5) **Citation lag of patent literatures**	-0.041	0.0279	0.0086	0.0144	1			
(6) **Num. forward citations**	0.0145	-0.0015	0.2598	0.2538	-0.1028	1		
(7) **Dummy: International co-invention**	0.1241	0.1123	0.0634	0.055	-0.0088	0.0386	1	
(8) **Dummy: International co-application**	0.0324	0.4188	-0.0023	-0.001	-0.0083	-0.0002	0.2848	1

Source: Authors.