



RIETI Discussion Paper Series 15-E-113

Combining Knowledge and Capabilities across Borders and Nationalities: Evidence from the inventions applied through PCT

TSUKADA Naotoshi
RIETI

NAGAOKA Sadao
RIETI



Research Institute of Economy, Trade & Industry, IAA

The Research Institute of Economy, Trade and Industry
<http://www.rieti.go.jp/en/>

September 2015

**Combining Knowledge and Capabilities across Borders and Nationalities:
Evidence from the inventions applied through PCT¹**

TSUKADA Naotoshi

National Graduate Institute for Policy Studies and RIETI

NAGAOKA Sadao

Tokyo Keizai University and RIETI

Abstract

This paper analyzes how co-inventions with foreign residents and/or foreign-born inventors contribute to the inventive performance, using the Patent Cooperation Treaty (PCT) applications. We find that combining inventors across borders and nationalities have become important in major industrialized countries, especially in the sectors where science is important for inventions. Both inventions with foreign-born inventors and those with foreign resident inventors have high science linkages, controlling for the sectors. We also find that the inventions based on such collaborations have high performance in terms of forward citations (but not in terms of the geographic scope of patent protection), relative to the inventions by the purely domestic team. These effects diminish but remain significant even if we control for firm fixed effects. However, these effects disappear once we control for the first inventor fixed effects, indicating the possibility that the matching between the high performing domestic inventors and the foreign resident and/or foreign-born inventors plays an important role.

Keywords: Patent, Co-invention, Foreign born, Knowledge, Matching, PCT

JEL codes: O31, O32, O34

RIETI Discussion Papers Series aims at widely disseminating research results in the form of professional papers, thereby stimulating lively discussion. The views expressed in the papers are solely those of the author(s), and neither represent those of the organization to which the author(s) belong(s) nor the Research Institute of Economy, Trade and Industry.

¹ This study is conducted as a part of the Project “Research on Innovation Process and its Institutional Infrastructure” undertaken at Research Institute of Economy, Trade and Industry (RIETI). We used the results of the “PatVal-Japan Survey” conducted in an international collaborative research project between RIETI (Prof. Nagaoka), Università Commerciale Luigi Bocconi (Prof. Gamberdella) and Ludwig-Maximilians-Universität (Professor Harhoff). The author is grateful for helpful comments and suggestions by participants of the Discussion Paper seminar at RIETI and participants of the International Workshop on Patent System and Inventor at Max Planck Institute for Innovation and Competition. Furthermore, this research was partly supported by financial assistance provided by the Japan Society for the Promotion of Science Grant in Aid for Scientific Research Grant No.25780182.

1. Introduction

Combining knowledge and capabilities across borders and nationalities have become important in the invention process. Even in the United States which has the largest inventive resources in the world, the share of international co-inventions across borders in all granted patents with at least one US domestic resident inventor increased from 1.8% in the 1980s to 8% in the period of 2001-2010 (see Tsukada and Nagaoka (2015)). The share of patents co-invented with a foreign born and domestic resident inventor(s) increased from 10% in 1990 to more than 20% in 2010s in the patent applications through PCT (see section).

The formation of the inventor teams across borders and nationalities can have significant impact on invention performance by enhancing efficient combination of knowledge and capabilities. As R&D tasks have become more complex and they require combinations of more diverse knowledge input and inventive capability (Jones (2009)). If a research team is to consist of only domestic born and domestic resident inventors, it may become increasingly difficult to form an efficient research team. Engaging foreign born inventors and/or foreign resident inventors is one effective measure to overcome such a constraint. As more countries in the world, including East Asian countries, have significantly strengthened their research capabilities, the probability that a firm can make a significantly more efficient team from the pool of global inventors increases with the size of the pool.

In addition, collaboration with foreign born and/or foreign resident inventor can be especially important in those technology areas where science is an important input to inventions. While scientific publications are publicly and globally available, knowledge embodied in human capital is also critically important in science-based innovations (Zucker et al. (1998) and Jensen and Thursby (2001)). Thus, international co-inventions may become especially important in those sectors where science becomes important as a driver of inventions.

These gains from efficient combination are especially important when matching by quality is important for inventor teams (Kremer (1993)). If the task of each inventor is essential to the success of the invention and if the probability of the success of each task is given by q , the probability of the success of such invention is given by q^N . Thus, the improvement of the capability and knowledge for each task as a consequence of exploiting a large pool of inventors affect the performance in a multiplicative manner.

This paper analyzes how the co-inventions with a foreign born and foreign resident inventor and with a foreign born inventor with domestic residency contribute to the inventive performance. Briefly, we find that combining inventors across borders and across nationalities have become important in major industrialized countries, especially in the sectors where science is important for inventions. Both the invention with a foreign born and foreign resident inventor and that with a foreign born and domestic resident inventor have high science linkage, controlling for the sectors.

We also find that the inventions based on such collaborations have high performances in terms of forward citations (but not in terms of the geographic scope of patent protection), relative to the inventions by the purely domestic team. These effects diminish but remain significant even if we control for firm fixed effects. However, these effects disappear once we control for the first inventor fixed effects, indicating the possibility that the matching between the high performing domestic inventors and the foreign resident and/or foreign born inventors plays an important role.

This paper is structured in the following way. Section 2 briefly reviews the prior literature as well as develops the hypotheses to be tested, and section 3 describes the construction of data set and provides descriptive statistics. Section 4 explains the estimation model and Section 5 provides the results of estimation. Section 6 concludes the paper.

2. Prior literature and hypotheses

2.1. Prior Literature

There is a great deal of literature devoted to research collaborations, focusing on the incidence of co-ownership (for an example, Cassiman and Veugelers (2002), Hagedoorn et al. (2000), Hagedoorn (2002), and Hagedoorn (2003)) and on the effects of research cooperation on the economic performance of a firm (see, for an example, Cockburn and Henderson (1998), Sakakibara (1997), Branstetter and Sakakibara (1998), Lerner and Merces (1998) and see the survey by Siegel (2002)). Adams et al. (2005) analyses scientific teams from U.S. universities to examine the increasing importance of “institutional” collaborations as well as the effects of the rapid decline of the cost of international communications. Most these existing studies are done at the firm level (One exception is Mowery et al. (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.

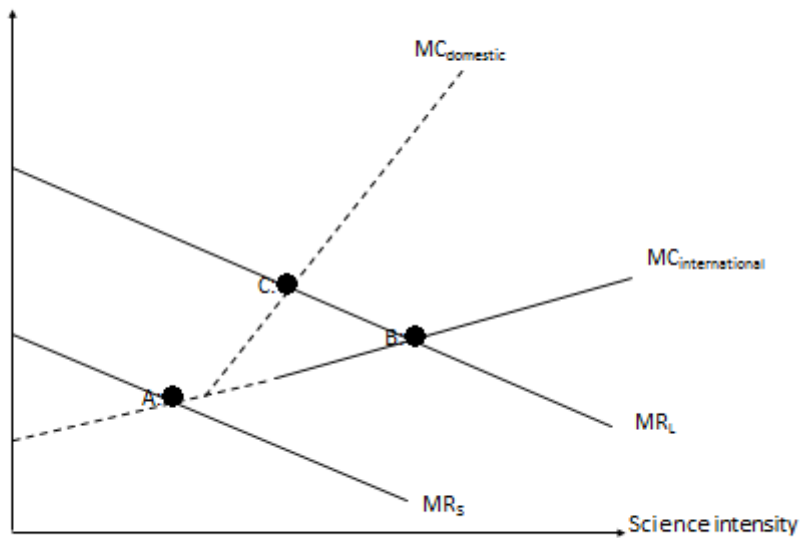
There are recent researches focusing on the university and industry collaboration from the perspective of a matching theory, so that they provide important insights on how research collaboration actually affects the process of knowledge production. Mindruta (2013) shows that firms and scientists complement each other in publishing capabilities but substitute each other in patenting skill, based on the analysis using 447 research contracts involving a US medical school. Banal-Estañol et al. (2013) develops a model, which predicts that a positive assortative matching in terms of both scientific ability and affinity for type of research, but negative assortative in terms of ability on one side and affinity in the other, and finds that the predictions are supported by the empirical analysis based on the 5,855 research proposals submitted to the UK’s Engineering and Physical Sciences Research Council. Both of these studies develop counterfactual pairs from their sample.

There are also increasing number of studies that examine the gains from international research collaborations. Guellec and van Pottelsberghe de la Potterie (2001) analyze the degree of international collaborations using a cross-country sample, and conclude that it is higher for small countries and for countries with lower R&D intensities, suggesting that a firm in a small country needs to look for a collaborative partner in foreign countries. Tsukada and Nagaoka (2015) analyzes what gains drive the expansion of international research collaborations and what costs prevent it, finding that international co-inventions become more prevalent in those technology sectors where scientific literature becomes important as prior art, inventor team size increases and the relative inventor resources of the own country in the world declines. There are important recent researches analyzing the incidence of international collaborations, using the gravity model (Miguélez (2014), Montobbio and Sterzi (2013), Picci (2010) and Tsukada and Nagaoka (2015)). The study by Miguélez (2014) is perhaps the first study which analyzes the nationalities of the inventors, using the PCT applications. Our current study also uses this data source from WIPO, combined with the US patent data.

2.2. Hypotheses

This paper examines how the co-inventions with a foreign resident and/or foreign born inventor contribute to the inventive performance as well as its mechanism. Our first hypothesis is on exploitation of science. There are two choices for the firm: First, whether an international pool of inventors is used for forming an inventor team or the domestic pool of inventors is used. Second, how intensively the scientific knowledge be used. If a firm uses an international team, the marginal cost of using the scientific knowledge declines, given that knowledge embodied in human capital is critically important in science-based innovations (Zucker et al. (1998) and Jensen and Thursby (2001)) and the domestic inventive human resources would become more limiting in expanding the use of scientific knowledge. Moreover, the foreign born and domestic resident inventors are likely to have high-level of educations, given that many of them chose to leave their home countries for pursuing study in the destination countries. Thus, the firm has a lower marginal cost of increasing the science linkage if it adopts an international team, as illustrated in Figure 1. In this figure MC represents the marginal cost of increasing the science intensity of the R&D and MR represents the marginal revenue from increasing the science intensity of the R&D. At the same time, the firm incurs a higher fixed cost of coordinating an international team, due to geographic, language and the other distances.

Figure 1. Choice of science intensity



As illustrated in this Figure, we would expect that the invention with an international team is associated with higher intensity of research (B relative to C), controlling for the marginal revenue schedule of the invention.

Hypothesis 1 on the use of scientific knowledge:

A co-invention with a foreign resident and/or foreign born inventor is likely to be exploit scientific knowledge intensively, controlling for the marginal revenue schedule of the invention.

We can also hypothesize that co-inventions with a foreign resident and/or foreign born inventors are likely to be correlated with higher quality inventions, for the following two major reasons. The first reason is that such inventor team is likely to be the choice of exploiting a larger pool of inventors (international pool rather than domestic (both domestic born and domestic resident) pool, so that they can more effectively realize the gains from the combinations, including more intensive use of science. The second reason is that such inventions (especially co-inventions

with a foreign resident inventor) will face higher cost for collaborations due to geographic, language and the other distances. Thus, such combination is selected only if its higher invention performance compensates more than the higher cost of coordination. For these two reasons, the quality distribution of the invention with a foreign resident and/or foreign born inventor is likely to have longer right-hand tail and to have more truncated from the left-hand side. Thus, we have the following hypothesis:

Hypothesis 2 on the invention quality:

A co-inventions with a foreign resident and/or foreign born inventors is likely to have higher quality, controlling for the marginal revenue schedule of the invention.

3. Construction of data set

3.1. Data

Patent data provided by most national or regional patent office includes the following important information for analysis on collaborative activities of inventions: the addresses of the inventors and the owners (or assignees) of the patents.

If inventors of two or more different national addresses work together (international co-invention), it implies that the human resources of different nations are combined for inventive activities. If firms of two or more different national addresses share the ownership of the patent (international co-ownership), it would typically imply that these firms engaged in R&D co-invention in term of finance, human resources or in other ways. Although co-invention or co-ownership does not cover all possible forms of research co-invention, they cover an important part of the research co-invention involving the combination of significant resources. Research co-invention defined in these terms has become important in recent years (Nagaoka et al. (2010), OECD (2009), Nagaoka and Tsukada (2014), Tsukada and Nagaoka (2015)).

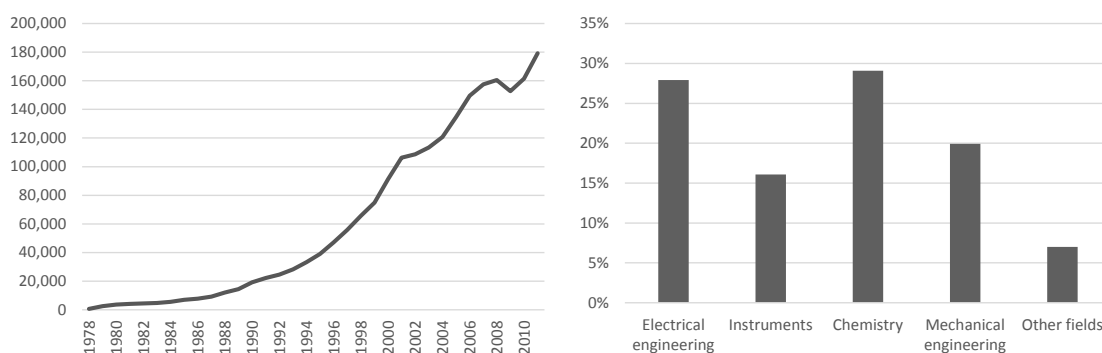
In addition, the bibliographic data of PCT applications provides also nationality of inventors. Using this data, several recent studies examined international mobility of inventors, impact of highly skilled migrants on internationalization of inventive activity in developed and developing countries (Miguélez and Fink (2013), WIPO (2013), Miguélez (2014)).

Only entities with nationality or residence of a PCT contracting nation can file PCT applications. The US patent system required that all inventors should be listed as applicants until 2012, because the right to apply for patent protection on an invention is supposed to be intrinsically held by the inventors. Thus, if a PCT application includes the US as a designated country, all inventors listed as applicants must report their nationality and residence. Most of PCT applications includes the US as a designated country. There was an amendment in procedure of PCT application

in 2004, in which all PCT applications automatically includes all PCT members as designated countries. However, the amendment of US Patent Acts in 2012 removed the requirement that inventors should be listed as applicants. Most of applicant firms did not report nationality and residence country of inventors, since the amendment enacted in 16 September 2012.

Since Patent Cooperate Treaty was enacted at 1978, the number of PCT applications rapidly increased. The number of PCT applications in 2014 exceeded 200 thousands in the world. Until 2014, totally 2.5 million of PCT applications have been made cumulatively. PCT applications are relatively often used in Chemistry area and Electrical engineering area.

Figure 2. Number of PCT applications and share by technology area



PCT applications cover important patent applications for which the firm would like to obtain global patent protection. The shares of applications based on PCT in patent applications to each national/regional patent office are unevenly distributed. After 2000, over 50% of EP applications are based on PCT applications. The share of applications to JPO based on PCT applications was about 12% in 2005. In US, the share of PCT based applications over granted patents was 20% in 2005 (the recent decline as seen in Figure 2 is likely to reflect the truncation due to the use of grant date for the USPTO, since the patents applied through the PCT route is likely to be granted late from the date of application).

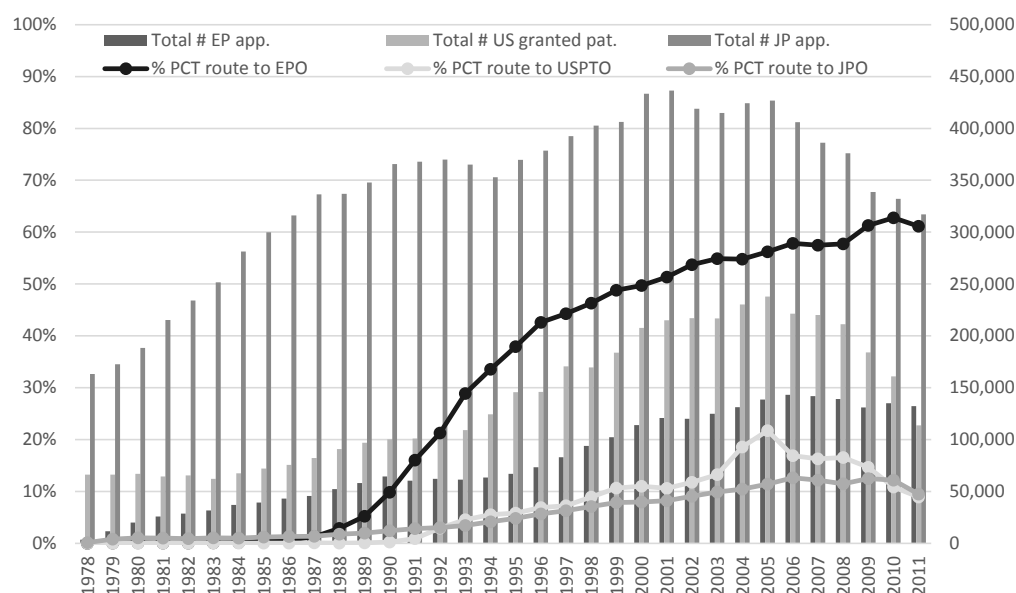
The share of the PCT applications including information of inventors' nationality and residence country in the total PCT applications are relatively high. According to Miguélez and Fink (2013) and WIPO (2013), it was approximately 80% for the 1978-2012. The coverages differ across countries: US² (66%), Germany (95%), United Kingdom (92%), and Japan (94%). We need to bear in mind that it is difficult to distinguish Chinese applicants and Taiwanese applicants, because Taiwan is not

² PCT applications have to list up inventors as applicants when US is a designated country. However, US applicants often file their applications directly to the USPTO at first, and then file as PCT application with the application to the USPTO as the priority application. Thus, their PCT applications do not include US as designated country. It is true with Canada. They often file their applications to the USPTO at first.

a PCT contracting country³. As a result, the residence country code of Taiwanese applicants is CN.

We purchased bibliographic data from WIPO as XML bulk data in 2014. The WIPO data includes bibliographic information of 2.2 million PCT applications filed from 1978 to 2012. We developed a data set using this WIPO data and combined with the Worldwide Patent Statistical Database released by the European Patent Office (PATSTAT, spring 2014 version) for extracting detailed citation information including the citation of non-patent literature (mainly scientific literature) available for US granted patents.

Figure 2. Number of applications (or granted patents) and share of applications based on PCT application by PCT application year



3.2. Descriptive statistics

3.2.1. Structure of co-inventions in residency and nationality

We can classify inventors' residence country structure of a patent by using its bibliographic data into four types: domestic single inventor invention, domestic co-invention (that is, all the inventors are residents of the domestic country), international co-invention (that is, at least one of the inventors is a resident abroad), and the cases with no domestic inventors. We can also classify inventors' nationality structure and applicants' resident structure: a single domestic born, all domestic born, co-invention between domestic and foreign born and all foreign born. In this section, we provide descriptive statistics on the structures of inventors' residence country and nationality from 2003 to 2012 in PCT application year (Table 1). For an example, the US sample consist of the PCT applications including at least one inventor resident in US or one inventor with US nationality.

³ The PCT now has 148 contracting states. http://www.wipo.int/pct/en/pct_contracting_states.html

The percentages of single inventor inventions are at similar level for most developed countries (about 20%~30%). However, there are significant differences across countries in the percentages of domestic co-inventions and international co-inventions in terms of residency as well as the co-inventions share of foreign born inventors. Japan is the country with distinctly small share of both international co-invention (3.4%) and co-invention with foreign born (6.8%). Purely domestic inventions of Japan amount to 90%. The United States is characterized by the large share of co-inventions with foreign born in domestic research (21.4% in the all patents), reflecting that many high-skilled foreign born scientists and inventors are working at firms and research institutes in the US. On the other hand, there are a large number of emigrant inventors who collaborate with the inventors of foreign nationality at foreign countries in Great Britain (23% of the total patents)⁴.

Table 1. Structure of inventors' resident country and nationality (app year: 2003-2012)

United States

		Nationality				Total
		D.B. single	D.B. co-inv	Mixture	No D.B.	
Resident country	Domestic single inventor	22.1%	-	-	3.3%	25.4%
	Domestic co-invention	-	36.7%	21.4%	2.3%	60.4%
	International co-invention	-	0.3%	9.7%	2.1%	12.2%
	No domestic inventor	0.4%	0.0%	1.6%	-	2.0%
Total		22.5%	37.1%	32.7%	7.7%	414,525

Japan

		Nationality				Total
		D.B. single	D.B. co-inv	Mixture	No D.B.	
Resident country	Domestic single inventor	27.1%	-	-	0.6%	27.8%
	Domestic co-invention	-	63.0%	2.0%	0.8%	65.9%
	International co-invention	-	0.3%	2.9%	0.2%	3.4%
	No domestic inventor	0.5%	0.5%	1.9%	-	2.9%
Total		27.6%	63.9%	6.8%	1.7%	231,398

Germany

		Nationality				Total
		D.B. single	D.B. co-inv	Mixture	No D.B.	
Resident country	Domestic single inventor	23.0%	-	-	1.1%	24.1%
	Domestic co-invention	-	43.3%	7.0%	0.3%	50.6%
	International co-invention	-	1.5%	11.9%	0.9%	14.2%
	No domestic inventor	1.6%	0.4%	9.0%	-	11.0%
Total		24.6%	45.1%	28.0%	2.3%	197,460

⁴ Among the other OECD economies, there are a large number of emigrant inventors who collaborate with the inventors of foreign nationality at foreign countries in Canada (35% of the total patents). Switzerland has a large share of patents involving both co-inventions across borders and those across nationalities (24%). Among the developing economies, India is the outstanding country in the importance of emigrant inventors ("brain drains") collaborating with foreign nationality inventors in foreign countries (64.4%) and among themselves or alone (4.9% + 1.8%), in total 71%. See the Appendix 1.

Great Britain

		Nationality				Total
		D.B. single	D.B. co-inv	Mixture	No D.B.	
Resident country	Domestic single inventor	22.5%	-	-	2.3%	24.8%
	Domestic co-invention	-	23.3%	7.0%	0.7%	31.0%
	International co-invention	-	0.8%	14.3%	2.6%	17.8%
	No domestic inventor	3.1%	0.3%	23.0%	-	26.5%
Total		25.6%	24.4%	44.3%	5.6%	87,899

The classification 3 and 6 in Table 2 means inventions made by foreign born inventors living in domestic country (Immigrant inventors). Classification 7 and 8 in Table 2 inventions by domestic born inventors living in foreign countries (Emigrant inventors). Although both captures the important mobility of high-skilled workers, we mainly focus on co-inventions including at least one domestic born inventor living in domestic country (Classification 1, 2, 4, and 5 in Table 2).

Table 2. Classification of co-invention structure

		Nationality			
		D.B. single	D.B. co-inv	Mixture	No D.B.
Resident country	Domestic single inventor	0	-	-	3
	Domestic co-invention	-	1	2	
	International collaboration	-	4	5	6
	No domestic inventor	7		8	-

1: pure domestic co-inventions

2: co-inventions only across nationalities (co-inventions with foreign born in the domestic country)

4: co-inventions only across borders (co-inventions with domestic born in foreign countries)

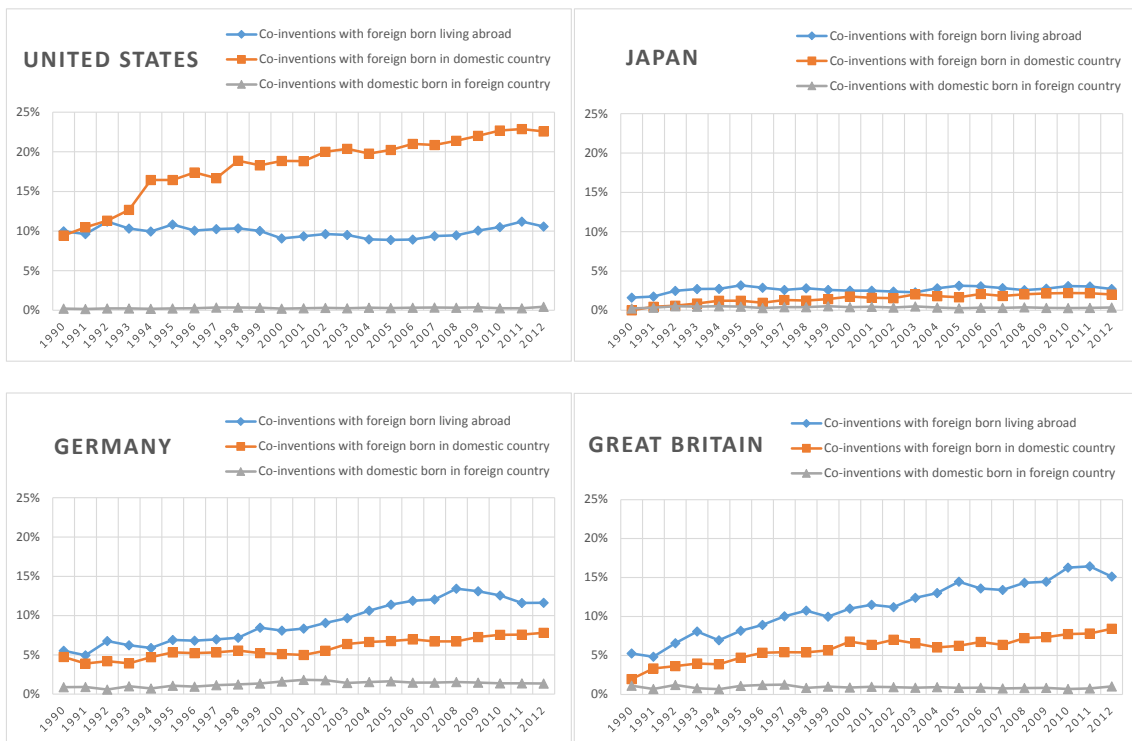
5: co-inventions across both nationalities and borders (co-inventions with foreign born living abroad)

3.2.2. Changes over time

Figure 3 shows the changes of the shares of three types of co-inventions over-time from 1990 to 2012: across both nationalities and borders (co-inventions with foreign born living abroad), only across nationalities (co-invention with foreign born in the domestic country), and only across borders (co-invention with a foreign resident) in the four countries (US, Japan, Germany and Great Britain). In the US, the co-invention across nationalities (resident in the US) has the largest share and it has become more important from around 10 % to more than 20% in recent years. The share of the co-inventions across both nationalities and borders remain at around 10 % of the patents since early 1990s, and the share of the co-inventions involving only cross-border collaborations among domestic born inventors remain very low. Internationalization across border has a large share in Germany and Japan. In Germany the share of the co-invented patents involving both across border

and nationalities increased from around 5% to more than 10% from early 1990s to early 2010s. Great Britain is distinguished in the large share and the speed of the growth of both in the share of the co-inventions across both nationalities and borders as well as that of the co-inventions across nationalities (domestic residents)⁵.

Figure 3. Over-time changes in co-invention types of four countries (excluding pure domestic inventions)



Focusing on three types of co-inventions: co-inventions with foreign born(s) within country, co-invention with collaborations across border, and internationalization outside country, Table 2~ Table 4 provide shares of PCT applications from 2003 to 2012 involving each nationality⁶ or residence country of collaborating inventors.

As for co-inventions with foreign born(s), in the US, there is a significant presence of inventors with Chinese nationality or Taiwanese nationality (in total 29%), inventors with Indian nationality

⁵ About one quarter of inventions involving at least one British inventor is yielded outside the country, since 2003.

⁶ US: United States, JP: Japan, DE: Germany, GB: Great Britain, FR: France, CN: China, TW: Taiwan, KR: Korea, SE: Sweden, CA: Canada, NL: Netherlands, IT: Italy, IN: India, AU: Australia, CH: Switzerland, IL: Israel, RU: Russia, BR: Brazil, SG: Singapore.

(24%), and inventors with Canadian nationality (13%). In Japan, over 60% of foreign born inventors within Japan come from China or Taiwan, and Korea. In Germany and Great Britain, foreign born inventors coming from the other EU countries have large shares.

Table 3. Foreign born partner of co-inventions (app year: 2003-2012)

	Nationality of co-inventor																		All	
	US	JP	DE	GB	FR	CN,TW	KR	SE	CA	NL	IT	IN	AU	CH	IL	RU	BR	SG		Oth
United States	100%	2.8%	6.4%	10.5%	4.1%	29.0%	4.9%	0.9%	13.4%	1.7%	23.8%	2.2%	0.9%	1.7%	3.1%	0.9%	0.6%	26.7%	88,779	
Japan	2.8%	100%	2.4%	1.1%	3.4%	43.3%	19.3%	0.6%	1.3%	0.3%	0.3%	5.7%	0.4%	0.4%	0.0%	1.2%	1.0%	0.5%	22.4%	4,652
Germany	4.9%	2.1%	100%	8.0%	11.2%	4.2%	0.6%	1.0%	0.8%	8.7%	6.6%	2.6%	0.8%	2.5%	0.3%	5.2%	1.0%	0.0%	56.0%	13,893
Great Britain	6.1%	1.7%	11.5%	100%	16.1%	8.5%	0.6%	1.4%	2.6%	5.3%	9.7%	4.8%	4.4%	1.3%	0.5%	2.3%	0.6%	0.8%	46.0%	6,153

As for the co-inventions involving collaborations across borders, in the case of US, inventors with Great Britain, Germany and Canadian nationality/residence have large shares as the partner of the US inventor. As for JP, US is the most important collaborating partner (35%) and the next is Germany (13%). Regarding Germany, inventors in Switzerland (CH) are the important partners after the US.

Table 4. Partner of co-inventions involving collaborations across borders (app year: 2003-2012)

	Residence of co-inventor																		All	
	US	JP	DE	GB	FR	CN,TW	KR	SE	CA	NL	IT	IN	AU	CH	IL	RU	BR	SG		Oth
United States	100%	5.8%	14.2%	14.2%	7.0%	7.8%	2.0%	2.3%	12.3%	4.6%	2.8%	4.6%	2.6%	4.4%	3.1%	1.6%	0.7%	1.3%	22.3%	40,335
Japan	38.3%	100%	12.2%	6.2%	4.3%	6.0%	3.9%	1.3%	2.1%	1.3%	0.8%	0.6%	0.7%	2.4%	0.5%	0.8%	0.2%	1.6%	30.6%	6,599
Germany	27.1%	3.4%	100%	7.1%	13.4%	3.0%	0.7%	3.0%	1.7%	8.4%	3.1%	1.1%	1.2%	17.6%	0.6%	0.9%	0.6%	0.8%	27.4%	23,514
Great Britain	45.4%	3.1%	12.6%	100%	8.1%	2.9%	0.4%	3.3%	4.5%	5.9%	3.0%	1.6%	2.6%	4.4%	1.1%	0.6%	0.3%	0.8%	21.9%	12,603

	Nationality of co-inventor																		All	
	US	JP	DE	GB	FR	CN,TW	KR	SE	CA	NL	IT	IN	AU	CH	IL	RU	BR	SG		Oth
United States	100%	6.4%	17.2%	17.8%	9.4%	14.3%	3.2%	2.6%	14.9%	5.6%	4.2%	10.6%	3.6%	2.9%	3.4%	2.6%	1.0%	0.9%	32.4%	40,335
Japan	34.8%	100%	13.0%	8.5%	6.4%	12.8%	5.6%	1.4%	3.8%	2.3%	1.5%	4.6%	1.0%	1.8%	0.7%	1.3%	0.4%	1.1%	40.0%	6,599
Germany	24.4%	3.8%	100%	11.3%	15.5%	5.5%	1.0%	3.3%	3.1%	10.0%	5.7%	3.4%	1.5%	14.3%	0.8%	2.1%	0.9%	0.4%	38.7%	23,514
Great Britain	42.2%	3.4%	16.2%	100%	12.0%	6.9%	1.0%	3.7%	6.5%	7.1%	5.5%	5.0%	3.6%	2.7%	1.3%	1.3%	0.6%	0.7%	33.1%	12,603

3.2.3. Ownership structure

The following Tables show the ownership structure for four types of the co-inventions. It is important to note that the ownership information is from the US applicant status based on PCT application, so that the employee inventors are counted as owners in the US. As is clear, international co-ownership or foreign ownership is more involved when co-invention with foreign born and/or foreign resident inventor is involved in all of the US, Japan, Germany and Great Britain. For purely domestic inventions, the domestic single (or co-) ownership accounts for 90 % (=87.6%+2.4%) of the patents in Japan, while international coownership and foreign ownership jointly accounts for 9.9% (=2.1 %+7.8%) of the patents. On the other hand, for the inventions involving a foreign born inventor living in Japan, the domestic ownership accounts for 72.3% (=66.1%+6.2%) of the patents, while international coownership and foreign ownership jointly accounts for 27.6% (=14.6%+13%) of the patents. Foreign ownership is especially important for the inventions involving a foreign born

and foreign resident inventor: the domestic ownership accounts for 55% (=54.3 % +0.7%) of the patents, while international coownership and foreign ownership jointly accounts for 45% (=9.1%+35.9%) of the patents. Similar patterns are observed for the US and Great Britain for the co-inventions with foreign born (but not in Germany). Foreign ownership is more dominant in the US, Germany and Great Britain in the inventions with foreign-born inventor with foreign residency (more than 90 % in Great Britain).

Table 5. Ownership structure and co-invention types based on PCT applications⁷

US

	Inventor structure		Ownership residence structure				All
	Residence	Nationality	D.Single	D.collabo	Int.collabo	No US	
Purely domestic	Domestic	D.B.	36.1%	38.0%	9.4%	16.4%	126,517
Co-inv with foreign born	Domestic	Mixture	39.1%	20.1%	27.6%	13.2%	46,178
Co-inv with foreign resident	International	D.B.	16.7%	1.4%	33.8%	48.1%	642
Co-inv with foreign born and foreign resident	International	Mixture	21.4%	3.8%	10.9%	64.0%	18,676

Japan

	Inventor structure		Ownership residence structure				All
	Residence	Nationality	D.Single	D.collabo	Int.collabo	No JP	
Purely domestic	Domestic	D.B.	87.6%	2.4%	2.1%	7.8%	92,461
Co-inv with foreign born	Domestic	Mixture	66.1%	6.2%	14.6%	13.0%	2,021
Co-inv with foreign resident	International	D.B.	8.0%	0.0%	31.8%	60.2%	369
Co-inv with foreign born and foreign resident	International	Mixture	54.3%	0.7%	9.1%	35.9%	2,844

Germany

	Inventor structure		Ownership residence structure				All
	Residence	Nationality	D.Single	D.collabo	Int.collabo	No DE	
Purely domestic	Domestic	D.B.	56.8%	1.5%	3.5%	38.2%	44,243
Co-inv with foreign born	Domestic	Mixture	65.8%	1.2%	4.9%	28.1%	5,676
Co-inv with foreign resident	International	D.B.	19.8%	0.1%	16.6%	63.4%	1,139
Co-inv with foreign born and foreign resident	International	Mixture	11.0%	0.0%	2.4%	86.6%	9,531

Great Britain

	Inventor structure		Ownership residence structure				All
	Residence	Nationality	D.Single	D.collabo	Int.collabo	No GB	
Purely domestic	Domestic	D.B.	47.8%	2.6%	9.6%	40.0%	13,788
Co-inv with foreign born	Domestic	Mixture	34.2%	2.3%	14.0%	49.4%	2,346
Co-inv with foreign resident	International	D.B.	7.0%	0.0%	22.8%	70.2%	257
Co-inv with foreign born and foreign resident	International	Mixture	4.1%	0.2%	0.9%	94.7%	5,405

3.2.4. Technology Sectors

Table 6 shows the share of the co-inventions with foreign born and/or foreign resident inventor by 5 technology fields for 4 countries. We used the IPC-Technology concordance table⁸ (January 2013 version) to convert IPC code to 35 technology classification. It is clear that such co-inventions

⁷ Note. The employee inventors are counted as owners in the US

⁸ http://www.wipo.int/ipstats/en/statistics/technology_concordance.html

are most active in the Chemistry sector (which includes drug and biotechnology), which is the most science intensive in all four countries. Chemistry patents accounted for 26.8 % of the purely domestic patents (i.e. the patent invented by the US born and the US resident inventors) for the US, while it accounted for 40.6 % of the patents with co-inventions with foreign born but resident in the US, 14% points larger than that of the purely domestic patents. The similar level (40.5%) is observed for the patents with co-inventions with foreign born and foreign resident inventor in the US. Similar level of differences are observed for Japan and even larger differences are observed for Germany and Great Britain.

Table 6. Inventor structure and Technology area⁹

US

	Inventor structure		Technology Area					All
	Residence	Nationality	Elec. Eng	Instruments	Chemistry	Mech. Eng	Others	
Purely domestic	Domestic	D.B.	27.1%	22.4%	26.8%	15.8%	7.9%	243,355
Co-inv with foreign born	Domestic	Mixture	34.6%	16.4%	40.6%	6.0%	2.4%	88,679
Co-inv with foreign resident	International	D.B.	25.6%	16.5%	35.6%	13.1%	9.2%	1,304
Co-inv with foreign born and foreign resident	International	Mixture	27.5%	17.0%	40.5%	10.2%	4.8%	40,284

Japan

	Inventor structure		Technology Area					All
	Residence	Nationality	Elec. Eng	Instruments	Chemistry	Mech. Eng	Others	
Purely domestic	Domestic	D.B.	33.6%	15.8%	27.1%	20.3%	3.2%	208,630
Co-inv with foreign born	Domestic	Mixture	36.8%	14.0%	36.8%	11.3%	1.1%	4,652
Co-inv with foreign resident	International	D.B.	29.1%	12.4%	45.7%	10.1%	2.8%	760
Co-inv with foreign born and foreign resident	International	Mixture	33.8%	15.8%	40.3%	8.1%	2.0%	6,595

Germany

	Inventor structure		Technology Area					All
	Residence	Nationality	Elec. Eng	Instruments	Chemistry	Mech. Eng	Others	
Purely domestic	Domestic	D.B.	20.3%	15.5%	22.3%	34.8%	7.1%	130,420
Co-inv with foreign born	Domestic	Mixture	22.8%	10.9%	43.0%	20.6%	2.7%	13,858
Co-inv with foreign resident	International	D.B.	16.9%	15.1%	43.5%	20.8%	3.6%	2,899
Co-inv with foreign born and foreign resident	International	Mixture	20.1%	14.7%	44.2%	17.7%	3.3%	23,476

Great Britain

	Inventor structure		Technology Area					All
	Residence	Nationality	Elec. Eng	Instruments	Chemistry	Mech. Eng	Others	
Purely domestic	Domestic	D.B.	22.3%	19.6%	24.7%	21.2%	12.2%	40,045
Co-inv with foreign born	Domestic	Mixture	26.5%	17.1%	45.6%	7.8%	2.9%	6,135
Co-inv with foreign resident	International	D.B.	17.8%	15.2%	43.5%	12.1%	11.3%	735
Co-inv with foreign born and foreign resident	International	Mixture	25.6%	15.2%	41.8%	11.9%	5.5%	12,585

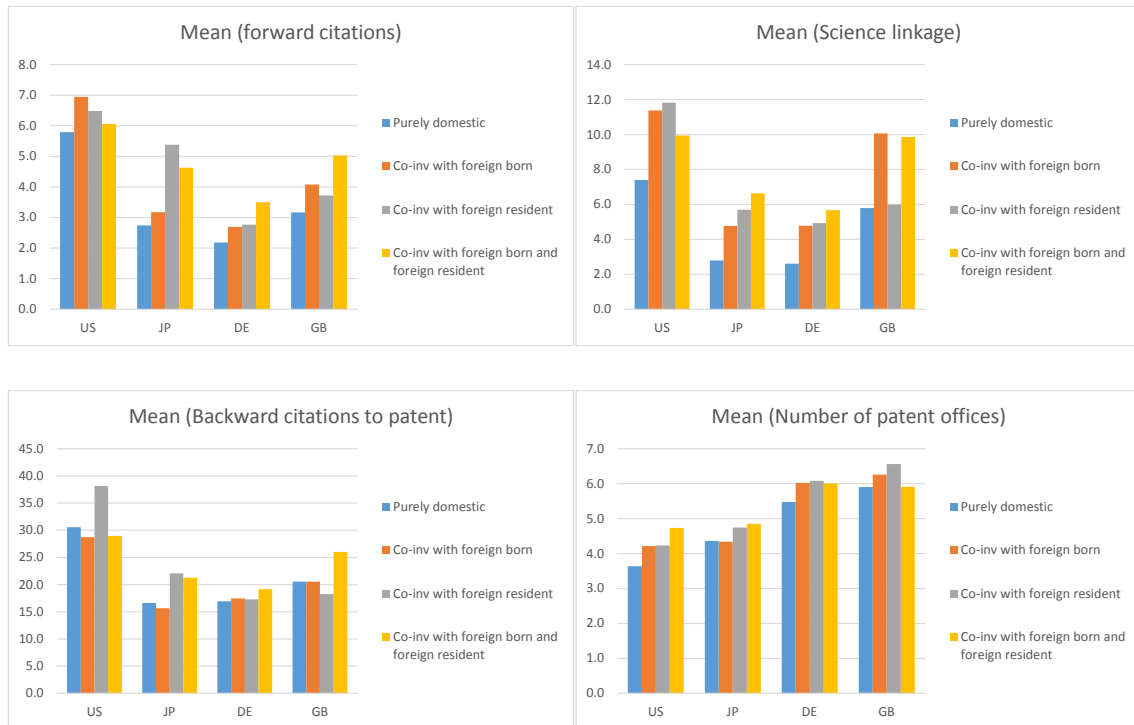
The citation information available for US granted patents provide information for assessing the quality of the patent, and scope of knowledge used for the invention process. The number of forward citations, that is, the frequency by which a particular patent is cited, is an indicator often used as the quality of the patent, once we control for the technology and the length during which the citations can be made. The number of backward citations to the patent and to the non-patent literature indicate the extent of prior knowledge exploitation in the invention process, although bulk of citations (especially backward citations to patent literature) are made by an examiner (not by the inventor). In

⁹ The cell highlighted by “yellow” indicates that the share shown in that cell is at the minimum 2% points higher than the share of the corresponding cell of purely domestic patents.

addition to these citation based indicators, we use number of patent offices which a PCT application is designated to and the procedure is transited to the phase of each national/regional patent office.

Figure 4 show average of these indexes by co-invention types for the four countries. We can observe that patents by three types of co-inventions tends to have higher average indexes in terms of forward citations, science linkage, and number of patent offices, compared to patents by purely domestic inventions in these four countries.

Figure 4. Mean of forward citations, science linkage, backward citations, and number of patent offices



4. Estimation Models and Sample

4.1. Estimation models

We estimate the following model which is specified in equation (1) (j denotes the patent and t denotes the application year). The dependent variables are the science intensity and the performance of the invention. We use science linkage (the number of non-patent literature cited by the focal patent) as a measure of science intensity and forward citations, and the number of patent offices the patent of which were applied for as performance measures.

The main independent variables are the dummies representing the composition of the inventors

(whether the inventor team has a foreign born inventor, a dummy $coinv_fborn$), an inventor resident abroad, a dummy $coinv_fresid$, or a foreign born inventor resident abroad, a dummy $coinv_fborn\&fresid$). These co-invention dummies represent the additional effect associated with hiring a foreign born and/or foreign resident inventor, instead of a domestic born inventor resident in the domestic country. As for controls, we use the team size (the number of co-inventors, num_inv) to control for the R&D project size, the number of backward citations to the patent to control for the prior knowledge exploitation in the research project ($bkcite_US$), and the dummies of application year by technology sector to control for technological and demand opportunities as well as the citation propensity which is different by year and technology area.

In addition, we introduce a term representing the contribution of the applicant firm, that of the lead inventor and the random term, as shown in equation (1). Firm characteristics, such as the availability of complementary assets for the commercialization of R&D would significantly affect the MR schedule in Figure 1. Thus, we expect that firm fixed effects will significantly control for the demand side factor for the invention. We also identify the first inventor, the name of which is roughly disambiguated by combining with information of inventor's resident country code and the applicant name. That is, we treat the same inventor who moved from one firm to another during the sample period as two separate inventors. First inventor plays an important role for the invention. He is often a key inventor in initiating the project (see Table A2-1 of Appendix 2) and in assembling the inventor team. If the first inventor plays a key role in realizing the gain from an international team of inventors, controlling the first inventor fixed effects will significantly diminish the effects of international co-inventions on the use of science and on the quality of the invention.

Thus, we perform three OLS models: (1) RE model, treating the first inventor as a random variable, (2) firm fixed effects model FE(F), introducing firm fixed effects, and (3) first inventor fixed effects model FE(FI).

$$\begin{aligned}
y_{j,t} = & \beta_1 + \beta_2 \ln bkcite_us_{j,t} + \beta_3 \ln num_inv_{j,t} + \beta_4 coinv_fborn_{j,t} \\
& + \beta_5 coinv_fresid_{j,t} + \beta_6 coinv_fborn \& fresid_{j,t} + \beta_7 firm_{j,t} + \beta_8 lead_inv_{j,t} \\
& + (\text{set of year dummies and technology sector dummies}) + \varepsilon_{j,t}.
\end{aligned} \tag{1}$$

4.2. Estimation sample

For this purpose, we use the sample of the patents yielded from either the inventor teams consisting of only domestic born and domestic resident inventors, or the teams with one inventor being a foreign-born and/or foreign resident inventor (the sample for the estimation is shown in Table 7). The base of our estimation is the case where all co-inventors are domestic born and domestic resident. That is, we estimate how patent quality is enhanced, when one inventor with foreign

nationality and/or with foreign residency participates in a research team, substituting for one domestic born and domestic resident inventor. Moreover, we limited our sample to the patents which have two to five inventors in total. Furthermore, our sample is limited to those with only one applicant, to control for the effects of the co-inventions between multiple companies and to those with the first inventors who are domestic born and domestic residents. Our sample patents are those granted first in patent family from 1978 until August 2012 in the PCT application year. In order to test the Hypotheses in the purest form, we focus on the patent with a single domestic applicant, up to one a foreign born and/or foreign resident inventor and up to totally from 2 to 5 inventors.

Table 7. Estimation sample and dummy variables

		Nationality			
		D.B. single	D.B. co-inv	Mixture	No D.B.
Resident country	Domestic single inventor		-	-	
	Domestic co-invention	-	*	<i>coinv_fborn</i>	
	International collaboration	-	<i>coinv_fresid</i>	<i>coinv_fborn&fresid</i>	
	No domestic inventor				-

* : baseline

Estimation method is ordinary least square. We present three estimation results for each dependent variable: random effect model (RE), which treat each first inventor as random, the firm fixed effect model (FE(F)), and the first inventor fixed effect model (FE(FI)).

5. Estimation results and discussions

5.1. Basic estimation results

Table 8 (summary table) and 9 (estimation results) shows the estimation results of US, JP, DE and GB sample. The coefficients of the number of backward citations and number of inventors, which are control variables, are estimated significantly positive in most estimations. The exceptions are the coefficients of the inventor team size for science linkage in the US.

The RE estimates for the US suggests that both the science linkage and the forward citations significantly increase with the co-invention with a foreign born inventor (24.3% and 5.1 %). The result are similar for Germany, although the coefficient is smaller (9.4% and 4.3%). In addition, the science linkage increases significantly with a foreign born and foreign resident inventor by 9.5% in the US. In the case of Japan, both the forward citations and the science linkage significantly increase with the co-invention with a foreign born and foreign resident inventor (16.6% and 14.9% respectively). The science linkage significantly increases with the co-invention with a foreign born inventor living in Japan, but the number of countries for patent applications significantly declines. In

Great Britain, science linkage significantly increases with the above two types of co-inventions, but forward citations do not.

Introduction of firm fixed effects substantially weakens the results, but significantly positive effects of international co-inventions remain. Science linkage increases with the co-invention with both foreign born and foreign resident inventor in the US and Japan, although the coefficient of the co-invention with a foreign born declines to a half, indicating that the foreign born inventors are hired by firms with significant complementary assets. Science linkage increases only with the co-invention with both foreign born in Germany and Great Britain. Thus, Hypothesis 1 and 2 are supported, especially with respect to science linkage.

Table 8. Coefficients of the co-inventions with a foreign-born and/or foreign resident inventor (Random Effect Model vs. Firm Fixed Model)

		US	Japan	Germany	Great Britain
Coinv. with a foreign-born	Forward citations	5.1%*** →4.4%***	-4.2% →-3.3%	4.3%** →4/5%**	3.3% →-4.3%
	Science linkage	24.3%*** →12.7%***	19.6%*** →9.5%***	9.4%*** →6.1%***	22.4%*** →8.1%**
Coinv. with a foreign-born and foreign resident	Forward citations	-2.5% →2.8%	16.6%*** →14.4%**	3.8% →4.6%	6.9% →7.2%
	Science linkage	9.5%*** →8.7%***	14.9%*** →9.8%***	1.5% →1.9%	16.7%*** →5.9%

Note: *** p<0.01, ** p<0.05, * p<0.1

Table 9. Estimation results (US)

United States		Forward citations			Science linkage			Number of patent offices		
Explanation	Variables	ln_forcite			ln_nplcite			ln_num_pto		
		RE (1)	FE(F) (2)	FE(FI) (3)	RE (4)	FE(F) (5)	FE(FI) (6)	RE (7)	FE(F) (8)	FE(FI) (9)
Backward citations to patent	ln_bkcite	0.213*** (0.00556)	0.183*** (0.00686)	0.0962*** (0.0138)	0.462*** (0.00596)	0.471*** (0.00692)	0.455*** (0.0125)	0.156*** (0.00476)	0.134*** (0.00550)	0.128*** (0.0108)
Inventor team size	ln_num_invt	0.135*** (0.0160)	0.105*** (0.0185)	0.187*** (0.0363)	-0.0386** (0.0171)	-0.0281 (0.0187)	-0.0289 (0.0331)	0.165*** (0.0137)	0.105*** (0.0149)	0.0803*** (0.0284)
Coinv with a foreign-born	coinv_fbom	0.0510*** (0.0140)	0.0444*** (0.0158)	0.0206 (0.0323)	0.243*** (0.0150)	0.127*** (0.0159)	0.0369 (0.0294)	0.00163 (0.0120)	0.00935 (0.0126)	-0.00802 (0.0253)
Coinv with a foreign-resident	coinv_fresid	0.166* (0.0897)	0.117 (0.0988)	-0.0524 (0.190)	0.00525 (0.0950)	-0.0851 (0.0997)	-0.0981 (0.173)	0.0627 (0.0763)	0.00502 (0.0793)	-0.0405 (0.148)
Coinv with a foreign-born and foreign resident	coinv_fbom&fresid	-0.0254 (0.0269)	0.0286 (0.0311)	0.107* (0.0616)	0.0945*** (0.0285)	0.0868*** (0.0314)	-0.0711 (0.0561)	0.0147 (0.0229)	0.0233 (0.0250)	0.0184 (0.0482)
	Constant	0.723 (1.424)	1.345 (39.064)	2.380 (2.165)	0.0700 (1.564)	0.933 (3.194)	2.410 (1.971)	1.256 (1.232)	1.216 (31,278)	0.0509 (1.694)
	Ayear*Tech dummy	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Observations		36,698	36,698	36,698	36,698	36,698	36,698	36,698	36,698	36,698
R-squared			0.221	0.198		0.233	0.229		0.086	0.130
Number of lead inventors		29,102		29,102	29,102		29,102	29,102		29,102
Number of firms			10,497			10,497			10,497	

Standard errors in parentheses, *** p<0.01, ** p<0.05, * p<0.1

(JP)

Japan		Forward citations			Science linkage			Number of patent offices		
Explanation	Variables	ln_forcite			ln_nplcite			ln_num_pto		
		RE (1)	FE(F) (2)	FE(FI) (3)	RE (4)	FE(F) (5)	FE(FI) (6)	RE (7)	FE(F) (8)	FE(FI) (9)
Backward citations to patent	ln_bkcite	0.202*** (0.00625)	0.187*** (0.00662)	0.104*** (0.0116)	0.212*** (0.00556)	0.239*** (0.00579)	0.253*** (0.00979)	0.0667*** (0.00303)	0.0622*** (0.00301)	0.0403*** (0.00490)
Inventor team size	ln_num_invt	0.111*** (0.0118)	0.118*** (0.0123)	0.156*** (0.0230)	0.0735*** (0.0105)	0.0579*** (0.0107)	0.0458** (0.0195)	0.0661*** (0.00575)	0.0528*** (0.00557)	0.0515*** (0.00974)
Coinv with a foreign-born	coinv_fborn	-0.0424 (0.0375)	-0.0326 (0.0392)	-0.164** (0.0708)	0.196*** (0.0335)	0.0946*** (0.0343)	0.0220 (0.0599)	-0.0428** (0.0183)	7.62e-05 (0.0178)	0.0282 (0.0300)
Coinv with a foreign-resident	coinv_fresid	0.114 (0.0812)	0.0807 (0.0825)	-0.104 (0.158)	0.0300 (0.0721)	0.0433 (0.0722)	-0.0420 (0.134)	-0.0586 (0.0394)	-0.0731* (0.0375)	-0.186*** (0.0670)
Coinv with a foreign-born and foreign resident	coinv_fborn&fresid	0.166*** (0.0609)	0.144** (0.0658)	0.0392 (0.113)	0.149*** (0.0541)	0.0979* (0.0575)	0.00500 (0.0956)	-0.0408 (0.0295)	-0.0399 (0.0299)	-0.0762 (0.0478)
	Constant	1.228 (0.926)	1.389 (13,248)	2.033 (20,533)	-1.113 (0.832)	-0.994 (11,611)	-0.251 (17,377)	0.256 (0.468)	0.446 (6,054)	0.411 (8,704)
	Ayear*Tech dummy	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Observations		48,636	48,636	48,636	48,636	48,636	48,636	48,636	48,636	48,636
R-squared		0.265		0.211	0.161		0.112	0.062		0.084
Number of lead inventors		33,644		33,644	33,644		33,644	33,644		33,644
Number of firms			3,472			3,472			3,472	

Standard errors in parentheses, *** p<0.01, ** p<0.05, * p<0.1

(DE)

Germany		Forward citations			Science linkage			Number of patent offices		
Explanation	Variables	ln_forcite			ln_nplcite			ln_num_pto		
		RE (1)	FE(F) (2)	FE(FI) (3)	RE (4)	FE(F) (5)	FE(FI) (6)	RE (7)	FE(F) (8)	FE(FI) (9)
Backward citations to patent	ln_bkcite	0.185*** (0.00771)	0.177*** (0.00855)	0.113*** (0.0139)	0.209*** (0.00644)	0.210*** (0.00694)	0.216*** (0.0106)	0.0226*** (0.00368)	0.0248*** (0.00382)	0.0159*** (0.00542)
Inventor team size	ln_num_invt	0.123*** (0.0150)	0.0973*** (0.0160)	0.126*** (0.0279)	0.0507*** (0.0126)	0.0324** (0.0130)	0.0168 (0.0213)	0.0413*** (0.00720)	0.0469*** (0.00713)	0.0267** (0.0109)
Coinv with a foreign-born	coinv_fborn	0.0434** (0.0211)	0.0452** (0.0218)	0.0224 (0.0370)	0.0939*** (0.0176)	0.0607*** (0.0177)	0.0686** (0.0283)	0.0125 (0.0100)	0.0107 (0.00976)	0.0309** (0.0144)
Coinv with a foreign-resident	coinv_fresid	0.0193 (0.0425)	0.0318 (0.0440)	-0.0137 (0.0714)	0.0169 (0.0352)	0.0343 (0.0358)	0.0516 (0.0547)	0.0134 (0.0199)	0.0165 (0.0197)	0.00582 (0.0279)
Coinv with a foreign-born and foreign resident	coinv_fborn&fresid	0.0380 (0.0277)	0.0464 (0.0302)	-0.0316 (0.0502)	0.0145 (0.0231)	0.0186 (0.0245)	-0.0158 (0.0385)	0.0141 (0.0132)	0.0101 (0.0135)	0.00283 (0.0196)
	Constant	0.226 (0.921)	-0.649 (1.242)	-1.401 (1.798)	-0.218 (0.759)	0.301 (1.008)	0.301 (1.378)	2.043*** (0.425)	1.955*** (0.555)	1.467** (0.702)
	Ayear*Tech dummy	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Observations		33,227	33,227	33,227	33,227	33,227	33,227	33,227	33,227	33,227
R-squared			0.230	0.198		0.128	0.115		0.070	0.092
Number of lead inventors		21,783		21,783	21,783		21,783	21,783		21,783
Number of firms			4,372			4,372			4,372	

Standard errors in parentheses, *** p<0.01, ** p<0.05, * p<0.1

(GB)

Great Britain		Forward citations			Science linkage			Number of patent offices		
Explanation	Variables	ln_forcite			ln_nplcite			ln_num_pto		
		RE (1)	FE(F) (2)	FE(FI) (3)	RE (4)	FE(F) (5)	FE(FI) (6)	RE (7)	FE(F) (8)	FE(FI) (9)
Backward citations to patent	ln_bkcite	0.208*** (0.0143)	0.189*** (0.0174)	0.0832** (0.0332)	0.305*** (0.0134)	0.326*** (0.0158)	0.383*** (0.0281)	0.0777*** (0.00766)	0.0628*** (0.00871)	0.0448*** (0.0158)
Inventor team size	ln_num_invt	0.165*** (0.0349)	0.170*** (0.0409)	0.245*** (0.0820)	0.0884*** (0.0328)	0.0959*** (0.0371)	0.0596 (0.0694)	0.105*** (0.0188)	0.0888*** (0.0204)	0.0896** (0.0391)
Coinv with a foreign-born	coinv_fborn	0.0333 (0.0389)	-0.0434 (0.0453)	-0.0364 (0.0931)	0.224*** (0.0366)	0.0810** (0.0411)	-0.0102 (0.0788)	-0.0255 (0.0210)	-0.0257 (0.0226)	0.00718 (0.0444)
Coinv with a foreign-resident	coinv_fresid	0.0122 (0.0971)	-0.147 (0.113)	-0.137 (0.236)	-0.0499 (0.0909)	-0.0954 (0.102)	0.172 (0.199)	-0.0612 (0.0521)	-0.114** (0.0562)	0.0585 (0.112)
Coinv with a foreign-born and foreign resident	coinv_fborn&fresid	0.0693 (0.0511)	0.0724 (0.0625)	0.0670 (0.141)	0.167*** (0.0481)	0.0587 (0.0567)	0.0574 (0.119)	0.00544 (0.0276)	0.000918 (0.0312)	0.0153 (0.0672)
Constant		0.131 (1.573)	-0.481 (2.567)	3.748 (2.493)	0.490 (1.501)	0.905 (2.327)	-1.459 (2.109)	1.852** (0.866)	1.602 (1.282)	2.699** (1.189)
Ayear*Tech dummy		Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Observations		8,632	8,632	8,632	8,632	8,632	8,632	8,632	8,632	8,632
R-squared			0.285	0.351		0.283	0.367		0.175	0.298
Number of lead inventors		6,507		6,507	6,507		6,507	6,507		6,507
Number of firms			2,459			2,459			2,459	

Standard errors in parentheses, *** p<0.01, ** p<0.05, * p<0.1

5.2. Effects of inventor fixed effects

The inventor fixed effects dramatically affect the estimation results, as shown in Table 9. In the case of the US sample, all strongly positive effects of co-inventions disappeared and become insignificant, since the size of the estimated coefficients declined further. That is, the coefficient of the co-invention with a foreign born inventor declined from 5.1 % (RE) to 2.1% (FE(FI)) for forward citations. For science linkage it declined from 24.3 % (RE) to 3.7% (FE(FI)), while the effect of co-invention with a foreign born and foreign resident inventor declined from 9.5 % (RE) to -7.1% (FE(FI)) for science linkage. That is, once we control for the first inventor, the effect of the participation of a foreign-born or foreign resident inventor, relative to that of a domestic-born and domestic resident inventor, becomes insignificant. We find broadly similar results for Japan, Germany and Great Britain, as for the US, as shown in the same Table, suggesting that the results are robust. The co-inventions with a foreign born and/or foreign resident inventor are associated with higher performance of the inventions in random effect models, as mentioned earlier. All of these significant positive associations, however, disappear once we control for the first-inventors, except for positive science linkage effect in the case of co-invention in Germany with a foreign born inventor.

Thus, the contributions of co-invention with a foreign-born and/or foreign resident inventor come predominantly only through their more frequent participations in the projects with high-performance domestic inventors in these four countries, and there are no significant differences from the contributions of pure domestic inventors, controlling for the first inventor. That is, while such a foreign resident and/or foreign born inventor may contribute significantly in capability and knowledge, such contribution is not significantly different from that of the purely domestic inventor matched to the same lead inventor.

Figure A2-2 in Appendix 2 shows that percentages of domestic born & domestic resident first

inventors who experienced four types of co-inventions. Although majority of the first inventors have experiences of participation into research collaborating with domestic born within country (US: 72%, JP: 78%, DE: 71%, and GB: 59%), number of first inventors with experiences of co-inventions across borders and/or across nationalities are very limited. However, the first inventors with experiences of co-inventions across borders and/or across nationalities have high performances with respect to number of PCT applications, number of US granted patents, and inventions exploiting more scientific knowledge, compared to that of co-inventions with domestic born living within same country, in the four countries (Figure A2-3 in Appendix 2).

Figure A2-4 in Appendix 2 shows average size of fixed effects of first inventors, which are calculated from the estimation results shown in Table 9. Especially in the estimations of science linkage in four country, the fixed effects of lead inventors who have experiences of co-inventions with foreign born and/or foreign resident inventors have significantly higher than purely domestic co-inventions.

These descriptive statistics regarding first inventors are consistent with the estimation results and implications as shown in the main sections. That is, contributions of co-invention with a foreign-born and/or foreign resident inventor come predominantly through their more frequent participations in the projects with high-performance first inventors in these four countries, especially with respect to exploitations of scientific knowledge.

6. Conclusions and discussions

This paper analyzed how the co-inventions with a foreign resident and/or foreign born inventor contribute to the inventive performance, using the PCT applications. PCT applications cover important patent applications for which the firm would like to obtain global patent protection. It provides information on both the resident county and the nationality of the inventors, which allows us to assess the contributions of a foreign resident and/or foreign born inventor to the invention performance.

We find that combining inventors across borders and across nationalities have become important in major industrialized countries, especially in the sectors where science is important for inventions. Foreign born inventors contribute significantly to such inventions: they participate in almost one third of the inventions made in the US (all inventors are the US residents), while it is 11% in Germany and is 3.6% in Japan. Co-inventions across borders are also important. More than 10% of the inventions involving a US born inventor have a co-inventor living abroad, while it is 14% in Germany and 3.4% in Japan.

We also find that the inventions based on such collaborations have high performances in terms of science linkage (a measure of exploiting scientific knowledge) as well as forward citations,

relative to the inventions by the purely domestic team, controlling the team size and technology areas. Both science linkage and forward citations significantly increase with the co-invention with foreign born inventor (24.3% and 5.1 %) in the US. In addition, science linkage increases significantly with a foreign born and foreign resident inventor by 9.5% in the US. Similarly significant results are observed for the other three industrialized economies: JP (both in science linkage and forward citations for the co-invention with a foreign resident inventor, as well as in science linkage for the co-invention with a foreign-born inventor), Germany (both in science linkage and forward citations for the co-invention with a foreign-born inventor) and Great Britain (in science linkage for the two types of the co-inventions).

Introduction of firm fixed effects, representing the complementary asset of a firm, do not change the conclusions. However, it significantly reduces the size of the coefficients, implying that the capability of a firm to efficiently use co-inventions with foreign born and/or foreign resident inventor matter significantly in realizing the gain from combining the inventive resources across borders and nationalities.

However, these effects disappear once we control for the first inventor fixed effects, indicating that the matching between the high performing domestic inventors and the foreign resident and/or foreign born inventors is the main channel of the effects of the co-inventions with them. While a foreign resident and/or foreign born inventor may contribute significantly in capability and knowledge, such contribution is not significantly different from that of the purely domestic inventor matched to the same lead inventor. The capability of the lead inventor is essential in realizing the gain from combining the inventive resources across borders and nationalities.

Although there are a number of limitations in the current research, we can discuss several important implications, including for policy. First, while combining inventive knowledge and capabilities across borders and nationalities are likely to contribute significantly to the invention performance, the gain depends strongly on the capability of a firm and the lead inventor with whom the foreign inventor or the foreign born inventor works. If complementarity cannot be realized, there will be no gains, or worse, merely increasing “diversity” can be counter-productive.

Secondly, the capability of the firm is an important component of the capability of the lead inventor. A firm can invest in R&D infrastructure which can best utilize the capability or knowledge of foreign inventor or foreign-born inventor. It can also support the efficient matching scheme between the lead inventor and the candidates, for an example, by allowing such inventors to participate in the recruitment process.

Thirdly, considering very low level of the collaborations in Japan engaging the foreign born and the inventors living abroad, it would be very important for the government to enhance the general capability of the Japanese professionals to collaborate internationally, including their language capability.

Appendix 1.

Table A1. Structure of co-inventions by residence and nationality (the other OECD and India)

France						
		Nationality				Total
		D.B. single	D.B. co-inv	Mixture	No D.B.	
Resident country	Domestic single inventor	21.3%	-	-	1.3%	22.6%
	Domestic co-invention	-	37.6%	4.6%	0.5%	42.8%
	International co-invention	-	1.2%	13.3%	2.1%	16.5%
	No domestic inventor	1.9%	0.3%	15.9%	-	18.1%
Total		23.2%	39.1%	33.8%	3.9%	84,118

Korea						
		Nationality				Total
		D.B. single	D.B. co-inv	Mixture	No D.B.	
Resident country	Domestic single inventor	31.1%	-	-	0.2%	31.4%
	Domestic co-invention	-	51.2%	1.7%	0.1%	53.0%
	International co-invention	-	0.3%	2.9%	0.2%	3.4%
	No domestic inventor	1.2%	0.3%	10.8%	-	12.3%
Total		32.4%	51.8%	15.3%	0.5%	65,663

Sweden						
		Nationality				Total
		D.B. single	D.B. co-inv	Mixture	No D.B.	
Resident country	Domestic single inventor	29.1%	-	-	1.9%	31.0%
	Domestic co-invention	-	33.8%	7.0%	0.4%	41.3%
	International co-invention	-	0.8%	13.8%	2.0%	16.6%
	No domestic inventor	2.4%	0.1%	8.7%	-	11.2%
Total		31.5%	34.7%	29.5%	4.3%	30,985

Canada						
		Nationality				Total
		D.B. single	D.B. co-inv	Mixture	No D.B.	
Resident country	Domestic single inventor	14.6%	-	-	1.3%	16.0%
	Domestic co-invention	-	19.9%	6.2%	0.4%	26.5%
	International co-invention	-	0.9%	14.3%	2.4%	17.6%
	No domestic inventor	4.1%	0.3%	35.4%	-	39.8%
Total		18.8%	21.1%	55.9%	4.2%	48,015

Netherlands						
		Nationality				Total
		D.B. single	D.B. co-inv	Mixture	No D.B.	
Resident country	Domestic single inventor	19.4%	-	-	2.2%	21.6%
	Domestic co-invention	-	27.0%	9.4%	1.4%	37.8%
	International co-invention	-	1.2%	17.6%	2.4%	21.2%
	No domestic inventor	2.6%	0.5%	16.3%	-	19.4%
Total		22.0%	28.7%	43.3%	6.0%	40,497

India						
		Nationality				Total
		D.B. single	D.B. co-inv	Mixture	No D.B.	
Resident country	Domestic single inventor	5.0%	-	-	0.1%	5.1%
	Domestic co-invention	-	15.5%	0.6%	0.0%	16.1%
	International co-invention	-	0.7%	6.6%	0.4%	7.7%
	No domestic inventor	4.9%	1.8%	64.4%	-	71.0%
Total		9.9%	18.0%	71.7%	0.5%	46,661

Australia						
		Nationality				Total
		D.B. single	D.B. co-inv	Mixture	No D.B.	
Resident country	Domestic single inventor	32.7%	-	-	2.6%	35.3%
	Domestic co-invention	-	24.1%	7.3%	0.6%	32.0%
	International co-invention	-	0.7%	9.2%	2.1%	12.0%
	No domestic inventor	3.1%	0.3%	17.3%	-	20.6%
Total		35.7%	25.1%	33.9%	5.3%	24,856

Swiss						
		Nationality				Total
		D.B. single	D.B. co-inv	Mixture	No D.B.	
Resident country	Domestic single inventor	16.5%	-	-	7.7%	24.2%
	Domestic co-invention	-	11.8%	12.8%	4.0%	28.7%
	International co-invention	-	0.3%	24.0%	14.0%	38.3%
	No domestic inventor	1.0%	0.1%	7.7%	-	8.9%
Total		17.5%	12.3%	44.5%	25.7%	28,375

Appendix 2. First inventors

The following table shows the distribution of the responses to the question of who is the source of the idea for the inventions with 2 to 4 inventors, according to the PatVal-Japan Survey. The survey randomly selected the respondent among the co-inventors, so that we have similar number of responses, irrespective of the inventor position. This Table clearly shows that the first inventor is two times more likely to be the inventor with the key idea for the invention than the other inventor.

Table A2-1. Source of the idea and the inventor position

(1) Two inventors					
inventor position	My idea	Team (including myself)	Team (excluding myself)	Other	N
1	45%	49%	2%	3%	442
2	25%	65%	7%	3%	453
(2) Three inventors					
inventor position	My idea	Team (including myself)	Team (excluding myself)	Other	N
1	38%	57%	3%	2%	260
2	15%	75%	7%	3%	223
3	15%	71%	11%	4%	206
(3) Four inventors					
inventor position	My idea	Team (including myself)	Team (excluding myself)	Other	N
1	37%	58%	3%	3%	117
2	17%	71%	9%	4%	113
3	15%	64%	19%	2%	111
4	7%	82%	11%	0%	106

Figure A2-2 shows share of first inventors by their nationality and residence. For example, The US sample consists of PCT applications including at least one inventor resident in US or one inventor with US nationality. Inventors born in the US and residing in the US are listed as the first inventor in 77% of the PCT applications in the US sample. A foreign born resident in the US is listed as the first inventor in 16% of the applications. Foreign born inventors living in a foreign country are the first inventor for 6% of the applications in the US sample. In Japanese sample, majority of applications invented by first inventor of domestic born and domestic residence (93%). Contrastingly, in Great Britain sample, foreign born and foreign resident first inventor makes up larger share (25% in GB).

In the analysis of the main sections, we focused on PCT applications listing domestic born and domestic resident as the first inventor.

Figure A2-2. Residence and nationality of first inventors

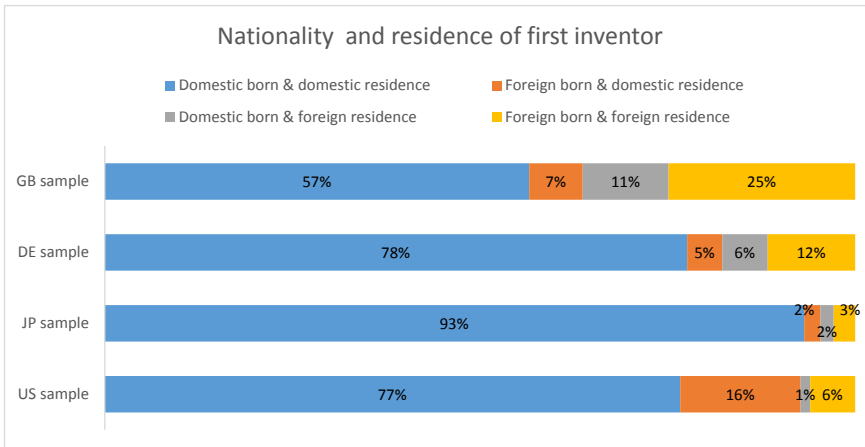


Figure A2-3. First inventor's experiences of co-inventions

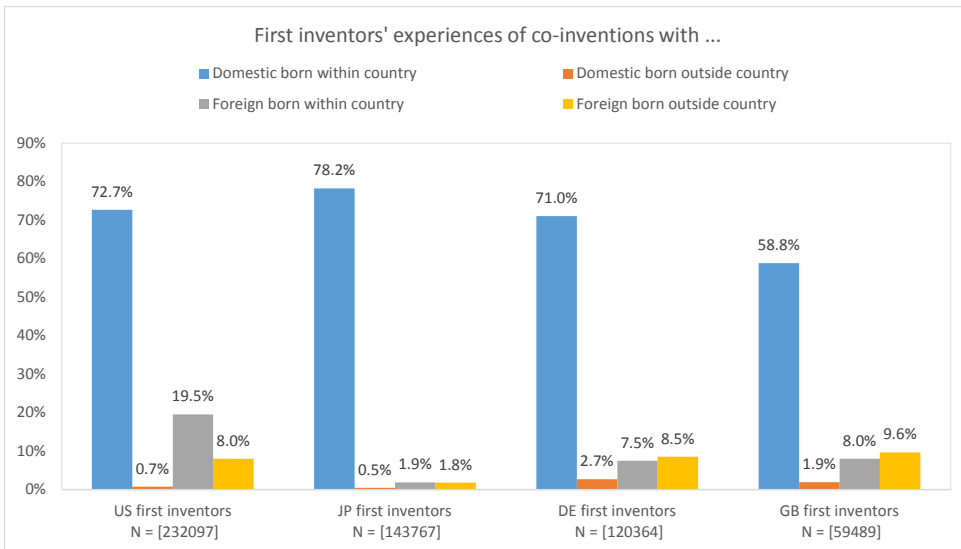


Figure A2-4. Performances of first inventors by experiences of four types of co-inventions

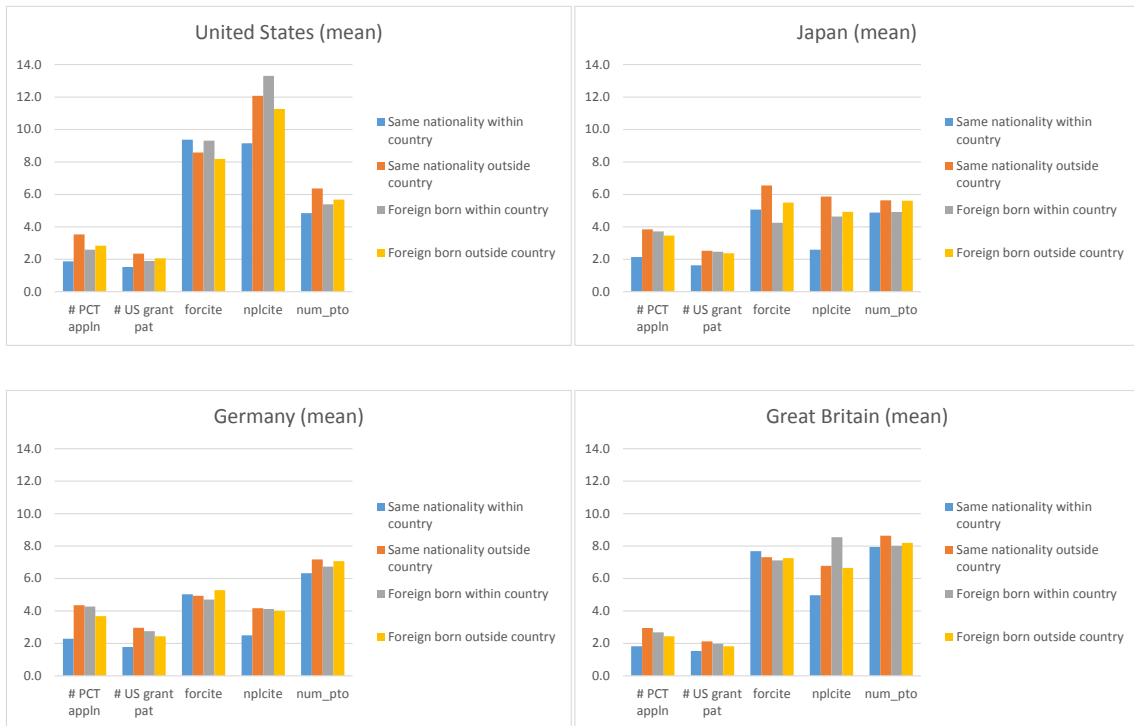
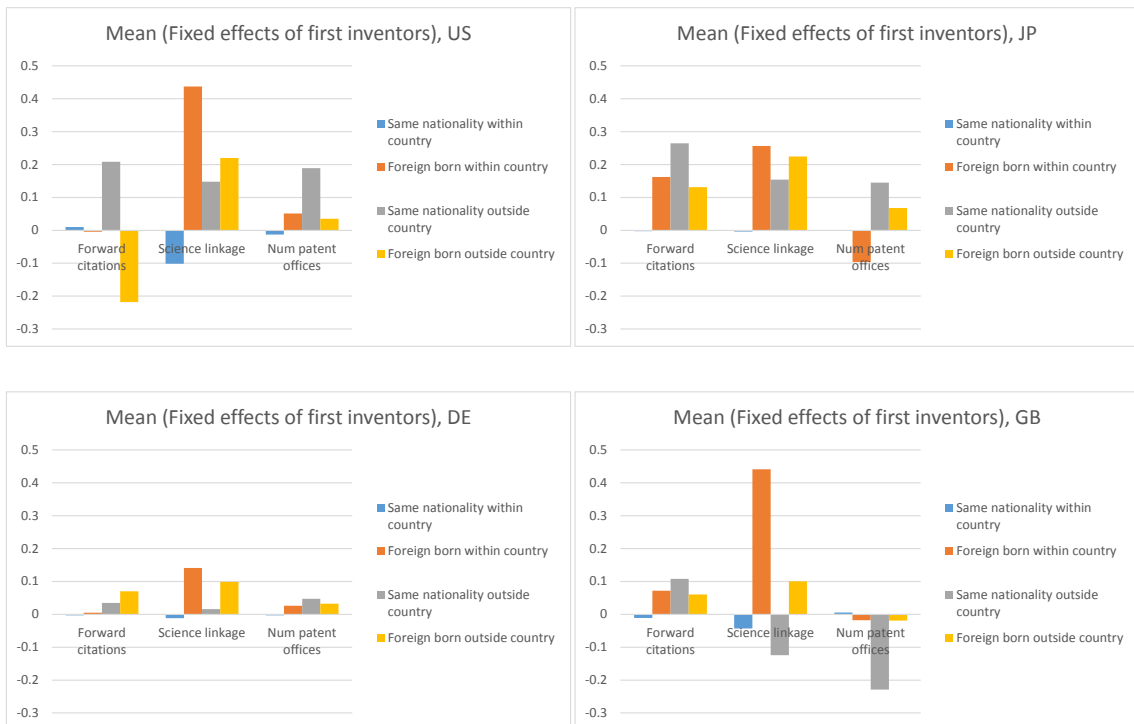


Figure A2-5. Size of fixed effect of first inventors by four types of co-inventions



References

- Adams J. D., Black G. C., Clemmons J. R. & Stephan P. E. (2005).** Scientific teams and institutional co-inventions: Evidence from U.S. universities. 1981–1999, *Research Policy*, 34, 259–285.
- Becker, G.S. (1973)** “A Theory of Marriage: Part I”, *Journal of Political Economy* 81, 813-846.
- Banal-Estañol A, I. Macho-Stadler and D. Pérez-Castrillo. (2013)** “Endogenous Matching in University-Industry Collaboration: Theory and Empirical Evidence from the UK,” *Barcelona GSE Working Paper Series Working Paper*, no.704
- Lee B. & Sakakibara M. (1998).** Japanese research consortia: A microeconomic analysis of industrial policy. *Journal of Industrial Economics*, 46 (2), 207-235.
- Cassiman B. & Veugelers R. (2002).** R&D cooperation and spillovers: Some empirical evidence from Belgium. *American Economic Review*, 92 (4), 1169-1184.
- Cockburn I. & Henderson R. (1998).** Absorptive capacity, coauthoring behavior, and the organization of research in drug industry. *Journal of Industrial Economics*, 46 (2), 157-182.
- European Patent Office (EPO) (2014).** EPO Worldwide Patent Statistical Database, Spring 2014 edition.
- Guellec D. & van Pottelsberghe de la Potterie B. (2001).** The internationalisation of technology analyzed with patent data. *Research Policy*, 30, 1253-1266.
- Hagedoorn J., Link A. N. & Vonortas N. S. (2000).** Research partnerships. *Research Policy*, 29 (4-5), 567-86.
- Hagedoorn J. (2002)** “Inter-firm R&D partnerships: An overview of major trends and patterns since 1960,” *Research Policy*, 31 (4), 477-492.
- Hagedoorn J. (2003)** “Sharing intellectual property rights-an exploratory study of joint patenting amongst companies,” *Industrial and Corporate Change*, 12 (5), 1035-1050.
- Jensen R. & Thursby M. (2001).** Proofs and prototypes for sale: The tale of university Licensing. *American Economic Review*, 91 (1), 240-259.
- Jones F. B. (2009).** The burden of knowledge and the ‘Death of the Renaissance Man’: Is innovation getting harder?. *Review of Economic Studies*, 76, 283-317.
- Kremer M. (1993).** The O-ring theory of economic development. *Quarterly Journal of Economics*, 108 (3), 551-575.
- Lerner J. & Merges R. P. (1998).** The control of technology alliances: An empirical analysis of the biotechnology industry. *Journal of Industrial Economics*, 46 (2), 125-156.
- Miguélez, Ernest and Carsten Fink (2013)** “Measuring the international mobility of inventors: A new database,” *WIPO Economics & Statistics Series*, Working Paper No.8.
- Miguélez, Ernest (2014)** "Inventor diasporas and the internationalization of technology," Centre for

Research and Analysis of Migration, University College London, *Discussion Paper Series CPD 25/14*.

- Mindruta, D. (2013):** "Value Creation in University-Firm Research Collaborations: A Matching Approach", *Strategic Management Journal*
- Montobbio F. & Sterzi V. (2013).** The globalization of technology in emerging markets: A gravity model on the determinants of international patent co-inventions. *World Development*, 44, 281–299
- Mowery D. C., Oxley J. E. & Silverman B. S. (1996).** Strategic alliance and inter firm knowledge transfer. *Strategic Management Journal*, 17, 77-91.
- Nagaoka, Sadao and Naotoshi Tsukada (2014)** "Assessing the effects of international research co-invention on the invention process: some evidence from triadic patent data," Chapter 7, pp.159-179, in Sanghoon Ahn, Bronwyn H. Hall and Keun Lee (eds.) *Intellectual Property for Economic Development*, Edward Elgar Publishing, Inc.
- Picci L. (2010).** The internationalization of inventive activity: A gravity model using patent data. *Research Policy*, 39, 1070–1081.
- Sakakibara M. (1997).** Evaluating government sponsored R&D consortia in Japan: Who benefits and how?, *Research Policy*, 26, pp.447-473.
- Siegel D. (2002).** Strategic Research Partnerships and Economic Performance: Data Considerations, Strategic Research Partnerships: *Proceedings from an NSF Workshop*, NSF 01-336, Accessed March 11, 2011. Available from URL: <http://www.nsf.gov/statistics/nsf01336/p1s2.htm>.
- Tsukada, Naotoshi and Sadao Nagaoka (2015)** "Determinants of International Research Co-invention: Evidence from International Co-inventions in Asia and Major OECD Countries," *Asian Economic Policy Review*, Vol.10, Issue 1, pp.96-119.
- Zucker G. Z., Darby M. R. & Brewer M. B. (1998).** Intellectual human capital and the birth of U.S. biotechnology enterprises. *American Economic Review*, 88(1), pp.209-306.
- WIPO (2013)** *World Intellectual Property Indicator*, Accessed at May 2015. Available from URL: http://www.wipo.int/edocs/pubdocs/en/intproperty/941/wipo_pub_941_2013.pdf