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Measuring Multinationals' R&D Activities in China on the Basis of a Patent Database: Comparing European, Japanese and US Firms

*Kazuyuki Motohashi**

Abstract

Using an internationally linked patent database, this paper compares the types of R&D activities undertaken by multinationals in China by home country and industry. In China, multinationals recently began investing in R&D, mainly in the areas of product and manufacturing process development. However, US firms, which are the most actively invested in R&D, are involved in some technology-driven R&D activities; European firms are inclined toward market-driven R&D, while Japanese firms, which lag behind the other two, focus on production-driven R&D. This pattern may be related to the relative competitiveness of each country: Japanese firms are strong in electronics and automobiles, where production process improvement is important, while US firms flourish in science-based industries, such as pharmaceuticals and software, where interacting with the local science base is a critical factor.

Key words: multinationals' R&D, international comparison, patent database
JEL codes: F23, O32, O57

I. Introduction

Since the opening of its market in the 1990s, multinational firms from Europe, Japan and the USA have invested heavily in China. During the 1990s, China earned the title of "the world's factory" by attracting manufacturing foreign direct investments (FDI). However, China's economy has grown to become the second largest after the USA's and China has become the most attractive market in the world. As China has rapidly gained prominence in

*Kazuyuki Motohashi, Professor, Department of Technology Management for Innovation, University of Tokyo, Japan. Email: motohashi@tmi.t.u-tokyo.ac.jp.

the world economy, multinational firms in developed economies have increasingly assigned R&D functions to their facilities in China. A United Nations Conference on Trade and Development survey identifies China as the country that firms from advanced economies consider most important as a site for R&D activities (UNCTAD, 2005). The world's leading high-technology firms, including IBM, Microsoft, Motorola, Nokia, Sony, Toshiba, Hitachi, Fujitsu, NEC and Samsung, have research facilities in China, where they undertake R&D activities in line with their global R&D strategies (Xue and Wang, 2001; von Zedtwitz, 2004).

Most offshore R&D in China focuses on "development" rather than "research" (von Zedtwitz, 2004). Motohashi (2010) demonstrates that R&D activities are generally production driven, with the intention to improve production processes at factories, or market driven, with the intention to develop products to meet the needs of local markets. Because China has abundant science and technology human resources, it is well-suited to cost-driven R&D as well. Even advanced foreign multinationals can benefit from China's local science base. Some research conducted at China's leading universities, including Peking University and Tsinghua University, is regarded as top notch by international standards. The Zhongguancun district of northern Beijing, where these universities are located, is referred to as the "Silicon Valley of China" and has become a site for technology-driven R&D activities; numerous high-technology firms, including IBM and Microsoft, have established R&D facilities in this area to acquire technology from leading universities (Chen, 2007).

While the popularity of China as an R&D location for multinational firms continues to grow, systematic understanding of the motivation to invest in China has not been achieved. Existing studies are either case studies of limited numbers of firms (e.g. von Zedtwitz, 2004; Chen, 2007) or statistical analyses using aggregated data (e.g. Motohashi, 2010). Using an individual patent dataset, the present paper attempts to fill this gap between the need for detailed analysis of multinational R&D in China and the inadequate existing work. Patent datasets are extensively used for analyzing the internationalization of R&D. However, most of the existing studies concentrate on developed countries; for example, Almeida's (1996) study focuses on the USA, Branstetter's (2000) on Japan and the USA, and Cantwell and Janne's (1999) on Europe. The present paper extends the framework of these studies by measuring both intra-firm knowledge flow (between company headquarters and local sites in China) and knowledge flow through local interactions (between local sites and local players, such as Chinese firms and universities).

The present paper also discusses the cross-country comparisons of the management practices of multinationals. Ghoshal and Bartlett (1990) characterize the management of multinationals using a framework of the balance between global integration and local responsiveness. They show that Japanese firms tend to be more globally integrated, while European firms allow local sites to be more responsive for their local environment; the US firms are neutral. This paper applies this framework to compare the management style of local R&D sites by home country (Europe, Japan or USA) and contributes to the international management literature by providing new insights into the management of overseas R&D activities.

The remainder of this paper is organized as follows. Section II provides a typology of offshore R&D activities and an analytical framework to identify the type of R&D on the basis of a patent database. The basic strategy for identification is to track the direction of knowledge flow between the home country headquarters and local R&D sites in China and to track interactions with the local innovation system. Section III describes the patent database used in this study. Section VI presents an econometric analysis that identifies the R&D type of multinationals by home country and industry. The paper concludes with a summary of findings and a future research agenda.

II. Typology of Offshore R&D and Analytical Framework

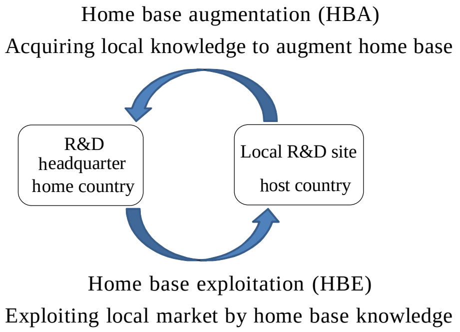
Firms' R&D activities involve a substantial degree of tacit knowledge exchange among researchers. Accessing the home location's innovation system is also important; thus, maintaining embeddedness in the home country creates inertia in the international R&D sites (Narula, 2002). Therefore, the R&D function usually has a lower degree of internationalization than other business activities, such as production and sales (Asakawa, 2003; Alcacer, 2006). The theory regarding the internationalization of firms' activities suggests that this process advances through the following stages (Dunning, 1993):

(1) indirect export (use of trading companies)
(2) direct export (establishment of local sales facilities)
(3) local production
(4) integration of facilities.

The R&D function is assigned to integrated facilities; thus, its internationalization occurs at the last stage and at the deepest level of a firm's globalization.

However, multinational corporations have increasingly internationalized their R&D activities since the 1980s (Gammeltoft, 2006). Although foreign R&D spending is concentrated in OECD countries, it is growing in emerging economies, such as China and India (OECD, 2008). WTO negotiations and international free trade agreements (FTAs) have led to the lowering of trade barriers and acceleration of regional integration, which

Figure 1. Categorizing Types of R&D Internationalization



have spurred multinationals to extend their business into emerging economies. Geographical specialization of production and intense innovation competition are pushing them to internationalize their R&D activities as well (Gammeltoft, 2006).

Offshore R&D activities can be grouped into the following two categories: (i) technology-acquisition activities that seek to apply advanced technologies from overseas to domestic business activities; and (ii) local development activities intended to localize overseas business activities based on domestic technologies. The two categories primarily differ in the direction of the flow of knowledge crucial for R&D: knowledge flows from the host country to the home country in the former case and from the home country to the host country in the latter.

Kuemmerle (1997) defines the former as *home-base augmenting* (HBA) and the latter as *home-base exploiting* (HBE). Cantwell and Mudambi (2005) define the former as *competence-creating R&D* and the latter as *competence-exploiting R&D*. R&D intended to acquire technologies occurs when technologies a firm wishes to acquire are present in the country in which it invests. An example would be the case of a firm establishing a research facility in a region such as Silicon Valley or the greater Boston metropolitan area in the USA seeking to acquire advanced technologies in fields such as information technology (IT) or biotechnology. However, several factors should be considered when firms localize products on the basis of their own technologies for markets in counterpart countries: these include differences in consumer tastes and the size of local markets.

To examine the content of overseas R&D activities in detail, we separate these activities into the two constituent elements of research and development, with *research* referring to activities at an abstract level and having no specific product or service image in mind and *development* referring to activities with specific outputs in mind, such as the development of new products.

Why do firms establish R&D facilities overseas? First, with regard to research, efficiently incorporating overseas technologies can generate advantages. Establishing a facility overseas for such technology-acquisition (HBA) activities enables continual contact with the local science community. Numerous electronics and pharmaceutical firms operate research facilities in Silicon Valley to gather information on the latest research, new business ventures and technological trends among local university researchers. Locating such sensor functions in this region enables joint research with local researchers when needed and allows the firms to apply research ideas at their research facilities in the home country. Because advanced technology fields are characterized by daily new discoveries, the benefits of opening a local facility to rapidly acquire information on such discoveries can be significant. Studies also show that firms operating such technology-acquisition-focused research institutions overseas do effectively incorporate technologies from the overseas science community into their own R&D (Iwasa and Odagiri, 2004).

The benefits of opening facilities overseas are less clear for product development. The focus of a local development (HBE) facility is localization to develop products matched with the consumer needs in the target country on the basis of existing competing products or technologies in the home country. Firms that undertake such activities characteristically have high levels of technology in the home country and gather local information for localization purposes. Because localization is partly a marketing function, the requirements to pursue development activities locally do not exist. For example, Panasonic operates the China Lifestyle Research Center in Shanghai, which studies the ways in which Chinese consumers use home appliances; this information is, in fact, channeled back to business sections in Japan, where the actual products are developed. Once product-development goals have been established, pursuing development activities in a centralized manner in the home country is often more efficient (Narula, 2002).

Opening a development facility in an emerging market such as China can cut development costs. For example, the average wage of a recent university graduate in China is approximately one-tenth of that of a similar employee in Japan. Pursuing product development in countries like China and India, which offer abundant high-quality scientific human resources, can result in significant cost savings. Existing studies on R&D internationalization, mainly focusing on developed countries, often fail to mention this point. The growing importance of emerging economies makes the arbitrage strategy of using low cost labor in a host country more important for global business (Ghemawat, 2007). In addition, certain cases require local operations to address issues such as product safety regulations. Pharmaceutical products require clinical testing in each country to comply with national drug regulations, making a local development facility beneficial. In short, the reasons for establishing overseas facilities related to development activities are heterogeneous.

Various typologies have been proposed for categorizing the activities of overseas R&D facilities, including those of aforementioned Kuemmerle (1997) and Cantwell and Mudambi (2005). While reporting on a survey of R&D internationalization, Gammeltoft (2006) bases the following categorization of such activities on a comprehensive study by management scholars of the nature of activities of overseas R&D facilities:

(1) market driven: gathering information on local consumer requirements and localizing products

(2) production driven: providing technical support for local production facilities

(3) technology driven: acquiring advanced local technologies and monitoring local technological trends

(4) innovation driven: gathering ideas for new products from the local market and strengthening global product-development structures for an entire company

(5) cost driven: utilizing low local science and technology staff cost

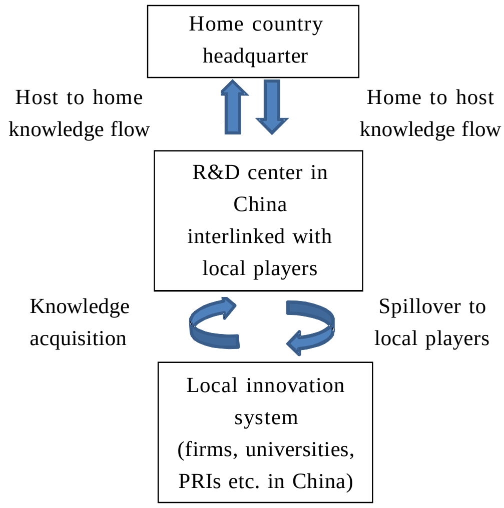
(6) policy driven: responding to various local regulations or participating in R&D incentive programs or local standardization activities.

In the present paper, the R&D activities of multinationals in China are measured on the basis of these categories. To identify a firm's activity type, we focus on the patterns of knowledge flow associated with its offshore R&D activities, as illustrated in Figure 2. First, R&D activities in China can be categorized as either HBA or HBE activities, and these two types can be distinguished on the basis of the direction of knowledge flow between the headquarters in the home country and the R&D sites in China. Gammeltoft's technology-driven category can be largely presumed to be the same as HBA activities, where knowledge flows from host to home. However, other types of R&D in this list, such as market-driven and production-driven types, are categorized as HBE activities, where knowledge is expected to flow in the reverse direction.

Another dimension of knowledge flow, as illustrated in Figure 2, is its linkage with the local innovation system. For some types of R&D, interaction with local innovation players, such as universities, public research institutions and technology-intensive firms in China, is important. For instance, technology-driven R&D often taps into the local innovation system. However, interaction with local players is not particularly important for cost-driven R&D, where a local site is intended to operate as an offshore branch that is heavily controlled by its headquarters in the home country.

Table 1 summarizes the knowledge-flow patterns of the six types of offshore R&D categorized by Gammeltoft (2006). This table illustrates how to identify the type of R&D (such as market-driven or production-driven) by measuring knowledge-flow patterns between headquarters and local R&D sites. Here, knowledge flow primarily refers to technological knowledge of products and/or process innovation; however, it also includes

Figure 2. Centralization and Decentralization of Global R&D Management



knowledge of local markets and regulations. Where a positive knowledge flow can be observed, a "+" appears in the relevant column, while "0" shows no such flow; "+/0" shows that a moderate or small knowledge flow is observed or can be expected.

Market-driven R&D primarily involves development of products for localization, based on existing home products. In this case, knowledge can be expected to flow from headquarters to the local R&D site. Market research should be conducted to identify local customer requirements and tastes. At the same time, adapting a product to a local market requires marketing knowledge at the local R&D site. Therefore, a small amount of knowledge flow from the local innovation system (e.g. from local firms and universities) is also expected.

The production-driven category represents a development function for localization

Table 1. Identifying R&D Types on the Basis of Knowledge-flow Patterns

	Headquarter->Local R&D site	Local R&D site->Headquarter	Local R&D center<->Local Innovation System
Market driven	+	0	+/0
Production driven	+	0	0
Technology driven	0	+	+
Innovation driven	+	+	+
Cost driven	+	+	0
Policy driven	0	0	+/0

from the standpoint of optimizing local production processes. Production-driven local development functions are especially important for automakers. Producing motor vehicles locally requires building a local supply chain of parts makers. Conceivably, automakers could adopt a knockdown assembly method of importing all important parts from the home country. However, in certain cases, this method is not feasible because of local content regulations or because the percentage of parts procured locally may need to be increased to cut manufacturing costs. When using parts from local makers, parts must be inspected to confirm that they meet the automaker's standards. Given the difficulty of finding parts that meet the required quality levels, global automobile manufacturers often need to adjust their production process development to incorporate lower quality parts from local suppliers. For such purposes, the major knowledge flow occurs from home to the host country, and no interaction with local players is expected.

Both technology-driven R&D and innovation-driven R&D augment the home technology base using local R&D centers. Therefore, knowledge can be expected to flow from the host to the home country for these types of R&D. Gammeltoft (2006) differentiates between "pull" and "push" activities for these types: technology-driven R&D, which taps into the local knowledge base to acquire technological content from the local innovation system, is motivated by *pulling* factors on the host country side, such as an advanced local technology base; in contrast, innovation-driven R&D, which gains home-base competitiveness through capitalizing on local knowledge, is motivated by *pushing* factors, such as an overall increase in the technological complexity of products and services and intense global competition in innovation. In a sense, innovation-driven R&D applies more to development activities, while technology-driven R&D focuses on research activities. Therefore, knowledge flow from home to host is important for innovation-driven R&D, while it is not so important for technology-driven R&D. For both types of R&D, interaction with the local innovation system is important because local embeddedness is a critical factor for knowledge augmentation of local R&D sites (Castellani and Zanfei, 2004; Narula and Zanfei, 2005). The concept of innovation-driven R&D is closely related to the concept of reverse innovation, as typified by the case of GE Healthcare's portable ultrasonography in the Chinese market (Immelt *et al.*, 2009).

A goal of cost-driven R&D is to reduce the cost of R&D activities by transferring them to emerging economies. Because R&D is an advanced intellectual production activity, multinational firms have, so far, given little consideration to establishing such activities in less developed countries such as China. However, China has significantly improved its higher education institutions and a large pool of science and technology talent has emerged. In China, by and large, all the above-described types of R&D benefit from the lower cost of science and technology talent. However, the degree of cost-driven R&D can be measured by the degree to which local R&D centers are treated as enclaves of the home country and their activities are insulated from the local environment. Therefore, for this R&D type, both home-to-host and host-to-home knowledge flows are observed, and there is no linkage with the local innovation system.

Finally, policy-driven R&D is conducted when compliance with local rules is required for local products. Numerous standards and regulations require localization activities; these include environmental regulations and safety standards for motor-vehicle exhaust, safety standards for cosmetics and pharmaceuticals, and electrical standards for electronics products. In many cases, shipping products that fail to meet these standards can result in significant costs and damages to both brand image and company reputation. Monitoring developments in various regulations and compliance with relevant standards is important for managing such risks. This activity is quite location specific and totally separate from home country activities. Therefore, some interaction via the local innovation system may be necessary (e.g. with the public research institutions in charge of product inspection); however, knowledge flow back to the firm's headquarters is very difficult.

III. Patent Database for Identifying Multinational R&D Activities in China

Patent data have been extensively used to measure the attributes of R&D activities at overseas subsidiaries in connection with R&D internationalization. Almeida (1996) uses patent data from the US Patent and Trademark Office (USPTO) to demonstrate that the subsidiaries of foreign multinationals in the USA were strongly inclined to cite domestic US patents, indicating that they had primarily been established to incorporate US technologies. Branstetter (2000), again considering subsidiaries in the USA, shows that Japanese subsidiaries in the USA often cite domestic US patents. Focusing on automobile and pharmaceutical firms, Frost and Zhou (2005) investigate reverse knowledge integration by tracking patent citations from foreign subsidiaries to their headquarters. Data from the European Patent Office are used for a similar exercise (Cantwell and Janne, 1999; Criscuolo *et al.*, 2005), which proves that European multinationals internationalize their R&D more extensively than their US and Japanese counterparts.

Using location information of inventors to track R&D locations and patent citation data to identify knowledge flows, the present paper conducts a similar exercise in order to measure multinationals' R&D activities in China. The previous published literature primarily examines R&D internationalization across developed countries, whereas this study applies to a "modern type of R&D internationalization" (von Zedtwitz, 2005); that is, investments from advanced to developing countries. In addition, the present study combines multiple patent datasets to ensure fair comparisons across home countries; that is, European, Japanese and US firms.

Using patent data for innovation research has its own advantages and disadvantages. [1] One major drawback is that not all innovation activities are patented. In addition, patent citations capture only codified knowledge flows. However, we can assume that codified and tacit knowledge moves in the same direction, as suggested by detailed case studies of product development by Japanese consumer electronics manufacturers (Nonaka and Takeuchi, 1995). Jaffe *et al*. (1998) also provide a case study of limited patents and support the validity of citation data as an indicator of knowledge spillover. However, an advantage of patent data is that it allows a detailed look at innovation activities within firms. The R&D types presented in the previous section are not mutually exclusive, and multiple types of activities are conducted at the firm level. In fact, overseas R&D facilities usually perform both HBA and HBE activities (Zander, 1999). In this sense, a patent level analysis is useful for disentangling the complex nature of R&D activities within firms, which cannot be accomplished through empirical analysis of firm-level survey data.

The structure of the patent database used in this study is described in Figure 3. We began with the patent dataset provided by the Chinese patent office, the State Intellectual Patent Office (SIPO), from 1985 to 2009. [2] First, we extracted the patent applications on the basis of the priority applied by the patents to European, Japanese or US patent offices (EPO, JPO or USPTO, respectively). For the international patent family information linking SIPO patents with their priority patents at home, we used the EPO Worldwide Patent Statistical Database (PATSTAT; October 2010 version). [3] The patent information required for statistical analysis in this paper, such as priority dates, inventor locations (China or elsewhere) and applicant industries, was processed on the basis of the SIPO patent database. The applicant name from the original dataset was cleaned and industry classification was added using publicly available information via the Internet (Motohashi, 2008).

Patent citation data was required to track knowledge flow patterns. Because citation data was not available from SIPO, we used patent citation data from each patent office,

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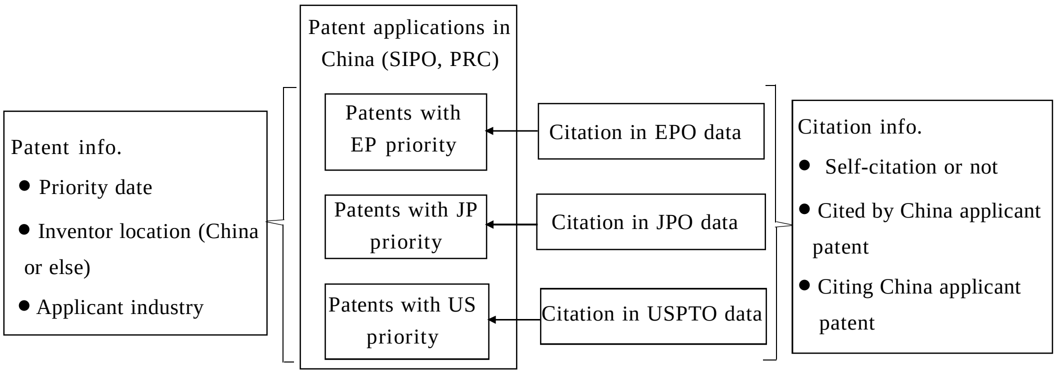
[1]A survey of patent data indicators is provided in Griliches (1990) and updated by Nagaoka *et al*. (2010).
[2]The dataset in this paper covers all invention patent applications up to those published in 2009. Notably, an 18-month delay exists between application and publication; thus, a data truncation is observed in recent application years.
[3]The EPO Worldwide Patent Statistical Database (PATSTAT) covers patent application data to patent offices in over 80 countries, as well as international patenting (patent family) information. The database is updated twice a year and is commercially available from the EPO.

Figure 3. Structure of Patent Database Used in This Study



instead of relying on one, such as the USPTO. This process mitigated home-base biases associated with patent citations. For example, the USPTO data is more likely to cite a patent by a US firm than by a European or Japanese firm, because regional proximity matters with citation patterns (Goto and Motohashi, 2007). Therefore, we used EPO citation data for European firms, JPO citation data for Japanese firms and USPTO citation data for US firms, to avoid the bias caused by regional proximity in citation data. [4]

R&D activities in China were identified by the existence of an inventor located in China. For each such patent, the pattern of knowledge flow in Figure 2 is identified as follows:

- Home-to-host flow: citing own patent(s) (backward own-citation)
- Host-to-home flow: cited by own patent(s) (forward own-citation)
- Linkage with local innovation system: citing and cited by local applicants (within China).

To construct these indicators, we needed information on the location of applicants, inventors, and the applicants of citing and cited patents to identify own-citations. In addition, we assigned industrial classification codes to the applicant firms in this database. The information for EPO and USPTO patents was extracted from PATSTAT, and that for JPO patents was supplemented using the Institute of Intellectual Property (IIP) patent database

[4]Notably, some differences are persistent in patent citation data across countries. For example, USPTO citations are made by the applicants, while EPO and JPO citations are drawn from patent examiner citations. In addition, EPO and JPO data cannot be compared directly because of the differences in the patent examination guidelines. However, approximately 40 percent of the citations in the USPTO data are made by patent examiners instead of applicants (Alcacer and Gittelman, 2006). The citation counts can also be positively correlated by comparing equivalent patents on the basis of the OECD triad patent family database (Goto and Motohashi, 2007).

Table 2. Number of Patents Represented in Database

	With inventors in China	With non-Chinese foreign inventors	All domestic inventors	Total
EP	125	3789	14 846	18 635
JP	93	1338	181 656	182 994
US	981	43 456	93 011	136 467
Total	1199	48 583	289 513	338 096

(Goto and Motohashi, 2007) because inventor and application information in PATSTAT is missing for a substantial number of JPO patents. The patent database for China was constructed from the patent information DVD-ROM from SIPO (Motohashi, 2008).

The patents in our database are presented in Table 2. There are 338 096 SIPO application patents with priority of EPO, JPO or USPTO patents. Only 1119 out of 338 096 (0.33 percent) have inventors located in China. According to the patent data, multinational firms ' R&D activities in China consist of only a very small portion of global R&D. In Japan, the share of Chinese inventor patents is particularly small (only 93 out of 182 994 patents). More than 90 percent of Japanese patents are invented by domestic researchers, which is in steep contrast to the cases of European and US firms.

Figure 4 shows the number of patents with Chinese inventors by year of priority date of the original patent. For US applicants, this number has significantly increased since 2000, suggesting that US multinationals have recently started serious research in China. While the number of Chinese invention patents by European firms has also started to increase even more recently, we do not find an increasing trend for Japanese firms. The share of the total number of Chinese invention patents for European and US firms in China

Figure 4. Number of Chinese Invention Patents by Home Country of Multinational Firm

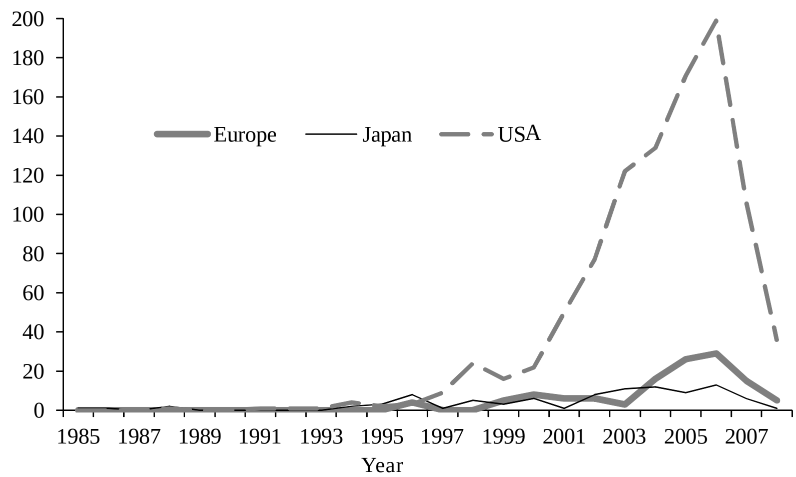
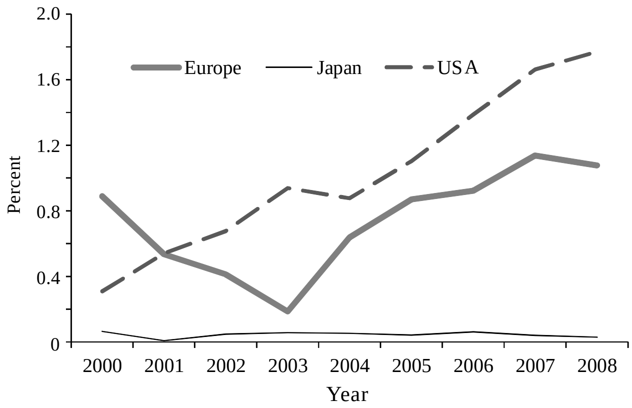


Figure 5. Share of Chinese Invention Patents by Home Country of Multinational Firm



is also increasing; this is not the case for Japanese firms (see Figure 5).

Table 3 shows the share of patents with Chinese inventors by industry, and Table 4 lists firms with large numbers of patents with Chinese inventors. The share of patents with Chinese inventors is higher in general for the machinery sector. In particular, electrical machinery firms such as GE, Intel, Thomson Licensing and Nokia, have made substantial patent applications to China, and the number with Chinese inventor patents is also large. In addition, there is a higher share of patents by US software and information services. This

Table 3. Share of Chinese Invention Patents
by Industry and Home Country of Multinational Firm (1985–2008)

	Europe (%)	Japan (%)	USA (%)
Primary sector	0.0	0.0	0.1
Food, textile and paper	0.3	0.1	0.3
Chemicals	0.4	0.0	0.3
Iron, steel, metal products	0.0	0.0	0.0
General machinery	1.1	0.1	0.6
Electrical machinery	1.0	0.0	0.8
Transport machinery	0.1	0.0	0.5
Precision machinery	1.1	0.0	0.3
Other manufacturing	0.8	0.0	0.2
Software and information services	0.2	0.1	2.5
Other services	0.0	0.0	0.4

Table 4. Firms with Large Numbers of Patents with Chinese Inventors (1985–2008)

	Region	With Chinese inventor	All patents
Microsoft	US	145	2739
General Electric	US	64	3958
Intel	US	54	3608
Thomson Licensing Inc.	Europe	28	1195
Nokia	Europe	28	1539
SAP	Europe	25	124
VIA Technologies Inc.	Japan	15	279
IBM	US	15	7087
Procter and Gamble	US	11	1278
Honeywell International	US	10	810
SMC Inc.	Japan	10	283

can be explained by the activities of Microsoft, which along with GE and Intel, is outdistancing others in terms of the number of patents with Chinese inventors. Microsoft established Microsoft Research Asia in 1998 to conduct global R&D activities that are closely linked with the company's headquarters in Redmond, Washington in the USA (Chen, 2007). A portable ultrasonography machine developed in GE's R&D center in China has become a global product and is an example of "reverse innovation" (Immelt *et al*., 2009). Finally, the Intel China Research Center (ICRC) is also integrated into Intel's global research networks and is conducting research on future wireless technology, systems architecture for future chipsets and advancement of microprocessors. All of these are good examples of multinationals' R&D in China, not only for product development but also for advanced research.

IV. Econometric Analysis

This section provides a regression analysis to identify the R&D type by home country and industry. The indicators representing knowledge flows in Figure 2 are regressed using dummy variables for home country, industry and other control variables, and the results are interpreted using expected signs of coefficients by R&D type, which are described in Table 1.

The dependent variables are own-citation counts, including those wherein the firms cite their own patents and where they are cited by their own patents (backward and forward own-citation counts, respectively). Own citation of patents occurs when new inventions are achieved on the basis of existing technology (patent) inside the company. Therefore, this index reflects knowledge flow within the same firm. When such knowledge flows between inventors at the headquarters in the home country and R&D sites in China, this reflects the knowledge flow between these two places. In addition, citation counts within China, where the patent application either cites or is cited by other applicants in China, such as local firms and universities, are also used as dependent variables. These can be used as proxies for interactions between local R&D sites and innovation systems in China. Notably, citation propensity differs by technology field and by application year. Citation counts tend to be larger in a complex technology patent (such as in the electronics industry) compared with a discrete technology patent (such as in the chemical industry) (Hall *et al*., 2001). In addition, the number of forward citations is affected by data truncation; thus, controlling the application year is also important. Therefore, we normalize all citation indicators, taking the ratio to an average number for each indicator by application year and International Patent Classification section (Nagaoka *et al.*, 2012). We use the Tobit model for regression because the distribution of continuous dependent variables is bounded by zero.

As an explanatory variable, we create dummies (US and EP) and apply values to them for identifying the characteristics of R&D by home country. For example, a US dummy assumes the value of one if this patent is applied by US firms, and zero otherwise. In terms of industry classification, we group all industries into three categories: machinery sectors (general, electronics, transportation and precision machinery); other manufacturing sectors; and nonmanufacturing sectors. The machinery industry can be characterized by complex technology, while the other manufacturing sectors, such as food, chemicals and textiles, tend to have a discrete technology nature. Patents in nonmanufacturing sectors are primarily applied by software and information service companies. We create dummy variables for machinery sectors (MACH) and for nonmanufacturing sectors (NOMA). We take cross terms of home country and industry dummy variables with dummies for the patents with inventors located in China. This cross term is our point of interest, which captures home country and industry characteristics of patents with Chinese inventors after controlling various characteristics of all patents applied to China. We include the size of the patent pool of each applicant (LPAT: log of the number of patents applied for), and we also include the cross term of this variable and a dummy for a patent with inventors located in China as a control variable. Finally, we use samples from after 2000 because there are almost no patents with Chinese inventors before 1999. Therefore, the sample size of regression reduces to 250 589 from 338 096. The descriptive statistics of dependent and independent variables

Table 5. Descriptive Statistics

	Mean	Standard deviation	Minimum	Maximum
(Dependent variables)				
Own citing counts	0.2390	0.0108	0.000	851.250
Own cited counts	0.1111	0.0011	0.000	73.750
China citing counts	0.0011	0.0001	0.000	10.567
China cted counts	0.0045	0.0003	0.000	29.846
(Independent variables)				
Log (# patent counts)	5.7329	0.0051	0.693	9.248
US dummy	0.3763	0.0010	0.000	1.000
EP dummy	0.0619	0.0005	0.000	1.000
Machinery	0.5804	0.0010	0.000	1.000
Non manufacturing	0.1375	0.0007	0.000	1.000

are provided in Table 5, and the regression results are shown in Table 6.

Japanese firms serve as the basis for home country comparisons; thus, all interpretations below are relative to Japan, and we focus on the coefficient of a cross term of the home country dummy with a dummy for Chinese inventor patents. For US firms, negative and statistically significant coefficients can be found in own-citation counts, and positive and statistically significant coefficients can be found in citation counts within China. Therefore, a US firm depends less on its home-base knowledge and is more connected with the local innovation system. According to Table 1, this pattern corresponds to technology-driven R&D. For European firms, statistically significant coefficients are found in citation counts within China. In addition, the coefficients for own-citing counts are not statistically significant, implying that European R&D sites in China rely on home-base knowledge at the same level as Japanese firms but to a greater degree than US firms. Therefore, European firms depend on home-base knowledge and capitalize on the local innovation system, which is close to the market-driven or innovation-driven pattern in Table 1. These characteristics of US and European firms suggest that the R&D of Japanese firms is primarily production driven or cost driven.

The industry dummies for machinery and nonmanufacturing sectors are based on nonmachinery manufacturing sectors. Again, only cross terms with dummies for patents with Chinese inventors are discussed here. A dummy for a machinery sector has negative and statistically significant signs for own-cited and China-cited counts. A smaller interaction with the local innovation system and host-to-home knowledge flow suggests that production-driven R&D is dominant in this industry. Nonmanufacturing sectors (primarily software and information service patents) show less home-to-host knowledge flow but are

Table 6. Regression Results (Tobit Model)

	Own citing counts	Own cited counts	China citing counts	China cited counts
Log (# patent counts)	0.447	0.066	0.004	–0.017
(LPAT)	(12.16)**	(23.36)**	(1.17)	(1.96)+
LPAT*China dummy	0.593	0.020	0.041	0.187
	(1.47)	(0.61)	(2.88)**	(4.98)**
US dummy	4.389	–0.509	0.703	2.897
(US)	(32.93)**	(48.26)**	(26.98)**	(29.01)**
EP dummy	–19.691	–2.222	0.109	1.262
(EP)	(28.81)**	(46.26)**	(2.14)*	(9.23)**
US*China dummy	–6.212	0.109	0.128	0.952
	(2.04)*	(0.43)	(0.82)	(2.54)*
EP*China dummy	6.714	–	0.783	1.094
	(1.15)		(4.16)**	(1.79)+
Machinery	–1.527	–0.178	–0.072	0.149
(MACH)	(7.08)**	(10.49)**	(4.01)**	(3.05)**
Non manufacturing	1.757	0.099	–0.057	–0.295
(NOMA)	(8.08)**	(5.80)**	(2.79)**	(4.83)**
MACH*China dummy	–1.620	–0.881	0.009	–0.728
	(0.50)	(3.14)**	(0.06)	(1.94)+
NOMA*China dummy	–2.625	–0.479	0.194	–0.011
	(0.88)	(1.93)+	(1.30)	(0.03)
Constant	–27.252	–1.598	–2.010	–6.517
	(118.57)**	(99.13)**	(42.63)**	(46.65)**
Log Liklihood	–165 498.41	–150 067.29	–8267.24	–13 765.24
Prob > Chi(10)	0.00	0.00	0.00	0.00
Sigma	17.89	1.59	0.62	1.87
(Standard Error)	0.08	0.01	0.01	0.03
Observations	250 589	250 589	250 589	250 589

Notes: Absolute value of *t* statistics in parentheses. *, ** and *** represent significant at 10, 5 and 1 percent, respectively. –, not estimated due to not enough degree of freedom.

not different from nonmachinery manufacturing sectors in other ways. The machinery sectors' relatively larger home-to-host knowledge flows and linkages with the local innovation systems suggest that the R&D activities of the nonmachinery manufacturing sectors are technology driven.

China has been attracting FDI as a result of its low labor costs and the large domestic market. Multinationals from developed countries have invested significantly in expanding production and marketing facilities. Recently, these multinationals have started increasing

R&D in China; however, production and sales are still major activities at most foreign subsidiaries in China. Therefore, naturally, multinationals' R&D in China focuses on product localization and production support activities. Motohashi (2010) supports this view through a quantitative analysis based on a large-scale firm-level dataset from the National Bureau of Statistics. However, we have found some differences in R&D focus by home country and industry. These two factors might be related; Japanese firms, with strength in electronics and automobiles, are inclined to invest in production-driven R&D, while European and US firms, which are strong in science-based industries, such as pharmaceuticals and software, have greater incentive to have deeper involvement with the local innovation system.

Multinational R&D in China is also beneficial to China's local innovation system. The knowledge flow from local R&D sites to local firms and universities (China's local innovation system) can be captured in China-cited counts. As shown in Table 6, European and US firms with positive and statistically significant coefficients for China-citing counts (technology acquisition from locals) show greater contributions to China's local innovation system (positive and statistically significant coefficients for China-cited counts) as well. Naturally, stronger linkages with the local system induce knowledge flows in both directions, leading to a "win–win" scenario. Therefore, it would be most beneficial for China to attract technology-driven or innovation-driven R&D of multinationals with stronger linkages with the local innovation system as compared with the other types of R&D.

V. Conclusion

This paper uses patent citation information to identify the motivations for multinational firms' R&D in China. Measuring intra-firm knowledge flow between home country headquarters and local R&D sites and measuring interactions between local sites and Chinese innovation systems such as universities and firms allows us to identify the type of overseas R&D for each firm, based on six categories of R&D proposed by Gammeltoft (2006): (1) market driven, (2) production driven, (3) technology driven, (4) innovation driven, (5) cost driven and (6) policy driven. US firms that actively engage in local R&D activities in China tend to conduct technology-driven R&D. European firms are inclined toward market-driven R&D, while Japanese firms focus on production-driven R&D.

Another important finding in this paper is that Japanese firms significantly lag behind European and US firms in terms of R&D in China, even though Japanese firms are heavily invested in China as a place of production. This is possibly due to the different management style of foreign subsidiaries from different countries. According to Ghoshal and Bartlett (1990), who performed a case study of the organizational forms adopted by the foreign subsidiaries of Japanese, North American, and European firms, Japanese firms tended to adopt organizational forms that were more centralized at the head office, while European firms employed the most distributed organizational forms, and US firms adopted intermediate forms of organization. Asakawa (1996) provides a detailed description of the coordination mechanism between headquarters and local R&D sites of Japanese firms. However, too much coordination entails larger transaction costs and slower decision-making, which may explain why R&D activities for Japanese firms are domestically concentrated compared with European and US firms. In an era of rapid technological change and growing emerging economies, there seems to be a shift toward decentralization. This is a key area for future research.

In addition, compared with US and European firms, Japanese firms do not actively interact with the local innovation system. This may be due to the fact that Japanese firms are more conservative about interacting with local players for fear of leaking their trade secrets. An interaction with local players is a two-way process, which may support technological upgrades for the local players and help them to become competitors in the local market. However, effective knowledge acquisition from the local innovation system may be achieved without crossing this line. This trade-off between centralization and decentralization of local R&D center management is another point of interest for future research (Sanna-Randaccio and Veugelers, 2007). Chinese firms are catching up rapidly with other firms in advanced economies. An empirical question to ask now is to what extent firms should consider this potential competitive effect in managing their R&D activities in China.

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