Whether and how international research collaboration affect invention quality? :some evidence from triadic patent data

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Outline of the presentations

I. Motivations
II. Frequency of international co-inventions and co-applications
III. International co-applications and size of invention team
IV. Use of prior knowledge as measured by US patent references
V. Quality of patents
VI. Conclusions

I. Introduction: Motivations

- Does the international expansion of the research collaborations enhance research productivity?

Two main channels

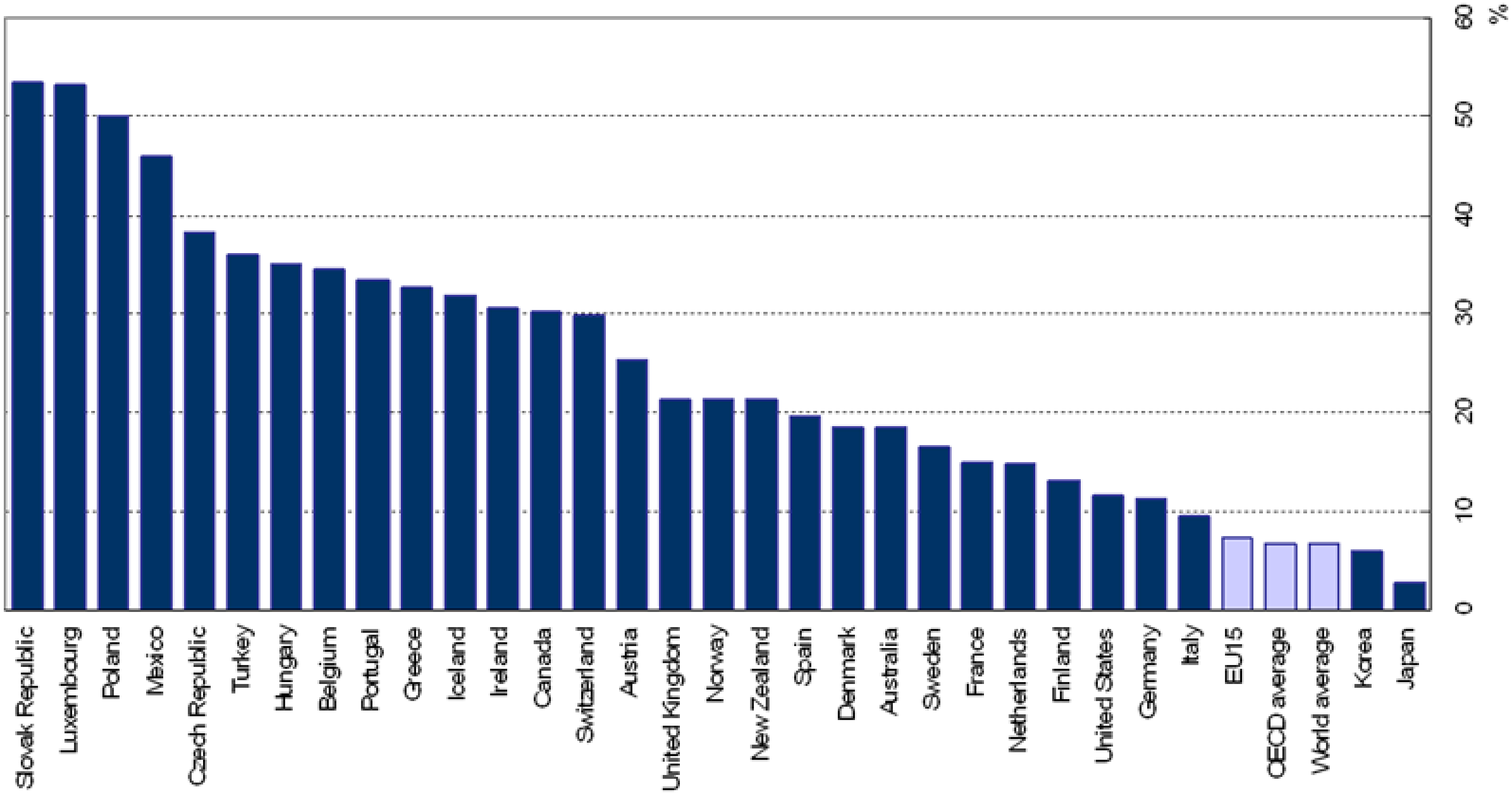
- Pooling of human capital service

  combination of different expertise

- International sharing of knowledge

- “Self-contained” R&D system of Japan and its potential costs

Figure 1-R. **Percentage of patent applications to the EPO with foreign co-inventors**
1999-2000 (OECD(2005))



International research collaborations as defined in this paper

- Two indicators of international collaborations in this paper
  - *International co-inventions*: co-inventions by the inventors of different national address. Such R&D can be sponsored by a single firm.
  - *international co-applications: international collaborations* by the firms of different national address for sponsoring an R&D, as captured of joint ownership

- Another type: combination of national ownership and purely foreign inventors

- Our analysis does not cover an important part of international research collaborations such as research outsourcing.

Different types of research collaborations

		Inventor		
		Domestic	International	Only foreign
Ownership	Domestic	A: Purely domestic	B:○	-
	International	C：◎	D:○◎	-
	Only foreign	-	-	-

Japanese sample: patents wit at least one Japanese inventor and one Japanese Applicant (=A+B+C+D)

Four sources of the patent data

- *OECD Triadic patent family* database (2008 April version)
  - It covers the patents applied for all three of USPTO (granted), EPO and JPO.
  - Around 650, 000 with priority years from 1978-2006, which cover important inventions worth trilateral patent applications.

- Citation information from US patents as made available by the *PATSAT database* of the EPO.
  - References disclosed by US patent documents, including non-patent documents
  - Backward and forward citations

- Number of claims of each patent from the *NBER patent database*.

- Payments of patent renewal fees from *USPTO website*.

Three research questions

- Hypothesis 1. International co-ownership would expand the pool of inventors, relative to domestic co-ownership, controlling the number of co-applicants.

- Hypothesis 2. International research collaborations would enhance the scope of knowledge used for research.

- Hypothesis 3. International research collaborations would enhance research productivity, controlling for the number of inventors and the use of knowledge embodied in public literature.

II. Structure of international co-inventions and co-applications

- Three quarters of the Triadic patents involve co-inventions.
- The share of international co-inventions varies significantly across countries: from 27 % for the UK to 2% in Japan (Figure 1).
- The share of international co-inventions increased significantly over time, except for Japan (Figure 2).

Figure 1. Frequency of co-inventions by major industrialized countries (Application Year: 2000-2006)

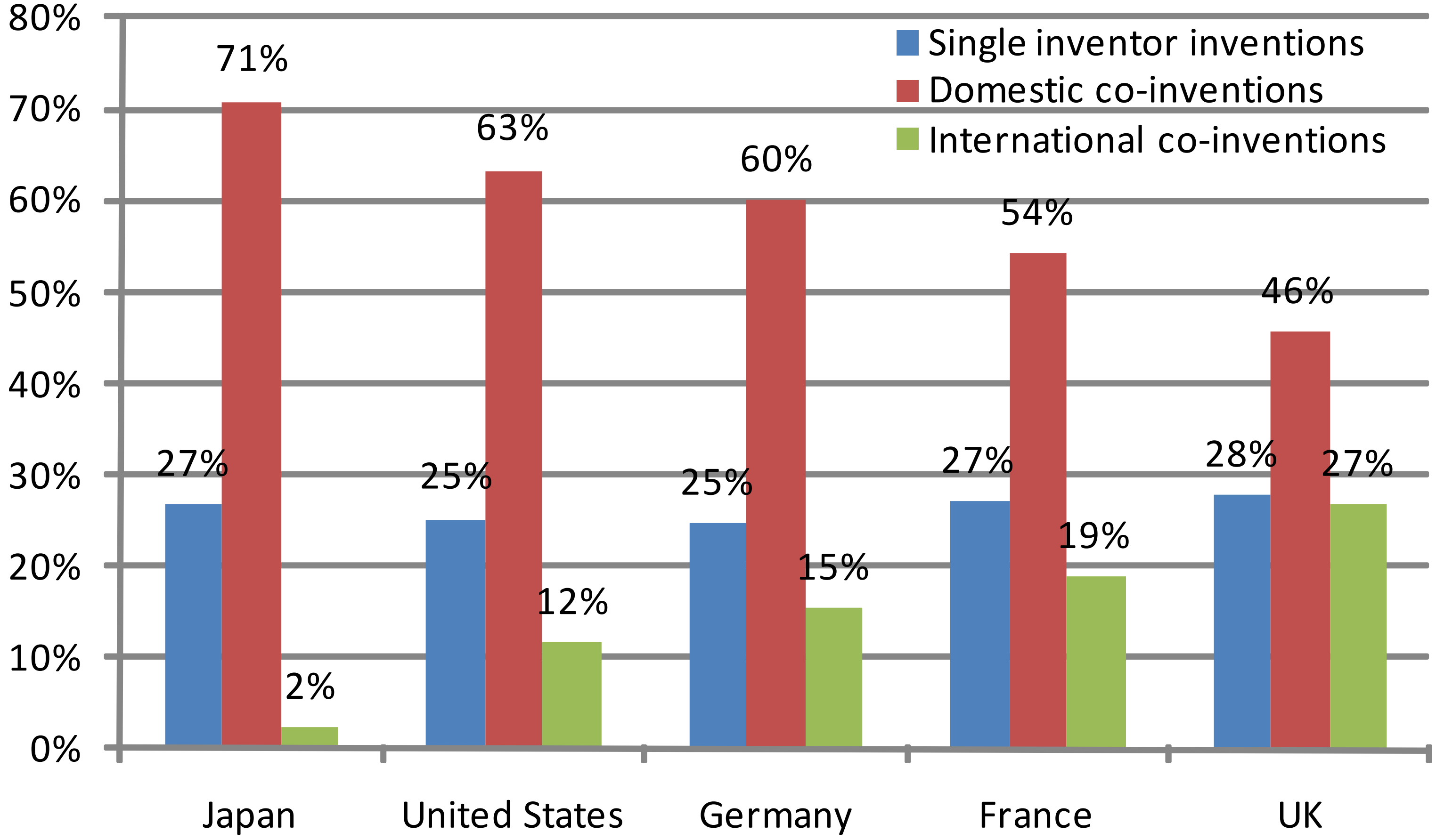
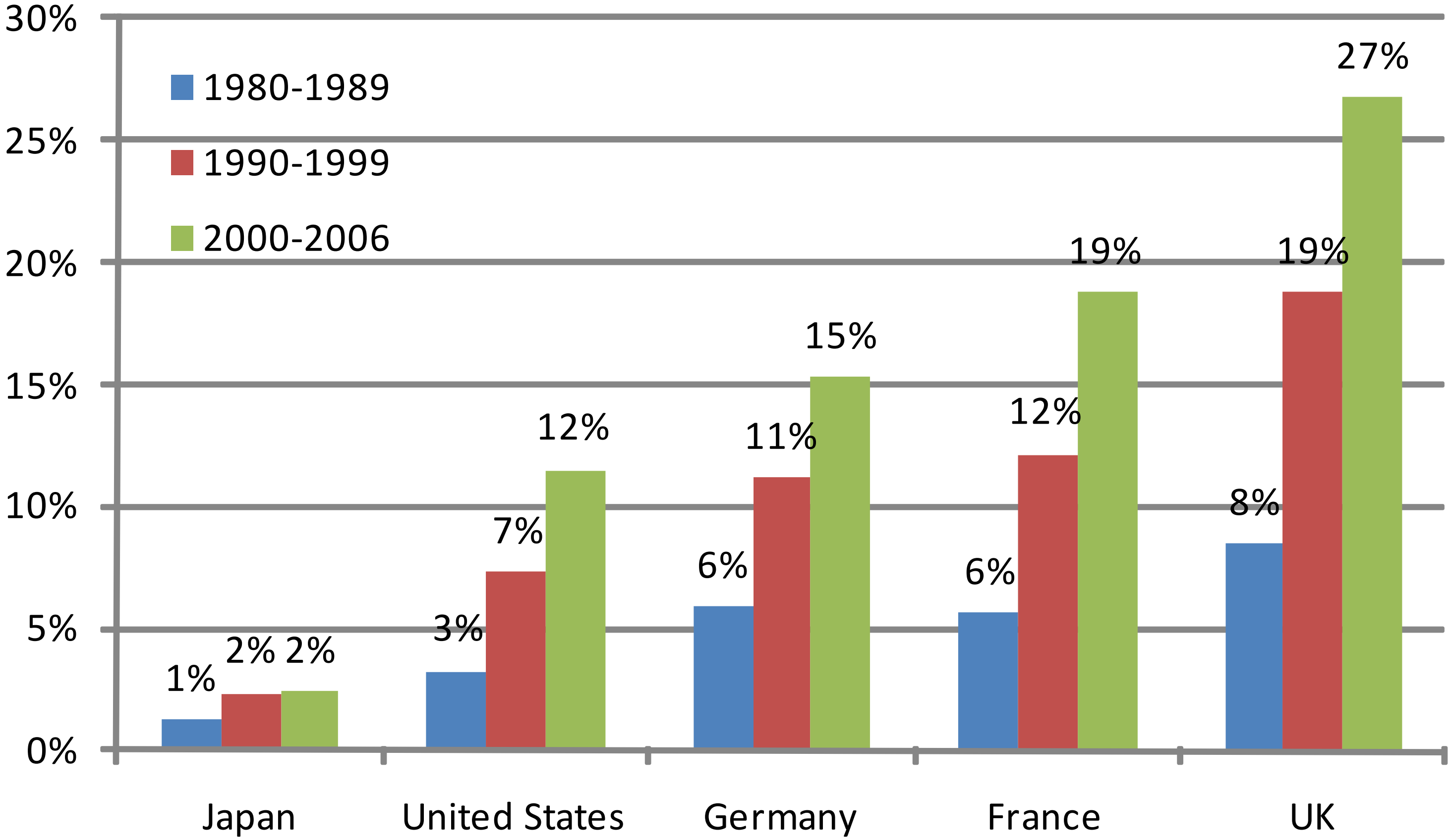


Figure 2 The evolution of the frequency of international co-inventions



Note. Patents classified by application years

US vs. Japan vs. Germany in the frequency of international co-inventions

- Japan (1.3% →2.4%) relative to the US (3%→12%) from 1980-1989 to 2000-2006
- The lower degree of intra-firm internationalization of research activities of Japanese firms accounts for most of the difference.
- But, the difference of the frequency of international research alliance has also become important.

Table 1 The incidence of triadic patents by inventor and ownership structures for 2000-2006

Japan (2000-2006)

	Single inventor	Domestic co-inventions	International co-inventions	Total
Single applicant	25.9%	64.1%	1.0%	91.0%
Domestic co-applications	0.8%	7.3%	0.1%	8.2%
International co-applications	0.1%	0.2%	0.5%	0.8%
Total	26.8%	71.7%	1.5%	100.0%

United States (2000-2006)

	Single inventor	Domestic co-inventions	International co-inventions	Total
Single applicant	25.0%	62.7%	7.0%	94.7%
Domestic co-applications	0.2%	3.3%	0.2%	3.7%
International co-applications	0.1%	0.4%	1.2%	1.6%
Total	25.3%	66.4%	8.3%	100.0%

Germany (2000-2006)

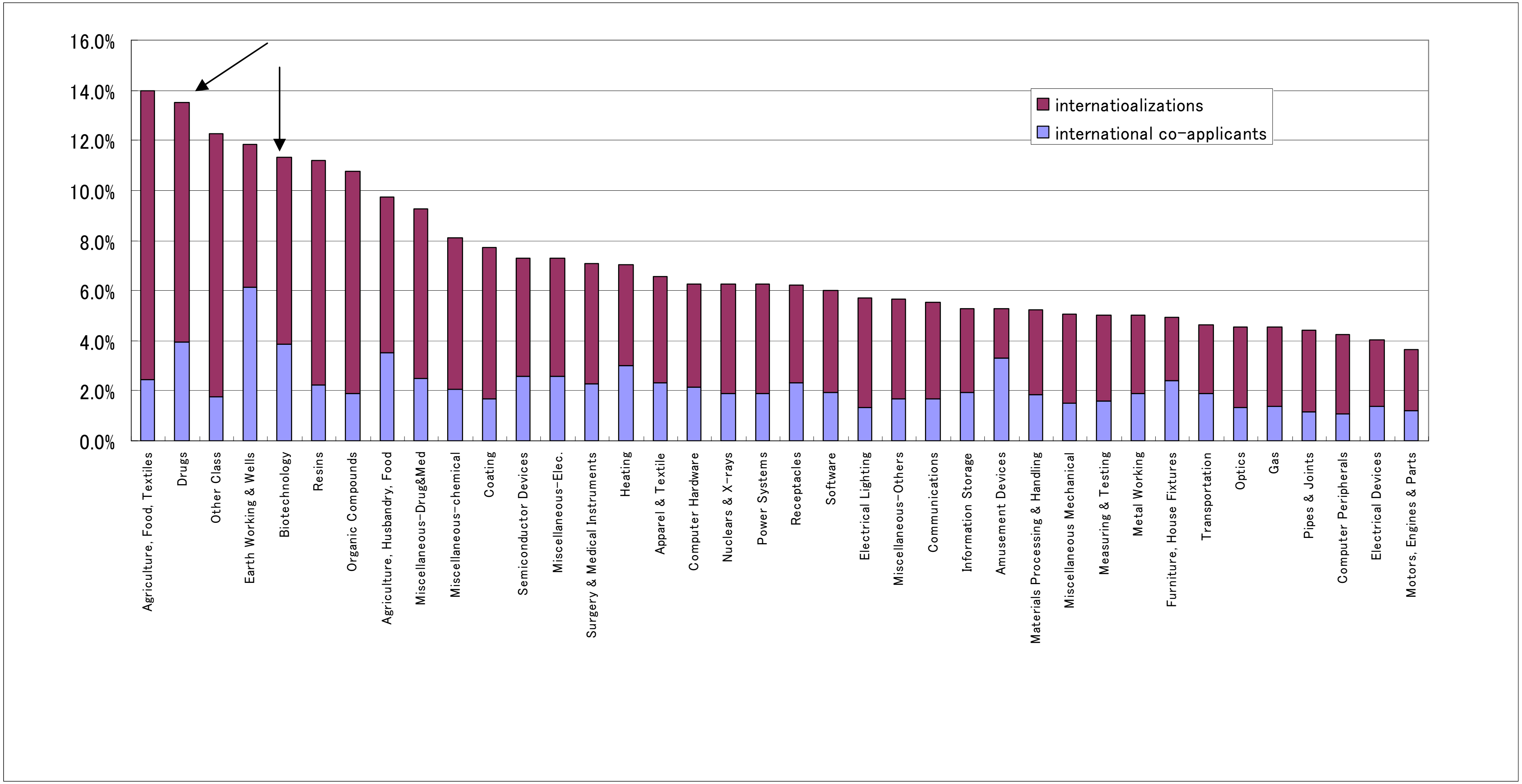
	Single inventor	Domestic co-inventions	International co-inventions	Total
Single applicant	25.2%	61.3%	7.6%	94.1%
Domestic co-applications	0.4%	3.5%	0.2%	4.1%
International co-applications	0.1%	0.3%	1.4%	1.8%
Total	25.6%	65.2%	9.2%	100.0%

Variations across technology areas

- More intra-firm internationalizations of research in chemical and life science area and high level of international alliances in life science area.

- Positive correlations between “science linkage” and international intra-firm internationalizations of research

Figure 3 Frequency of intra-firm internationalization of research and that of international co-applications by technology sectors (1995-2002)



III. International co-applications and size of invention team

- Hypothesis 1. International co-ownership would expand the pool of inventors, relative to domestic co-ownership, controlling the number of co-applicants.

- This effect is the largest for the UK applicants (25%), and not significant for the Japanese applicants.

Figure 4. Size of research team

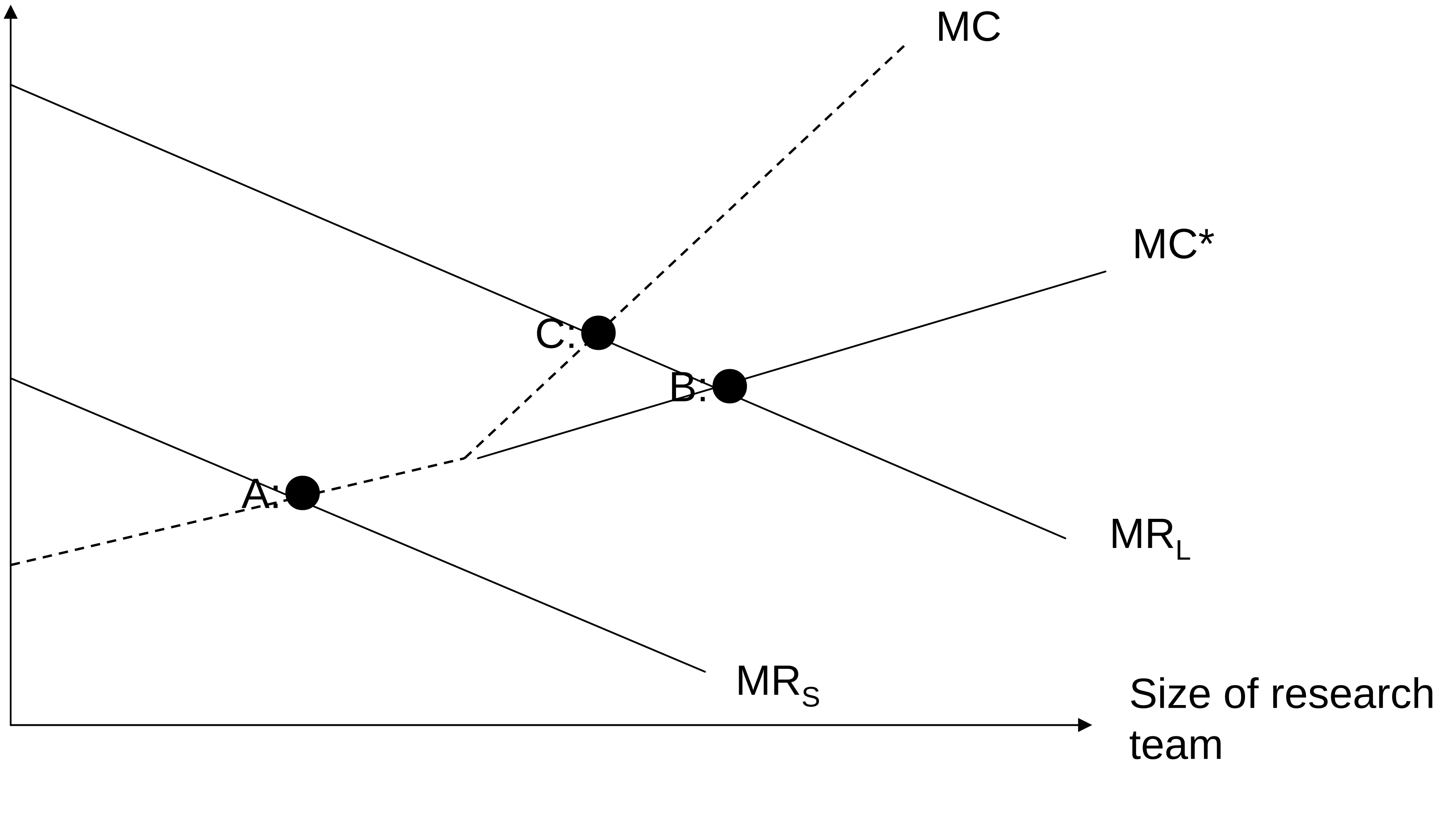


Table 2: International co-ownership and size of invention team (grant year: 2000-2006)

OLS: Gyear: 2000-2006

	ln(Inventors)									
	JP		US		DE		FR		GB	
ln(Applicants)	0.499***	0.341***	0.375***	0.554***	0.408***	0.426***	0.405***	0.589***	0.417***	0.699***
	(0.012)	(0.035)	(0.013)	(0.030)	(0.022)	(0.046)	(0.029)	(0.067)	(0.041)	(0.083)
Single ownership		-0.141***		0.198***		0.019		0.186***		0.319***
		(0.029)		(0.030)		(0.045)		(0.062)		(0.083)
International co-ownership	-0.023	-0.039	0.063***	0.111***	0.097***	0.100***	0.179***	0.199***	0.176***	0.246***
	(0.028)	(0.028)	(0.021)	(0.022)	(0.034)	(0.034)	(0.044)	(0.044)	(0.052)	(0.055)
Constant	-0.344	-0.375	-0.000	-0.198	1.623	1.598	-0.687	-0.928	-0.633	-1.007
	(1.070)	(1.070)	(1.046)	(1.046)	(13,287.83	(13,289.20	(1.566)	(1.565)	(1.837)	(1.837)
Observations	68815	68815	71696	71696	28761	28761	9654	9654	5611	5611
R-squared	0.09	0.09	0.06	0.06	0.16	0.16	0.16	0.16	0.22	0.22

Standard errors in parentheses

* significant at 10%; ** significant at 5%; *** significant at 1%

Application year by technology dummies included, but not reported.

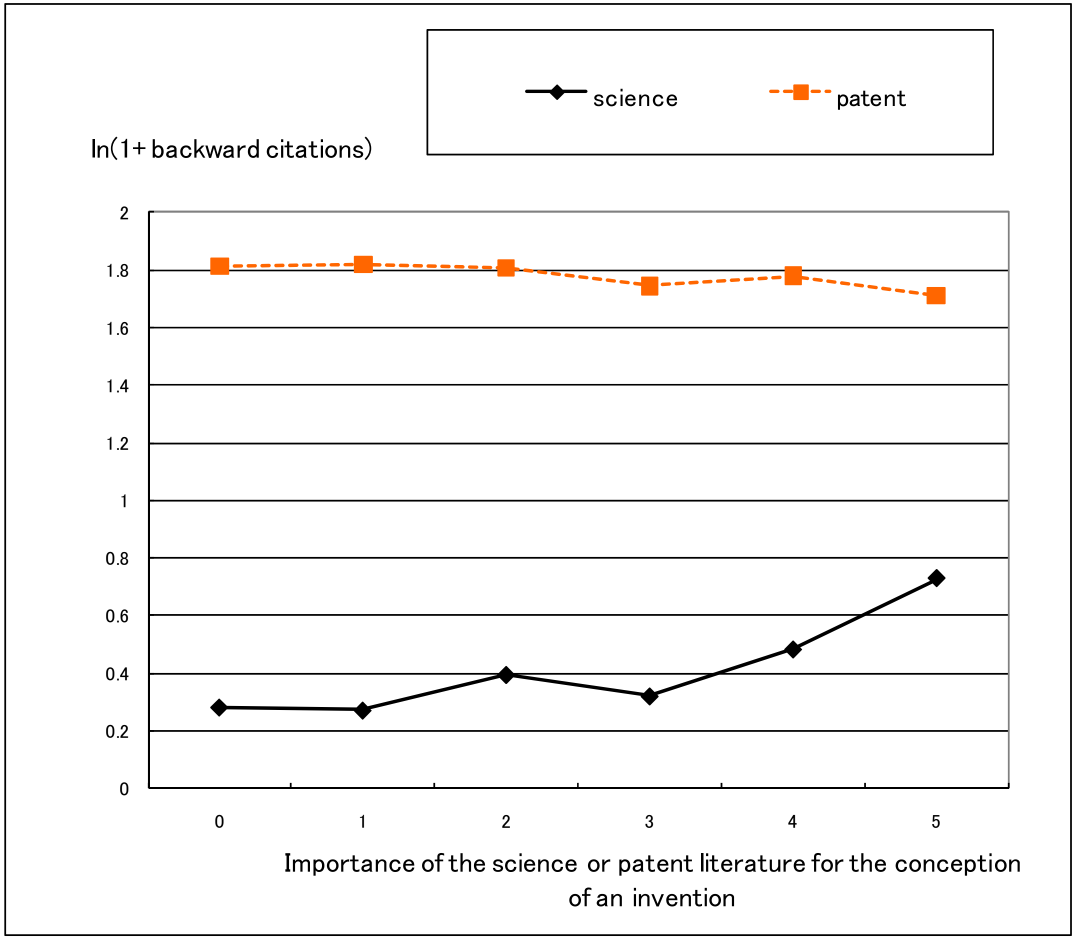
IV Use of prior knowledge as measured by the scope of US patent references

- Hypothesis 2. International research collaborations would enhance the scope of knowledge used for research.

- Use of knowledge measured by
  - the number of prior non-patent literature cited (*Non-patent literature citation*)
  - the number of prior US patent literature cited
  - the median citation lag to the prior US patent literature (*citation lag*)

- Backward citations are often added by examiners and patent attorneys. The number of backward citations to non-patent literature is significantly correlated with the importance of knowledge flow.

Figure_R1 Number of backward citations and the importance of knowledge flow



Made from the RIETI inventor survey

Use of prior knowledge in international research collaborations

- *Use of prior knowledge = f(the number of inventors, the number of applicants, the dummies for the international collaborations (co-applicants and co-inventors) , technology by time dummies) (4)*

- *the dummies for the international collaborations* :

-two dummies for international collaborations and

-separate dummies distinguishing the interaction effects.

- Period 2000-2006, control for 37 sectors

- *the Japan sample* and the three European country *pool sample* (German, France and UK *)*

Results (Basics)

- More inventors significantly help
  - adding scientific knowledge and
  - use of new and more patent literature

  in both Japanese and the European pool samples.

- However, more applicants do not.

Results (additional effects of international research collaborations)

- International co-inventions enhances the use of scientific knowledge in both samples.

- On the other hand, international co-ownership is less significantly associated with science linkage.

- An international co-invention has a significantly higher coefficient than a domestic co-inventions in the case of single domestic co-ownership, controlling for the number of inventors.

Table 3: Knowledge use (2000-2006)

	ln(Non-patent literature citations		ln(Backward citations)		ln(Citation Lag)	
	Model 1 for Japan	Model 2 for Pool	Model 5 for Japan	Model 6 for Pool	Model 9 for Japan	Model 10 for Pool
ln(Applicants)	-0.022*	0.039*	-0.100***	-0.049***	0.030***	0.039**
	(0.013)	(0.020)	(0.013)	(0.019)	(0.011)	(0.017)
ln(Inventors)	0.061***	0.056***	0.086***	0.021***	-0.017***	-0.058***
	(0.004)	(0.006)	(0.004)	(0.006)	(0.004)	(0.005)
International co-ownership	0.110**	0.015	0.068	0.086**	-0.007	0.006
	(0.045)	(0.037)	(0.045)	(0.034)	(0.040)	(0.030)
International co-invention	0.149***	0.123***	-0.029	-0.049***	0.030	-0.014
	(0.034)	(0.016)	(0.034)	(0.015)	(0.030)	(0.013)
Constant	0.584	2.300	2.364	2.529	2.986	2.314
	(5,694.705)	(8,456.586)	(5,709.893)	(7,837.441)	(5,020.673)	(6,908.524)
Observations	68168	42729	68168	42729	68168	42729
R-squared	0.13	0.25	0.06	0.07	0.11	0.11

Standard errors in parentheses
* significant at 10%; ** significant at 5%; *** significant at 1%
Application year by technology dummies included, but not reported.

Table 3A: Interaction terms (2000-2006)

		ln(Non-patent literature citations		ln(Backward citations)		ln(Citation Lag)	
		Model 3 for Japan	Model 4 for Pool	Model 7 for Japan	Model 8 for Pool	Model 11 for Japan	Model 12 for Pool
Single domestic ownership	Domestic co-inventions	-0.014	0.047***	-0.063***	0.025*	0.003	-0.035***
		(0.010)	(0.014)	(0.010)	(0.013)	(0.009)	(0.011)
	International co-inventions	0.127***	0.169***	-0.112***	-0.030	0.004	-0.060***
		(0.040)	(0.022)	(0.040)	(0.020)	(0.035)	(0.018)

		ln(Non-patent literature citations		ln(Backward citations)		ln(Citation Lag)	
		Model 3 for Japan	Model 4 for Pool	Model 7 for Japan	Model 8 for Pool	Model 11 for Japan	Model 12 for Pool
International co-inventions	Domestic co-ownership	0.146	0.352***	0.005	0.124	0.015	0.080
		(0.156)	(0.103)	(0.157)	(0.095)	(0.138)	(0.084)
	International co-ownership	0.267***	0.174***	0.002	0.120**	0.114**	0.064
		(0.062)	(0.057)	(0.062)	(0.053)	(0.054)	(0.047)

IV. Quality of patents

- Hypothesis 3. International research collaborations would enhance research productivity, controlling for the number of inventors and the use of knowledge embodied in public literature.

- The number of forward citations received by US patents as well as the number of claims, or the duration of patent protection in the US as the quality measures.

-The truncation bias of the number of forward citations are controlled by introducing year by sector dummies.

-The duration of patent protection is independent of bibliographic indicators so that it is not dependent on the difference of referencing behaviors of the inventors of different nationalities.

Knowledge production function

- *Citedness (or Claims or Duration of patents) = f (the number of prior US patent literature cited by the patent, the science linkage, the citation lag, the number of co-applicants, the number of inventors, the dummies for the international collaborations (co-applications and co-inventors), technology by time dummies)* (5)

- the ordered-logit model for the duration of patent protection

Figure 4 Duration of patents granted in 1995

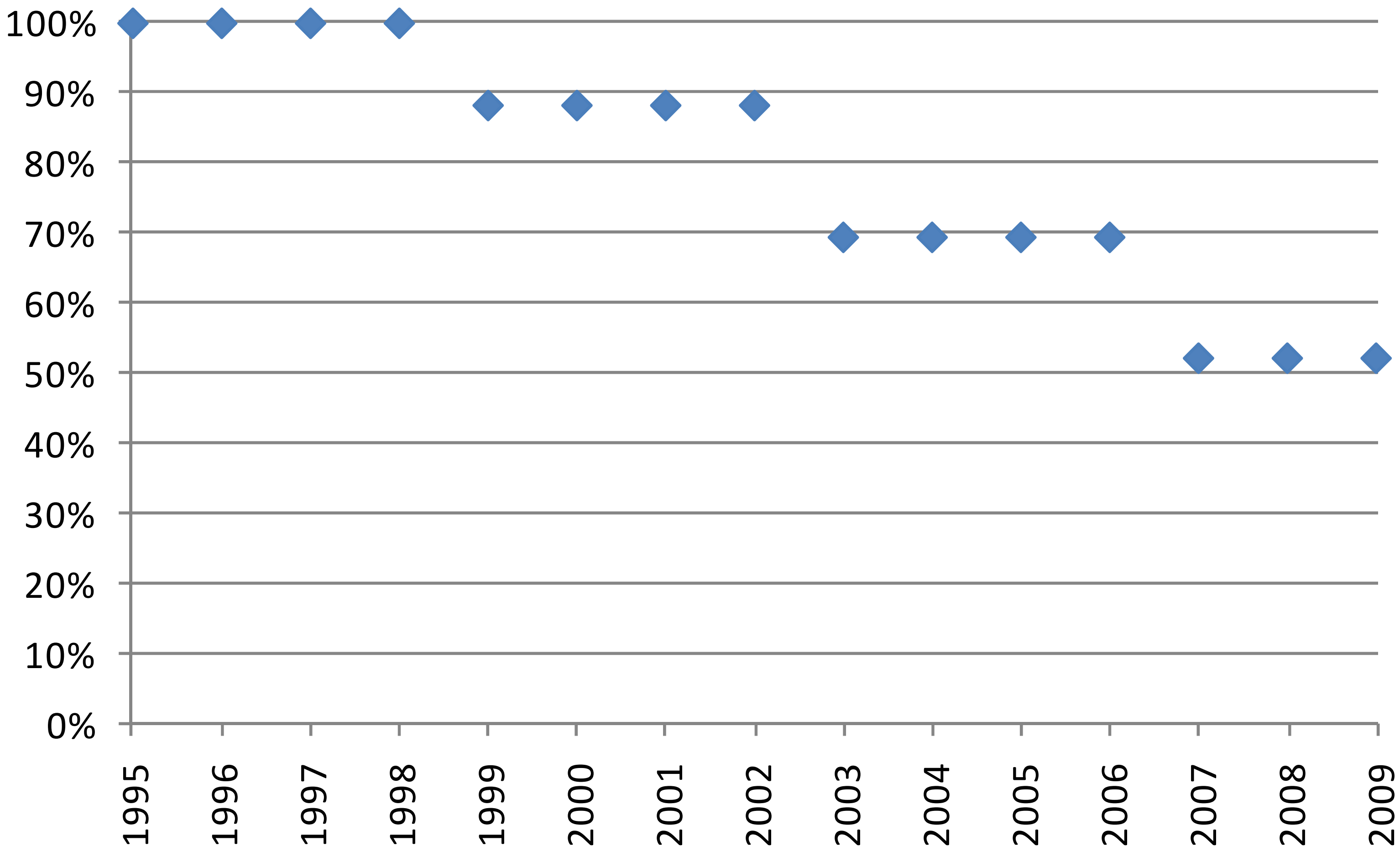


Table 4. duration of patent protection by structures of applicants/inventors

The earliest applied patents in the patent family (granted in 1992-1996)					
	Expired patents			Full term protected	Total Patents
	4th year	8th year	12th year		
Single applicant	9.9%	18.4%	18.0%	53.7%	134,760
Domestic co-applications	10.0%	20.2%	18.7%	51.2%	5,379
International co-applications	11.1%	18.0%	17.9%	53.0%	821
Single inventor	10.6%	18.6%	17.9%	52.9%	45,868
Domestic co-inventions	9.5%	18.3%	18.1%	54.2%	89,664
International co-inventions	11.1%	19.8%	17.4%	51.6%	5,428
Total	9.9%	18.4%	18.0%	53.6%	140,960
Including US applicants					
	Expired patents			Full term protected	Total Patents
	4th year	8th year	12th year		
US single applicant	6.8%	16.3%	16.9%	60.0%	54,330
US domestic co-applications	6.6%	14.6%	16.1%	62.8%	1,219
International co-applications	7.6%	15.0%	17.4%	60.0%	432
No US inventors	11.9%	22.6%	22.3%	43.2%	6621
US single inventor	6.5%	15.7%	16.0%	61.8%	16,502
US domestic co-inventions	5.9%	15.0%	16.2%	62.8%	30,738
International co-inventions	6.2%	17.9%	16.8%	59.1%	2120
Total	6.8%	16.2%	16.9%	60.1%	55,981
Including JP applicants					
	Expired patents			Full term protected	Total Patents
	4th year	8th year	12th year		
JP single applicant	7.0%	17.9%	20.6%	54.6%	37,740
JP domestic co-applications	7.3%	21.7%	21.2%	49.8%	2,633
International co-applications	3.5%	16.5%	15.4%	64.6%	285
No JP inventors	4.9%	16.4%	13.8%	65.0%	428
JP single inventor	6.6%	18.1%	22.4%	52.9%	10,164
JP domestic co-inventions	7.1%	18.1%	20.0%	54.7%	29,641
International co-inventions	7.8%	20.5%	19.1%	52.7%	425
Total	7.0%	18.1%	20.6%	54.4%	40,658

Results (Basics)

- A patent with more reference to prior patent literature, science literature and shorter citation lag tend to have significantly higher values in all three quality measures.

-Although the effect of science linkage on the duration of patent is not significant for the Japanese sample.

Results (continued)

- The patent quality increases highly significantly with the number of inventors, while it often declines significantly with the number of applicants.

- The international collaboration in terms of either co-inventions or co-ownership does not have significant coefficients.

Table 6. Estimation Results (gyear: 1992-1996)

	OLS				Ologit	
	ln(Forward citations)		ln(Claims)		ln(Duration of protection)	
	Model 1 for Japan	Model 2 for Pool	Model 3 for Japan	Model 4 for Pool	Model 5 for Japan	Model 6 for Pool
ln(Backward Citations)	0.170***	0.175***	0.146***	0.096***	0.078***	0.039**
	(0.007)	(0.009)	(0.006)	(0.007)	(0.015)	(0.018)
ln(Science Linkage)	0.037***	0.047***	0.037***	0.011	-0.045***	0.044**
	(0.007)	(0.009)	(0.006)	(0.007)	(0.015)	(0.018)
ln(Citation Lag)	-0.204***	-0.198***	-0.074***	-0.017**	-0.172***	-0.080***
	(0.008)	(0.009)	(0.007)	(0.007)	(0.017)	(0.018)
ln(Applicants)	-0.061***	0.013	-0.116***	0.017	-0.235***	-0.091
	(0.023)	(0.037)	(0.021)	(0.028)	(0.050)	(0.075)
ln(Inventors)	0.079***	0.053***	0.134***	0.017**	0.078***	0.049**
	(0.008)	(0.010)	(0.007)	(0.008)	(0.016)	(0.021)
International co-ownership	0.080	0.091	0.158	0.092*	0.227	0.219
	(0.121)	(0.071)	(0.108)	(0.055)	(0.264)	(0.148)
International co-invention	-0.056	0.005	-0.022	0.000	0.225	0.059
	(0.086)	(0.033)	(0.076)	(0.026)	(0.188)	(0.068)
Constant	1.531	1.311	2.177	2.026		
	(7,256.682	(11,137.42	(6,459.202	(8,598.239)		
Observations	38332	26312	38332	26312	38332	26312
R-squared	0.15	0.13	0.07	0.04	0.01	0.01
Log Likelihood					-43525.12	-34174.96

Standard errors in parentheses. * significant at 10%; ** significant at 5%; *** significant at 1%

Application year by technology dummies included, but not reported.

IV. Main findings and Discussions

- First, internationally co_applied patents are associated with significantly larger inventor size, except for Japan.
- Second, international co-inventions are strongly associated with more science linkage but not with backward patent citation (the number and the lag).
- Third, once we control for the number of inventors and the literature cited, international research collaborations are not associated with higher patent quality, in term of forward citation, the number of claims or the duration of patent term.
- Fourth, co-applications tend to be associated with lower patent quality, once we control for the number of inventors.

Thanks a lot for your attentions.

Comments on Whether and How Does International Research Collaboration Affect Invention Quality? by Nagaoka and Tsukada

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KDI International Seminar
Intellectual Property for Economic Development
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Overview

- Investigates whether and how international research collaboration affects invention quality using triadic patent bibliographical information
- International research collaboration defined as a patent having inventors or applicants from different countries
- Some evidence that international research collaboration is associated with more extensive exploration of prior knowledge
- No evidence that international research collaboration is associated with higher patent quality
- Number of inventors: the most robust explanatory variable.
- Very interesting; important issue to investigate

Some conceptual issues

- Research collaboration and invention quality: direction of causality
- Research collaboration (between unrelated parties) is a costly way to conduct research and development
  - Co-ownership of IP and thus sharing returns to invention is a high price to pay.
  - Collaboration risks divulging of trade secret and other proprietary knowledge.
- Research collaboration as a way to share risk and costs
- Distinguish between collaboration within a multinational corporation and that between two unrelated parties: different motivation

Specific issues

- General weakness of the USPTO citation data for the purpose of this project
  - Citations made to other USPTO patents
  - Language barriers
- Magnitudes of the estimates
- Clustered standard errors

Suggestions for future research

- Distinguish between co-invention/co-ownership within and between firms
- Construct a control group by matching

(Very preliminary, draft IIR working paper)

Whether and how does international research collaboration affect invention quality?[1]

:Some evidence from triadic patent data

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Abstract

This paper analyzes whether and how international research collaboration in terms of co-inventions and co-ownership may affect invention performance. We distinguish its potential effects on the number of inventors used for the invention, the scope and the speed of using the prior knowledge as measured by the US patent references and the other effects (productivity effect, hereafter). We focus on the OECD triadic patents which have been applied to the patent offices of the US and Japan and the European Patent Office. Our major findings are the following. First, internationally co_applied patents are associated with significantly larger inventor size, except for Japan. Second, international research collaborations in terms of co-inventions are strongly associated with more science linkage but not with backward patent citation (number and the lag). Third, once we control for the number of inventors and the literature cited, international research collaborations are not associated with higher patent quality, in term of forward citation, number of claims or the duration of patent term (renewal). Fourth, co-applications tend to be associated with lower patent quality, once we control for the number of inventors

Key Words: research collaboration, international co-invention, patent, inventors, research productivity
JEL classification: O31, O32, O34

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[1] We would like to thank Helene Dernis and Dominique Guellec of OECD for their kind help for us using the triadic patent database and for matching them to the Japanese patent data. We would like to thank Toshiaki Iizuka of Keio University.

1. Introduction

International research collaborations have become important, as more countries in the world, including East Asian countries as Korea and China, have significantly strengthened research capability and as firms globalize their research operations. This paper analyzes how international research collaborations affect invention quality, based on the triadic patent data. Patent data provides important information in this regard: the addresses of the inventors and the owners (or assignees). If inventors of more than two different national addresses work together, 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, it would imply that these firms collaborated for the R&D in term of finance, human resources or the other manners. Although co-invention or co-ownership does not cover all research collaborations[2], they would cover important part of the research collaborations involving the combination of significant resource. Research collaboration defined in these terms has become important in recent years (see OECD (2005)).

An important question is whether and how international research collaborations affect research performance. The combination of the inventors of different countries would allow a firm to undertake a research which might not have been possible if only the resources of a single nation inventor could be used

[2] It is important to note that co-ownership significantly under-represent the 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.

and would enlarge the pool of technological or scientific knowledge available for a research. Co-ownership by firms with different nationalities might be important for creating incentive for such firms to contribute various resources to the R&D, including the pool of inventors for the invention and tacit knowledge. On the other hand, it is important to note that co-ownership might create a free rider problem or an adverse selection problem.

This paper makes an attempt to assess the effects of international research collaborations on invention performance at patent level, focusing on internationally co-invented or co-owned patents. International collaborations might expand the size of research team, therefore the human capita available for research. It might also expand the scope of the knowledge used for invention by enhancing the absorptive capability of the research team and increase the speed of research. Finally, it might also have productivity effect, that is, it might enhance the productive use of the knowledge absorbed. The patent level study allows us to examine the effects of research collaborations through these various channels, so that it would help us understand how international research collaboration might work or might not work.

There are many literature on research collaboration, both on the incidence of co-ownership (see, 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 (see, for an 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. 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 research (One exception is Mowery, Oxley and Silverman (1996)). This paper makes an attempt to assess the potential effects of international research collaborations on the quality of invention at patent level, focusing on the effects on the scope of the use of the existing knowledge as well as on the productivity of using such knowledge.

For this objective we have developed the data set from three sources of the patent database: the triadic patent data developed by the OECD[1], the released PATSTAT database of the EPO, the NBER patent database and the USPTO website. The triadic patents consist of the inventions for which patents have been applied for in all three of USPTO (US Patent and Trademark Office), the EPO (European Patent Office) and JPO (Japan Patent Office) (granted from the USPTO). It thus consists of the family of US, EPO and JPO patents which share one or more priorities. For 1997 as a priority year, there are 41 thousands families, which have 58 thousands US patents, 49 thousands EPO patents and 50 thousands JPO patents. They represent important inventions worth global patent applications. There are two advantages for us to use the OECD triadic patents. First, it would facilitate international comparison, given the large national differences in patent administration, including the standards for patent grants. Second, given that the value of the patents is highly skewed (Scherer and Harhoff (2000) for an example), the analysis focusing on the important patents may well more accurately represent the nature of R&D collaboration. Our unit of analysis is the patent family of the triadic patents.

We have extracted the detailed citation information from the PATSTAT database, including the citation of non-patent literature (mainly scientific literature), available for the US patents. We have constructed the citation information of each triadic family by aggregating the citation information of US patents in each family (we have removed duplications in forward and backward patent citation). We use the technology classification and the priority year of the patent with the earliest priority year as those of the triadic family. We have also extracted the number of claims of each patent from the NBER patent database as well as the records of the payments of patent renewal fees from USPTO website. 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 the US patents allows us to assess the quality of the patent as well as the scope of the knowledge relevant to the invention process. In particular, the frequency of forward citations, the frequency by which a particular patent is cited, will tell us the quality of the patent, once we control 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 are made by an examiner (not by an inventor himself).

The paper consists of the following. Section 2 provides the description of the structure of inventions and ownership across countries and sectors. Section 3 provides economic framework analyzing the effects of research collaboration and the descriptive statistic of the sample for estimation. Section 4 provides the estimation results and section 5 concludes.

2. Structure of international co-inventions and co-applications

We focus on the OECD triadic patents which have both at least one inventor and one assignee of the patent in one of the five largest industrialized countries (US, Japan, Germany, France and UK). For an example, we identify the patents with at least one US applicant and one US inventor as the patents of that country. In those five countries, roughly speaking, one quarter of the triadic patents involve only a single-inventor while the rest are the co-inventions, involving more than two inventors in recent years (2000-2006), as shown in Figure 1. The share of international co-inventions varies significantly across countries: from 27 % for the UK to 2% in Japan. The share of international co-inventions increased significantly over time over the period from 1980-1989 to 2000-2006, as shown in Figure 2, in all countries except for Japan: from 3% to 12 % in the US versus from 1% to 2% in Japan.

(Figure 1, Figure 2)

Table 1 shows the incidence of triadic patents by inventor structure and ownership structure in a matrix form for 2000-2006, which help us understand the sources of the variations in the level of international co-inventions as indicated by Figure 1. There are several observations we can make. Co-ownership is also important from 5% for US and Germany to 9% for Japan[2]. The ratio of international co-ownership varies from 0.8% for the Japan to 1.8% for Germany. Second, international co-ownership is typically associated with international co-invention. In each country, more than 60% of the patents with international co-applications involve international co-inventions. Third, the extent of international co-invention for the patens with a single national ownership varies significantly among these countries. In the case of Japan, only 1% of the patents with national ownership involve international co-inventions. On the other hand, in the case of the US or Germany, 7 to 8% of them involve international co-invention. Thus, the low level of international co-inventions of Japan as shown in Figure 1 can be substantially accounted for by low incidence of international co-inventions for nationally owned patents. This indicates that the extent of intra-firm internationalization of research activities is low in Japan.

(Table 1)

Let us turn to the pattern of international co-inventions by technology sectors. Figure 3 shows the frequency of international co-inventions due to national applications and to international co-applications (1995-2002). According to this figure, the primary factor explaining the variation of the frequency of international co-inventions across sectors is intra-firm internationalization of research activities across sectors. That is, firms engage international teams for research in agriculture, food, drugs and biotechnology much more than (several more times higher than) in the other sectors such as motors, engines and parts, electrical devices and computer peripherals. Those with higher incidence of international research collaborations coincide with those with high degree of science linkage.

(Figure 3)

3.1 **International co-applications and size of invention team**

3.1 Theoretical framework

We start from the following simple model of knowledge production. A firm i hires x_i inventors for R&D. The invention quality measured by the value of a patent depends on how much external prior knowledge k the inventors can search and use for their invention:

$$k = k(x_i;\theta_i)\,, \qquad (1)$$

which increases with x_i and the efficiency parameter θ_i of a firm. The invention quality depends also on the number of inventors (x_i^{α} with $0<\alpha<1$) as well as the productivity of efforts (A_i). Thus, it is given by

$$v_i = A_i k(x_i;\theta)x_i^{\alpha} \qquad (2)$$

A firm chooses the number of inventors (x_i) to maximize the following profit

$$\pi_i = A_i k(x_i;\theta)x_i^{\alpha} - c(x_i;\lambda_i) \qquad (3)$$

The cost of hiring inventors $c(x_i;\lambda_i)$ depends on the scope of the pool of the inventors which the firms have access.

International research collaborations may affect both λ, θ, A. We can examine how international co-ownership is associated with significantly larger number of inventors than purely domestic patents. The domestic inventive human resources would become more limiting as the research task become larger and more complex. That is, the marginal cost of hiring additional inventor increases more rapidly if only domestic inventors are hired than if no such constraint exists (MC>MC* for a certain size of inventors and such gap expands as the size of research team increases) . Consequently, as illustrated in Figure 4, we would expect that as the size of the research task increases (the shift from MRs to ML_L), it would become more efficient to hire foreign inventors. Since engaging a foreign firm as the co-owner of the invention would enable a domestic firm to have better access to foreign researchers, we would expect a positive correlation between the size of the research team and the incidence of foreign ownership.

(Figure 4)

3.2 Empirical analysis

Table 2 provides the results of the simple regressions, based on the following model:

the logarithm of the number of inventors$_{i,k,t}$*= f (the number of co-applicants(and the single ownership dummy), the dummy for international co-ownership and application year by technology)* (4)

We introduce the technology by time dummies to control the variations of technological characteristics across technology areas and over time. We use 37 technology area dummies.

The estimated coefficient for the dummy for international co-ownership indicates the effect due to international co-ownership, relative to the effect of domestic co-ownership. The logarithm of the number of (total) applicants has a highly significantly positive coefficient with less than 1, implying that the number of inventors increase less than proportionately with the number of co-owners. The single ownership dummy is significant, implying that the incremental effect due to the change from a single ownership to a joint ownership of two firms are significantly different from the incremental effect due to the change from a joint ownership of two firms to that of four firms. According to the estimations, the latter effect is larger for US, Germany, France and Great Britain, while the latter is smaller for Japan. Except for Japan, the dummy for the international co-ownership has a significantly positive coefficient, implying that the inventions with international co-ownership, relative to domestic co-ownership, are associated with significantly larger number of inventors than purely domestic patents. Such effect is strong: around 10% for the US and Germany, and around 20% for France and 25%

for Great Britain, according to the model with a single ownership dummy. On the other hand, international co-ownership, relative to domestic ownership, is not associated with a larger team size in Japan, even though such co-ownership is still associated with a larger number of inventors.

(Table 2)

3. 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 the foreign inventors, in addition to using their inventive expertise and efforts. We can apply the reasoning behind Figure 4 to the issue of knowledge exploitation (we can replace size of the team by the scope of knowledge). If international collaborations reduce the cost of exploiting knowledge, we would observe that the patents from international research collaborations are more associated with larger scope of knowledge used for the research.

We use the following indicators as the extent of the knowledge used: the number of prior non-patent literature (mainly science literature) cited or science linkage (*Non-patent literature citation*), the number 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 be used in the invention process[3]. 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 i in technology area k granted in

[3] Backward citations are often added by examiners and patent attorneys, so that they can be poor predictors of knowledge flow (Thompson and Fox-Kean (2005) and Thompson (2006)). On the other hand, the number of backward citations to non-patent literature is significantly correlated with the importance of knowledge flow.

year *t*:

Use of prior knowledge$_{i,k,t}$*= f (the number of co-applicants, the number of inventors, the dummies for the international collaborations (co-applications and co-inventors), technology by time dummies)* (5)

We focus on two samples: the patents from Japan (those with at least one inventor and one applicant located in Japan) and the patents from three European countries (Germany, France and Great Britain, "Pool" thereafter). We do not use the patents involving the US inventor or applicant. There is a significant difference between the patents from the US and those from the other countries in the level of both forward and backward citations per patent and the number of claims per patent (see Appendix). High level of both backward and forward citations of the patents from the US seem to strongly reflect the fact that the patenting practices of the US firms and the US inventors are strongly tailored to their home markets, where the law requires strong disclosure requirements in patent applications with respect to prior literature. On the other hand, the examiners are mainly responsible for identifying the relevant prior art in Japan and EPO. As a result, the application behaviors of the applicants from these countries cite less references, although the discourse requirements are equally applicable to non-US applicants with respect to their applications for US patents. Thus, an international co-invention with a US inventor or an international co-applicant with a US firm tends to have more backward citations as well as more forward citations in the US patents, which could substantially bias the estimation of the effects of international co-inventions and co-ownerships.

Table 3 shows the results of the four set of estimations for each dependent variable: science linkage (the number of non-patent literature references), backward citation (the number of patent literature references) and the median citation lag in backward citation. For each dependent variable, the first two models use two international dummies (one on international co-ownership and the other on international co-invention) measuring the extent of international research collaboration, relative to domestic collaborations, and the latter two models introduce more detailed controls over the structure of ownership and inventor structure, including the interaction terms for the ownership and inventorship structures.

As shown in this Table 3, the number of inventors is highly significant for the number of non-patent literature citations or science linkage for Japan and the pool of three European countries, controlling for technologies, including yearly changes within each sector. It is also highly significant for backward citation of prior patent literature and citation lag for both samples, except for model 8 with interaction terms. A larger number of inventors is highly associated with more extensive use of the knowledge embodied in non-patent literature and exploitation of more number of and more recent patent literature. On the other hand, the number of applicants has a less significant coefficient or a coefficient with an opposite sign: coefficients with mixed signs for science linkage, negative coefficients for backward citation of patent literature and positive coefficients for citation lag. 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 or an ex-ante adverse selection problem.

(Table 3)

Our main concern is whether the international co-invention or co-ownership has a significant relationship with the additional use of prior knowledge. As Model 1 and 2 show, international co-invention has a positive and highly significant coefficient for science linkage for two samples of Japan and the pool of three European countries. The coefficients imply that the participation of one or more foreign inventors is associated with more significant use of scientific literature in both samples (15% more in the case of Japan and 12% in the case of the pool of three European countries), controlling for the number of inventors. On the other hand, international co-ownership is less significantly associated with science linkage. The interaction terms provide clues for us to improve our understanding of the sources of such correlations, in particular to see whether the international co-invention is significant, controlling for the ownership structure and whether international co-ownership is significant controlling for the inventor structure. Model 3 and Model 4 show that an international co-invention has a significantly higher coefficient than a domestic co-inventions in the case of patents with single domestic co-ownership, controlling for the number of inventors. On the other hand, an international co-ownership does not have a significantly higher coefficient in the case of international co-inventions. These effects indicate that international co-ownership may not have effects not caught by more inventors.

As for the model for backward citations to patent literature, the international co-invention dummy has a negative coefficient and insignificant coefficient for the citation lag for both samples. Thus, as a whole, international co-invention does not seem to have additional positive effect on the exploitation of knowledge embodied in prior US patent literature. As for international co-ownership, the presence of foreign applicant has a significantly positive coefficient for the reference to the prior patent literature (significant at 5%) in the Model 6, but only an insignificant coefficient in Model 5, 9 and 10. The interaction terms suggest that neither international co-invention in the case of single domestic ownership nor international co-ownership in the case of international co-inventions significantly enhances the exploitation of the knowledge embodied in prior patent literature.

4. Quality of patents

International research collaborations may affect the quality of inventions through three channels. We have seen that it allows a firm to undertake a larger research project and it facilitates the access to prior science literature. In addition, it may have effects due to a synergy between domestic and foreign inventor and to the exploitation of knowhow, not captured by the number of inventors or the use of literature.

We use three measures of the quality of patented inventions: the average number of forward citations received per patents, the average number of claims per patent as well as the duration of the patents, all of which are based on the US patents. More specifically, variable *Forward citation* ($cit_{i,k,t}$) indicates the average number of citations received by such patent the variable (we use the logarithm of $1+cit_{i,k,t}$ as an independent variable), variable *Claims* ($claim_{i,k,t}$) indicates the number of claims of patent *i* in technology area *k* granted in year *t,* and variable $duration_{i,k,t}$ (maintained up to the 4th year, the 9th year, 12th year and full term). The assignees are more willing to pay the renewal fees to maintain the rights for higher valued patents. One advantage of the renewal data is that it is independent of bibliographic indicators so that it is not dependent on the difference of referencing behaviors of the inventors of different nationalities, even though the US applicant still has an advantage since it has more complementary assets in the US. According to Figure 4, around 50% of the triadic patents granted in 1995 were maintained to the full term. As shown in Figure 5, while the patents with a Japanese applicant and the other foreign co-applications is more likely to be maintained for a full term, such is not the case for the patents with involving a US applicant and the other foreign co-applications, indicating the advantage of the US applicant in terms of complementary assets. Thus, we will again exclude the samples with US applicants or inventors.

(Figure 4 and Table 4)

We postulate the following estimation equation for the invention quality:

$\ln(claim_{i,k,t})$ or $\ln(1+cit_{i,k,t})$ or $\ln(duration_{i,k,t}) = f$ *(the number of prior US patent literature cited by the patent, the science linkage, the citation lag, the number of co-applicants, the number of inventors, family size, the dummies for the international collaborations (co-applications and co- inventors),technology by time dummies)* (5)

We use the ordered-logit model for the duration of patent protection and simple OLS for the other two variables. If co-ownership enhances the invention quality even if we control for its effects on the prior public knowledge used for invention and on the number of inventors, the international collaborations matter more than the number of inventors and the use of knowledge embodied in literature.

Table 5 shows four estimation models for each of the forward citation and the number of claims as dependent variables. Models use two international dummies (one on international co-invention and the other on international co-ownership) measuring the effect of international research collaboration, relative to domestic projects. As shown in this Table, most estimated coefficients for backward patent citation, science linkage and citation lag have highly significant coefficients (significant at 1% level) for all three patent quality variables. That is, a patent with more reference to prior patent literature, science literature and shorter citation lag tend to have significantly higher values in terms of both forward citation and the number of claims, consistent with our expectation and with prior research at firm level (nagaoka (2007)) as well as the renewal of the patent term.

(Table 5)

Let us turn to the effects of the number of inventors and that of applicants. The patent quality increases highly significantly with the number of inventors, while it often declines significantly with the number of applicants. According to model 1, the elasticity of forward citation with respect to the number of inventors (number of applicants) is 0.079 (-0.061) and that of the number of claims is 0.053 (0.013) in the case of Japanese patents. In addition, the elasticity of the duration of patent protection is 0.078 (-0.235). The international collaboration in terms of either co-inventions or co-ownership does not have significant coefficients. That is, there does not seem to exist additional effects other than the number of inventors and the use of knowledge embodied in literature. .

5. Conclusions and discussions

This paper has analyzed whether and how international research collaboration in terms of co-inventions and co-ownership may affect invention performance. We have distinguished its potential effects on the number of inventors used for the invention, the scope and the speed of using the prior knowledge as measured by the US patent references and the other effects (productivity effect, hereafter). We focused on the OECD triadic patents which have been applied to the patent offices of the US and Japan and the European Patent Office.

Our major findings are the following. First, internationally co_applied patents are associated with significantly larger inventor size than purely domestically owned patents, except for Japan. This seems to indicate that capabilities or opportunities for engaging foreign inventors enable a domestic firm to undertake large scale R&D project. This effect, however, is weak for Japanese inventions.

Second, international research collaborations in terms of co-inventions are strongly associated with more science linkage but not with backward patent citation (number and the lag). This may indicate that knowledge embodied in patent literature may be relatively well-known, while absorptive capability may be more important for using the scientific knowledge, where the international collaboration matter.

Third, once we control for the number of inventors and the literature cited, international research collaborations are not associated with higher patent quality, in term of forward citation, number of claims or the duration of patent term (renewal).

Fourth, co-applications tend to be associated with lower patent quality, once we control for the number of inventors The latter effect may indicate a significance of free-rider problem and/or an adverse selection problem. Co-ownership may harms invention process unless it is instrumental for expanding the pool of available inventors.

There are reservations and further issues to be addressed. First, our study does not decimate co-ownership by independent firms and that between related firms. Co-ownership between related firms may have smaller governance problem. Second, there is an endogeneity issue, even though we introduce technology by time dummies to control the variations of technological or market opportunities. The positive effect of the number of researchers on the quality of the invention as well as on the use of prior knowledge may reflect to a certain extent at least the reverse causality: good technological opportunities results in more inventors involved and in better research results.

Figure 1. Frequency of co-inventions by major industrialized countries
(Application Year: 2000-2006)

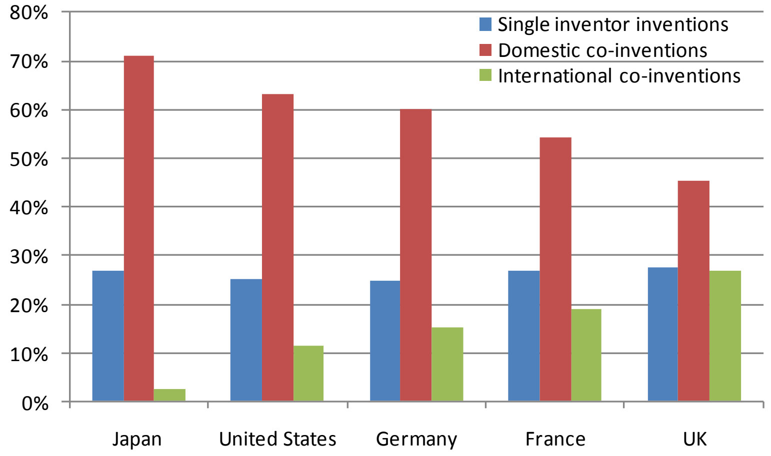
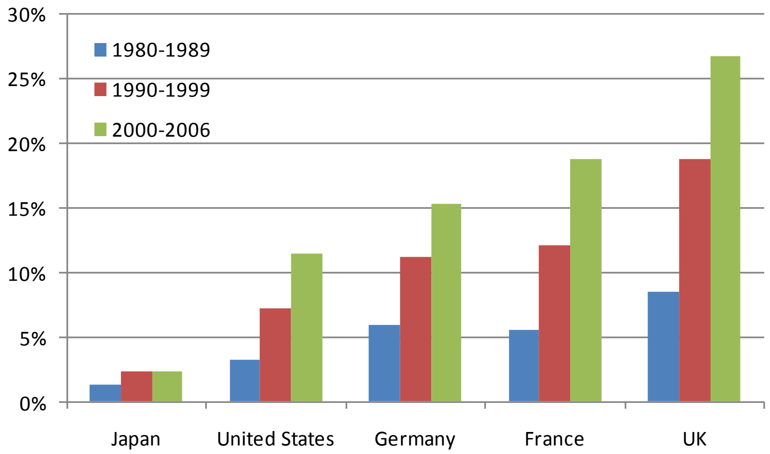


Figure 2 The evolution of the frequency of international co-inventions



Note. Patents classified by application years

Figure 3 Frequency of intra-firm internationalization of research and that of international co-applications by technology sectors (1995-2002)

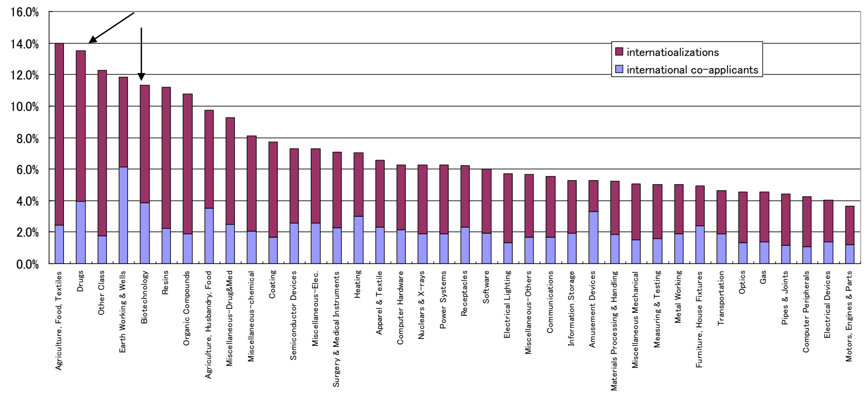


Table 1 The incidence of triadic patents by inventor and ownership structures for 2000-2006

Japan (2000-2006)

	Single inventor	Domestic co-inventions	International co-inventions	Total
Single applicant	25.9%	64.1%	1.0%	91.0%
Domestic co-applications	0.8%	7.3%	0.1%	8.2%
International co-applications	0.1%	0.2%	0.5%	0.8%
Total	26.8%	71.7%	1.5%	100.0%

United States (2000-2006)

	Single inventor	Domestic co-inventions	International co-inventions	Total
Single applicant	25.0%	62.7%	7.0%	94.7%
Domestic co-applications	0.2%	3.3%	0.2%	3.7%
International co-applications	0.1%	0.4%	1.2%	1.6%
Total	25.3%	66.4%	8.3%	100.0%

Germany (2000-2006)

	Single inventor	Domestic co-inventions	International co-inventions	Total
Single applicant	25.2%	61.3%	7.6%	94.1%
Domestic co-applications	0.4%	3.5%	0.2%	4.1%
International co-applications	0.1%	0.3%	1.4%	1.8%
Total	25.6%	65.2%	9.2%	100.0%

Figure 4. Size of research

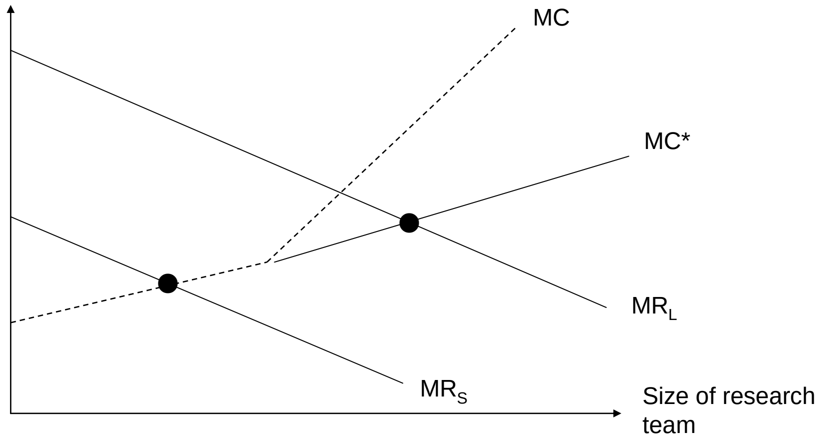


Table 2: International co-ownership and size of invention team (grant year: 2000-2006)

OLS: Gyear: 2000-2006

	ln(Inventors)									
	JP		US		DE		FR		GB	
ln(Applicants)	0.499*** (0.012)	0.341*** (0.035)	0.375*** (0.013)	0.554*** (0.030)	0.408*** (0.022)	0.426*** (0.046)	0.405*** (0.029)	0.589*** (0.067)	0.417*** (0.041)	0.699*** (0.083)
Single ownership		-0.141*** (0.029)		0.198*** (0.030)		0.019 (0.045)		0.186*** (0.062)		0.319*** (0.083)
International co-ownership	-0.023 (0.028)	-0.039 (0.028)	0.063*** (0.021)	0.111*** (0.022)	0.097*** (0.034)	0.100*** (0.034)	0.179*** (0.044)	0.199*** (0.044)	0.176*** (0.052)	0.246*** (0.055)
Constant	-0.344 (1.070)	-0.375 (1.070)	-0.000 (1.046)	-0.198 (1.046)	1.623 (13,287.83	1.598 (13,289.20	-0.687 (1.566)	-0.928 (1.565)	-0.633 (1.837)	-1.007 (1.837)
Observations	68815	68815	71696	71696	28761	28761	9654	9654	5611	5611
R-squared	0.09	0.09	0.06	0.06	0.16	0.16	0.16	0.16	0.22	0.22

Standard errors in parentheses
* significant at 10%; ** significant at 5%; *** significant at 1%
Application year by technology dummies included, but not reported.

Table 3: Knowledge use (2000-2006)

		ln(Non-patent literature citations				ln(Backward citations)				ln(Citation Lag)			
		Model 1 for Japan	Model 2 for Pool	Model 3 for Japan	Model 4 for Pool	Model 5 for Japan	Model 6 for Pool	Model 7 for Japan	Model 8 for Pool	Model 9 for Japan	Model 10 for Pool	Model 11 for Japan	Model 12 for Pool
ln(Applicants)		-0.022*	0.039*	-0.034	0.045	-0.100***	-0.049***	-0.107***	-0.091**	0.030***	0.039**	-0.006	-0.042
		(0.013)	(0.020)	(0.038)	(0.048)	(0.013)	(0.019)	(0.038)	(0.045)	(0.011)	(0.017)	(0.034)	(0.039)
ln(Inventors)		0.061***	0.056***	0.068***	0.028***	0.086***	0.021***	0.122***	0.005	-0.017***	-0.058***	-0.018***	-0.038***
		(0.004)	(0.006)	(0.007)	(0.010)	(0.004)	(0.006)	(0.007)	(0.009)	(0.004)	(0.005)	(0.006)	(0.008)
International co-ownership		0.110**	0.015			0.068	0.086**			-0.007	0.006		
		(0.045)	(0.037)			(0.045)	(0.034)			(0.040)	(0.030)		
International co-invention		0.149***	0.123***			-0.029	-0.049***			0.030	-0.014		
		(0.034)	(0.016)			(0.034)	(0.015)			(0.030)	(0.013)		
Single inventor	Domestic co-ownership			-0.027	0.047			-0.009	-0.025			0.080**	0.042
				(0.044)	(0.074)			(0.044)	(0.068)			(0.039)	(0.060)
	International co-ownership			0.088	0.066			0.029	0.118			0.003	-0.004
				(0.158)	(0.150)			(0.158)	(0.139)			(0.139)	(0.123)
Domestic co-inventions	Single domestic ownership			-0.014	0.047***			-0.063***	0.025*			0.003	-0.035***
				(0.010)	(0.014)			(0.010)	(0.013)			(0.009)	(0.011)
	Domestic co-ownership			-0.001	0.031			-0.061*	0.068			0.029	0.048
				(0.033)	(0.047)			(0.034)	(0.044)			(0.029)	(0.039)
	International co-ownership			0.088	0.084			-0.023	0.063			-0.066	-0.107
				(0.073)	(0.086)			(0.073)	(0.080)			(0.064)	(0.070)
International co-inventions	Single domestic ownership			0.127***	0.169***			-0.112***	-0.030			0.004	-0.060***
				(0.040)	(0.022)			(0.040)	(0.020)			(0.035)	(0.018)
	Domestic co-ownership			0.146	0.352***			0.005	0.124			0.015	0.080
				(0.156)	(0.103)			(0.157)	(0.095)			(0.138)	(0.084)
	International co-ownership			0.267***	0.174***			0.002	0.120**			0.114**	0.064
				(0.062)	(0.057)			(0.062)	(0.053)			(0.054)	(0.047)
Constant		0.584	2.300	0.586	2.303	2.364	2.529	2.367	2.530	2.986	2.314	2.979	2.316
		(5,694.705	(8,456.586	(5,694.865	(8,455.538	(5,709.893	(7,837.441	(5,708.479	(7,837.096	(5,020.673	(6,908.524	(5,020.591	(6,907.174
Observations		68168	42729	68168	42729	68168	42729	68168	42729	68168	42729	68168	42729
R-squared		0.13	0.25	0.13	0.25	0.06	0.07	0.06	0.07	0.11	0.11	0.11	0.11

Standard errors in parentheses
* significant at 10%; ** significant at 5%; *** significant at 1%
Application year by technology dummies included, but not reported.

Figure 4 Duration of patents granted in 1995

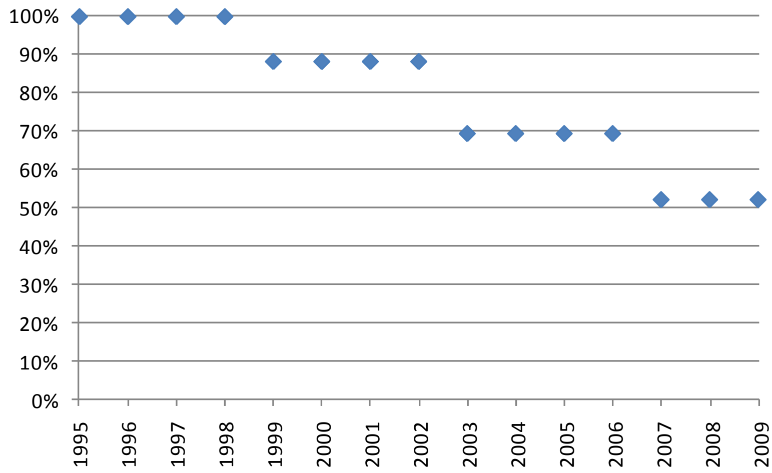


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Table 4. duration of patent protection by structures of applicants/inventors

The earliest applied patents in the patent family (granted in 1992-1996)					
	Expired patents			Full term protected	Total Patents
	4th year	8th year	12th year		
Single applicant	9.9%	18.4%	18.0%	53.7%	134,760
Domestic co-applications	10.0%	20.2%	18.7%	51.2%	5,379
International co-applications	11.1%	18.0%	17.9%	53.0%	821
Single inventor	10.6%	18.6%	17.9%	52.9%	45,868
Domestic co-inventions	9.5%	18.3%	18.1%	54.2%	89,664
International co-inventions	11.1%	19.8%	17.4%	51.6%	5,428
Total	9.9%	18.4%	18.0%	53.6%	140,960
Including US applicants					
	Expired patents			Full term protected	Total Patents
	4th year	8th year	12th year		
US single applicant	6.8%	16.3%	16.9%	60.0%	54,330
US domestic co-applications	6.6%	14.6%	16.1%	62.8%	1,219
International co-applications	7.6%	15.0%	17.4%	60.0%	432
No US inventors	11.9%	22.6%	22.3%	43.2%	6621
US single inventor	6.5%	15.7%	16.0%	61.8%	16,502
US domestic co-inventions	5.9%	15.0%	16.2%	62.8%	30,738
International co-inventions	6.2%	17.9%	16.8%	59.1%	2120
Total	6.8%	16.2%	16.9%	60.1%	55,981
Including JP applicants					
	Expired patents			Full term protected	Total Patents
	4th year	8th year	12th year		
JP single applicant	7.0%	17.9%	20.6%	54.6%	37,740
JP domestic co-applications	7.3%	21.7%	21.2%	49.8%	2,633
International co-applications	3.5%	16.5%	15.4%	64.6%	285
No JP inventors	4.9%	16.4%	13.8%	65.0%	428
JP single inventor	6.6%	18.1%	22.4%	52.9%	10,164
JP domestic co-inventions	7.1%	18.1%	20.0%	54.7%	29,641
International co-inventions	7.8%	20.5%	19.1%	52.7%	425
Total	7.0%	18.1%	20.6%	54.4%	40,658

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Table 6. Estimation Results (gyear: 1992-1996)

	OLS				Ologit	
	ln(Forward citations)		ln(Claims)		ln(Duration of protection)	
	Model 1 for Japan	Model 2 for Pool	Model 3 for Japan	Model 4 for Pool	Model 5 for Japan	Model 6 for Pool
ln(Backward Citations)	0.170***	0.175***	0.146***	0.096***	0.078***	0.039**
	(0.007)	(0.009)	(0.006)	(0.007)	(0.015)	(0.018)
ln(Science Linkage)	0.037***	0.047***	0.037***	0.011	-0.045***	0.044**
	(0.007)	(0.009)	(0.006)	(0.007)	(0.015)	(0.018)
ln(Citation Lag)	-0.204***	-0.198***	-0.074***	-0.017**	-0.172***	-0.080***
	(0.008)	(0.009)	(0.007)	(0.007)	(0.017)	(0.018)
ln(Applicants)	-0.061***	0.013	-0.116***	0.017	-0.235***	-0.091
	(0.023)	(0.037)	(0.021)	(0.028)	(0.050)	(0.075)
ln(Inventors)	0.079***	0.053***	0.134***	0.017**	0.078***	0.049**
	(0.008)	(0.010)	(0.007)	(0.008)	(0.016)	(0.021)
International co-ownership	0.080	0.091	0.158	0.092*	0.227	0.219
	(0.121)	(0.071)	(0.108)	(0.055)	(0.264)	(0.148)
International co-invention	-0.056	0.005	-0.022	0.000	0.225	0.059
	(0.086)	(0.033)	(0.076)	(0.026)	(0.188)	(0.068)
Constant	1.531	1.311	2.177	2.026		
	(7,256.682	(11,137.42	(6,459.202	(8,598.239)		
Observations	38332	26312	38332	26312	38332	26312
R-squared	0.15	0.13	0.07	0.04	0.01	0.01
Log Likelihood					-43525.12	-34174.96

Standard errors in parentheses. * significant at 10%; ** significant at 5%; *** significant at 1%
Application year by technology dummies included, but not reported.

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[1] According to the definition of the OECD, "the triadic patent families are defined at the OECD as a set of patents taken at the EPO, JPO and USPTO that share one or more priorities. In comparison with traditional indicators based on patent filings to a single patent office, the triadic patent families cover a homogeneous set of inventions as the most important inventions are deemed to be protected by a patent at the EPO, JPO and the USPTO" (see Dernis and Khan (2004)). There are around 50,000 US patents belonging to the triadic patents in late 1990s in terms of priority years, during which around 150,000 US patents were granted. Thus, one third of the US patents belong to the triadic patents.

[2] In this study we do not distinguish co-ownership by independent firms and that by related firms.