University spillover before the national innovation system reform in Japan: localization, mechanisms, and intermediaries

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Abstract
This study examined whether and how university knowledge affected industry R&D in the period when university-industry collaborations encountered institutional barriers in Japan. Estimation results of the regional knowledge production function using panel data (1983-1997) revealed that university research had localized impacts on valuable innovations, measured by US patents filed by the Japanese firms, with a five-year lag. University-industry joint research did not act as a conduit of university spillover, which suggested that informal channels, such as voluntary transfer of academic inventions in return to donation, worked in the pre-reform period. Intermediaries as a part of regional innovation policy, represented as local public technology centers, increased valuable innovations not through intermediation of university-industry joint research, but through technology diffusion, such as consultation.

Keywords
Innovation, universities, spillover, intermediaries, Japan

JEL Classification
L25, O33, M21

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1. Introduction
In the knowledge-based economy where the most critical input for economic growth is knowledge, (OECD 1996), universities play three key roles in the long-term economic growth. First, through education, they provide society with excellent human resources that are critical inputs for economic growth. Second, they engage in basic research that, while not directly associated with specific industrial use, can be applied and developed in various technological categories, thereby fostering economic growth in the long run. Third, they promote innovation and entrepreneurship, the key determinants of total factor productivity growth and hence long-term economic growth, by acting as an external source of knowledge for incumbents that attempt to innovate and by helping startups that attempt to commercialize university knowledge spawn. The significance of the third role of universities is more salient in science-based sectors where breakthrough innovations build on the advancement of academic research (Pavitt 1984). A number of empirical studies in science-based sectors like drugs show that university research has a positive implication on the improvement in R&D productivity of incumbents and the creation of new firms through academic spin-offs (Deeds and Hill 1996; Powell et al. 1996; Zucker et al. 1998b; Baum et al. 2000; Rothaermel and Deeds 2004). Furthermore, the number or proportion of inventors' backward citations to non-patent literature, typically academic papers, in prior arts (i.e., science linkage) increase not only in science-based sectors but also in the whole economy (Narin et al., 1997), which further highlights the significance of the third role of universities in the knowledge-based economies. These findings suggest that designing efficient university technology transfer should be the key policy issue in the knowledge-based economies.¹

In Japan, national universities have historically been research universities which were expected to play the third role in the national innovation system. However, formal collaborations between national universities and industry were limited because of institutional impediments, such as the regulations that scientists at national universities were civil servants, and thus not allowed to consult for private firms (Collins and Wakoh 2000; Kneller 2007). Furthermore, until the incorporation of national universities in 2004, patented inventions by scientists at national universities based on publicly-funded research were held by the government or by individual academic inventors, neither of whom were motivated to commercialize the outcomes of publicly-funded research. Such institutional obstacles hampered efficient university technology transfer. Instead, informal and long-term relationships between prestigious national universities and large firms, such as the recruitment of competent graduates and voluntary transfer of university inventions, were considered as a key conduit for transferring university knowledge. In response to the prevailing recognition that efficient university technology transfer is a critical factor in the growth of knowledge-based economies, a series of reforms of the national innovation system were implemented in Japan, which was set off by the enactment of Science and Technology Basic Law in 1995. The Technology Licensing Organization (TLO) Act of 1998 legitimized contractual transfers of university inventions to industry. The Act on Special

¹ As well as advantages of the promotion of university technology transfer, previous studies pointed out potential concerns about the extensive involvement of university scientists in the realm of proprietary technology, such as the tragedy of anti-commons (Heller and Eisenberg 1998). Subsequent research revealed working solutions employed in the real world to avoid negative impacts on open science (Walsh et al. 2003; Sampat mimeo).
Measures for Industrial Revitalization of 1999, also known as the Japan Bayh-Dole Act, had the same effect as the U.S. Bayh-Dole Act, except that it did not apply to national universities until they obtained legal status as semi-autonomous administrative entities in 2004. The most important reform in terms of university technology transfer was the National University Corporation Act of 2004 that gave national universities independent legal status, allowing them to apply Article 35 of Japan Patent Law, which enables employers to require assignment to them of employee inventions. The change in national innovation system can be observed in a rapid increase in university-industry research collaborations after the late 1990s as shown in Figure 1.

Japan’s share of high-impact scientific papers (i.e., papers that received forward citations in the top one percent in each field) in natural sciences and engineering was 3.9% in 1983 and 5.0% in 1997 (fourth in the world in both years), which shows that universities completely played the second role to provide high-quality scientific knowledge in the pre-reform period (NISTEP 2013). Even though the argument that the Japanese universities in the pre-reform period had nothing to offer industry has no empirical basis, it has been considered that university technology transfer in the pre-reform period has been ineffective because of the institutional obstacles shown above. Although several studies provided anecdotal evidence on the (informal) mechanisms of university technology transfer in the pre-reform period, little attempt has been made to quantitatively evaluate the third role of national universities in the pre-reform period. This study aims to fill this research gap. Specifically, this study collects information on industrial innovations, private R&D, university research, and university-industry collaborations, and establishes regional panel data in the period when national universities faced institutional obstacles (1983-1997). By doing so, this study evaluates whether university research affected industrial innovations, whether its impact was geographically constrained, whether joint research acted as an effective conduit of knowledge transfer, and whether policy initiatives to promote university-industry collaborations enhanced accessibility of local firms to university knowledge. Foreshadowing the key findings, first, industry R&D had immediate impacts on innovative outputs, which disappeared over time because of obsolescence. Second, in contrast, it took more time for university knowledge to exert an effect because of its basic nature. Third, the range of university spillover was geographically constrained whereas, unlike the US, academic entrepreneurship and labor mobility were unlikely to play a key role. Fourth, joint research did not act as an efficient conduit for university knowledge. Anecdotal evidences suggest that donation and voluntary transfer of academic inventions were the key mechanisms in the pre-reform period. Fifth, the absence of spillover via joint research may suggest the preemption of research outcomes of publicly-funded university research by large firms. Sixth, local public technology centers promoted industrial innovations via other channels than fostering university-industry research collaborations, such as technology diffusion for small local firms.

The remainder of this paper is organized as follows. Section 2 reviews previous studies

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2 Other major changes in innovation policy are as follows. The Industrial Technology Enhancement Act of 2000 established procedures under which university scientists can consult for, establish, and manage companies. The Intellectual Property (IP) Basic Law of 2002 had universities establish university IP Headquarters.
to identify three important perspectives to analyze university spillover, that is, localization, mechanisms, and intermediation of university spillover. Section 3 describes empirical strategies to analyze each issue on university spillover and introduces the regression models, variables, and datasets used in empirical analysis. Section 4 presents estimation results and discusses empirical and policy implications of the key findings. Section 5 refers to contributions of this research to the previous literature and agendas for future research.

Figure 1 here

2. Literature review
This section reviews previous studies from the viewpoints of the localization, mechanisms, and intermediation of university-industry knowledge transfer, including the ones that addressed each issue in the period before the national innovation system reform in Japan.

University scientists compete globally, and their achievements are evaluated through the publication of academic papers and the forward citations received by the paper. They want their research outcomes to be published in international journals as promptly as possible, so that the results can be widely disseminated in the scientific community and frequently cited by the subsequent research. Therefore, as far as "public channel" like publications is concerned, even though university knowledge is to spill over into industry R&D, the geographical range of its impact is not deemed to be localized. In this regard, previous studies employed the knowledge production function, formalized by Griliches (1979), at the different level of regional units in order to examine whether and how university spillover was geographically constrained. Jaffe (1989) is the first to employ the regional knowledge production function, using a state level dataset in the US. He introduced a geographic coincidence index, that is, an uncentered correlation between vectors of industry R&D and university research across standard metropolitan statistical areas (SMSA) to the regression model and found no evidence of localized university spillover. Jaffe's approach was further developed by Anselin et al. (1997) which incorporated a ring variable, that is, concentric circles from a certain region to measure university research conducted within, near, and remote areas. Estimating the regional knowledge production function with ring variables, they showed that university research conducted at remote areas did not increase patents generated by firms in an SMSA, whereas that conducted in vicinity significantly increased patents. Autant-Bernard (2001) also employed ring variables to measure geographically weighted university research and found localized university spillover in France. Ponds et al. (2010) employed an inverse of time distance between NUTS 3 regions to

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3 Varga (1997) identifies several alternative approaches to examine localized university spillover. One is statistical analysis of the probability of the locational coincidences of firms that cite academic patents and universities that originated the knowledge (Jaffe et al. 1993; Almeida and Kogut 1995; Gittelman 2007). The other is questionnaire surveys asking R&D managers the importance of the location of universities in achieving industrial innovations based on academic research (Mansfield 1991; 1995).

4 The NUTS classification (nomenclature of territorial units for statistics) is a hierarchical system that divides up the economic territory of the EU to NUTS 1 (major socio-economic regions), NUTS
generate a continuous spatial weight for university research and found positive impact, suggesting that university research conducted in closer (further) regions had greater (smaller) impacts on industrial innovations.\(^5\)

In the context of Japan in the pre-reform period, Zucker and Darby (2001) identified the geographical location of corporate scientists and university scientists who coauthored a paper in the field of biotechnology and examined how local ties affected valuable innovations. They showed that star scientists at universities had positive impacts on valuable innovations, measured as the number of US patents granted to the Japanese biotechnology firms with which a coauthor was affiliated. However, they found no evidence of localized impacts of star scientists on valuable innovations. This may have stemmed from the characteristics of university-industry collaborations in the pre-reform period when corporate scientists exclusively visited star scientists' laboratories, which implies less spillover in comparison to the opposite case where star scientists visit corporate laboratories, and scientists at national universities, with which most stars were affiliated, were not allowed to engage in entrepreneurial activities and were severely limited in interactions with the private sector through consultation. In light of the methodological advancement in developing spatial weight for university research and findings from previous studies, this study incorporates a variable representing university research weighted by the inverse of geographical distance into the regression model and examines whether university research impacted on industrial innovations in the pre-reform period, and whether the impact was geographically constrained.

If knowledge flows from university research are somehow localized, it is important to examine the mechanisms of university spillover other than public channel (Jaffe et al. 1993). The mechanisms of university spillover can be classified into rent spillover and (pure) knowledge spillover. First, rent spillover results from the use of university physical facilities (Fritsch and Franke 2004; Arvanitis et al. 2008), such as experimental facilities, libraries, and computers. This channel seems to be more significant for high-tech startups or small technology-based firms that are R&D-intensive and retain less managerial resources. A number of science park studies that highlight the advantage of on-park startups in R&D and innovation provide empirical support for this type of localized rent spillover from universities (Felsenstein, 1994; Westhead and Storey, 1994). Rent spillover also stems from formalized business relations via markets for technology and labor, such as licensing university patents (Henderson et al. 1998; Shane 2002 Thursby and Kemp 2002; Thursby and Thursby 2002; Siegel et al. 2003; Markman et al. 2004), faculty consulting as a scientific adviser (Audretsch and Stephan, 1996), academic spin-offs (Franklin et al. 2001; DiGregorio and Shane 2003; Goldfarb and Henrekson 2003; Lockett et al. 2003; Markman et al. 2004), contract research (Link

\(^2\) basic regions for the application of regional policies), and NUTS 3 (small regions for specific diagnoses).

\(^5\) Another important perspective on distance is the cognitive distance. Knowledge transfer would be more efficient when the technological profiles between the provider and user of knowledge are more similar as they are predicted to share greater knowledge base. Using the French data, Autant-Bernard (2001) measured the impact of scientific proximity (i.e., the number of publications of the nearest scientific neighbor of the region) on innovations as well as that of geographical proximity, and found that university research with scientific proximity did not increase patents generated by local firms while the geographical proximity to universities had a positive effect on them. Due to data constraints, this study exclusively addressed the geographical proximity.
and Rees 1990; Fritsch and Franke 2004; Arvanitis et al. 2008), student internships, recruitment of graduates (Ronde and Hussler 2005), and scientists' mobility between universities and industry (Odagiri et al. 1997). Academic spin-offs and labor mobility have been considered as typical drivers of localized knowledge spillover because of the tacit nature of knowledge to be transferred and scientists' being embedded into local communities though professional and personal life (Almeida and Kogut 1997; Almeida and Kogut 1999; Almeida et al. 2003). An extensive literature survey on localized university spillover argues that what had been recognized as pure spillover by many empirical studies on university spillover might have been rent spillover actually (Zucker et al. 1998a; Breschi and Lissoni 2001).

Next, involuntary knowledge spillover refers to public channels like publications and patents and private channels like informal information exchange at conferences and meetings. In many industries, publications are the most important channel of university spillover while licensing of academic patents tends to be the least important (Agrawal and Henderson 2002; Cohen et al. 2002). The geographical range of the impacts of academic publications is not deemed to be localized for the reason I stated earlier. Lastly, well-regulated knowledge spillover comes from university-industry collaborations in research, such as coauthorship (Cockburn and Henderson, 1998) and those in education, such as joint supervision of doctoral thesis (Schartinger et al. 2001; Fritsch and Franke 2004; Arvanitis et al. 2008). As for university-industry research collaborations, a number of previous studies found their positive and localized impacts on industrial innovations. Examining the Swedish pharmaceutical industry, McKelvey et al. (2003) found that university-industry research collaborations and coauthorship networks were more localized relative to interfirm collaborations. Ronde and Hussler (2005) employed R&D partnerships and recruitment of competent graduates as proxy variables of spillover channels and found their positive impacts on patents generated by firms in a department, a geographical unit of governance in France. Using a NUTS 3 level dataset of the Netherlands, Ponds et al. (2010) developed a variable that captures potential amount of university knowledge that was accessible to firms through coauthorship and found its positive impacts on patents generated by firms in a region.

As for the mechanisms of university spillover in the pre-reform period in Japan, donation, in the form of money or equipments, has been associated with informal connections between university scientists and large firms, such as voluntary transfer of undisclosed academic inventions under public funds to donators (Odagiri 1999; Yoshihara and Tamai 1999). Furthermore, donation also represents the long-term personal ties of firms to university scientists at leading research universities for the purpose of hiring competent graduates (Hicks 1993), which definitely improves R&D productivity of the firm. Although no statistical evidence of these mechanisms has been provided because of their informal nature, these are deemed as important channels of university spillover in the pre-reform period. As for more formal channels of university knowledge spillover, Fukugawa (2011) incorporated the same indicator as Ponds et al. (2010) to measure spillover pool that could be exploited through joint research with national universities. Despite institutional constraints on formal interactions between national universities and the private sector in the empirical period (1983-1996), joint research was found to be a significant localized spillover channel in the computer industry, and not in other high-tech industries including drugs. In light of the findings
from biotechnology in the pre-reform period (Zucker and Darby 2001), the results suggest sectoral variations in the significance of joint research as a channel of localized university spillover. This study measures university spillover pool accessible to firms through joint research in the same way as Fukugawa (2011), and controls for the sectoral variations in the impacts of university-industry joint research on industrial innovations by incorporating location quotients (i.e., industrial specialization index) in each prefecture, which will be described in Section 3.

One of the reasons for localized flows of university knowledge lies in the characteristics of knowledge to be transferred from universities to firms. Technological knowledge developed at universities tends to be in the embryonic stage (Jensen and Thursby 2001). Therefore, firms attempting to industrialize university inventions need to interact closely with the academic inventor in order to identify practical applications of the invention, which suggests that the geographical proximity to universities matters more for industrial innovations in the later phase of research (Mansfield, 1995). The needs for interactions between university scientists and corporate scientists pertain to uncertainty in knowledge transfer. For instance, in the case of technical consultation, the flow of knowledge tends to be unilateral and the effects of knowledge transfer (i.e., scientists' provision of a solution to technological problems in R&D or production) will become visible immediately. Thus, knowledge transfer via technical consultation would entail less uncertainty. In contrast, joint research requires research partners not only to retain complementary knowledge, but also to match contributions to the research outcomes, which implies that there should be greater extent of mutual learning and communication than technical guidance. Furthermore, research collaborations would entail greater uncertainty when research partners exhibit different codes of behavior, which is salient in the case of university-industry joint research where research partners follow opposite norms characterized as open science and proprietary technology.

Greater uncertainty in knowledge transfer implies the significance of intermediation. Previous studies identified intermediaries as organizations that provide players of national or sectoral innovation systems with relevant information for collaborations, and thus promote innovations through augmented knowledge flows (Stankiewicz 1995; Howells 2006). In many developed countries, various types of intermediaries have been developed as a part of regional innovation policy. Examples include public research institutes, technology transfer organizations (TTOs), and liaison offices and incubators in universities and science parks, where they develop and deploy human resources that act as a gatekeeper bridging different realms (Westhead and Batstone 1999; Collins and Wakoh 2000; Fritsch and Lukas 2001; Santoro and Chakrabarti 2002; Balconi et al.

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6 The significance of geographical proximity may vary not only by the phase of research but also by sector as localized knowledge flow is observed in biotechnology (Zucker et al. 1998b), but not in the semiconductor industry (Almeida and Kogut 1995). Again, this suggests the needs for controlling for the sectoral variations when analyzing localized impacts of university research on industrial innovations.

7 Uncertainty in university-industry knowledge transfer closely relates to the concept and findings on the information gap. Izushi argues that channels of technology transfer from public research institutes to the private sector can be characterized by the degree of information gaps between them (Izushi 2003; 2005). Information gaps are determined by the importance of communication between the provider and the user of knowledge and the time required for the user to evaluate the outcome of knowledge transfer.
As well as acting as a regional hub for knowledge flows, intermediaries are expected to play some roles in technology diffusion and knowledge creation, both of which could directly improve firms’ R&D productivity and promote regional innovations. Ponds et al. (2010) employed a dummy variable representing semi-public technology transfer organizations (TNO) to represent regional innovation policy in the Netherlands and found their positive impacts on patents generated by firms in a region, which suggested the importance of intermediaries as regional innovation policy.

In this context, local public technology centers were established before modern economic growth in Japan which began in the late nineteenth century. They increased in number during the twentieth century and now cover all prefectures and technological categories in the manufacturing sector. Local public technology centers, administrated by the prefectural and municipal governments, play three key roles in regional innovation systems: technology diffusion; knowledge creation; and intermediation. First, they diffuse technologies to small local firms through various routes, such as consultation to solve problems that small local firms encounter in production processes, the quality inspection of materials and products, and the organization of seminars to introduce new technologies. Second, they conduct their own research, patent their inventions (with ownership obtained by the local authorities), and license their patents mainly to small local firms. Third, they act as catalysts for small local firms in seeking external sources of knowledge to develop innovative networks for new product development. In view of the expected contributions of intermediaries to regional innovations, this study incorporates local public technology centers as intermediaries into the regional knowledge production function, which will be described in detail in Section 3.

3. Method
This study examines whether university research affects industrial innovations, whether its impact is geographically constrained, whether joint research acts as an effective conduit of university spillover, and the roles played by intermediaries in regional innovation systems. The log-transformed knowledge production function to deal with these issues can be described as

$$\ln Y_{it} = \alpha + \beta_1 \ln R_{it} + \beta_2 \ln U_{it} + \beta_3 \ln X_{it} + \epsilon_{it}$$

where $Y$ denotes the value of industrial innovations, $R$ denotes industry R&D stock, $U$ denotes university research stock, and $X$ denotes control variables in a prefecture $i$ and

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8 See Howells (2006) for numerous and diverse functions of an innovation intermediary.

9 Ronde and Hussler (2005) incorporated R&D expenditure by local authorities as a proxy variable of regional innovation policy and found a negative impact on patents generated by firms in a department. They interpreted the results as reflecting the regional innovation policy in France to support less innovative regions.

10 For more detailed information on the historical background and functions of local public technology centers, see Fukugawa (2009).

11 Agglomerations make technology transfer by local public technology centers more efficient because they enable policymakers to target and enable additional technology transfer activities to exert scale economies (Storey 1994). This study controls for the regional variations in the degree of industrial specialization by using location quotients.

2004; Woolgar 2007; Cassi et al. 2008; Molina-Morales and Martínez-Fernández 2010).
in an year $t$. The empirical period is from 1983 to 1997 which consists of the period before the national innovation system reform. The regional unit of analysis is a prefecture and there are forty seven prefectures in Japan. $^{12}$ Suffix $q$ denotes the time lag that is required for effects of innovative inputs to become visible. The coefficients of $R$ (i.e., the elasticity of industrial innovations to industrial R&D) can be interpreted as R&D productivity of firms while those of $U$ can be understood as the efficiency of university spillover.

A dependent variable is the commercial value of innovations measured as international patent application. Since international application is costly, only valuable innovations will be patented globally (Lanjouw and Schankerman 1999; Gambardella et al. 2008). $^{13}$ This study captures the value of innovations as the number of US patents filed by the Japanese firms. The idea is that the more valuable innovations are, the more likely firms will find it necessary to patent them in the world largest market which in many industries is the US. Suffixes $i$ and $t$ denote the prefecture in which the applicant is located and the year of application, respectively. The application year is used because not all the patents applied for were granted and patent registration can be greatly delayed for many reasons. Suffix $q$ ranges from one to five. For instance, taking a five-year lag means that university research conducted in 1997 in a prefecture $i$ (i.e., $U_{i1997}$) exerted an effect on innovative outputs, represented as US patents filed in 2002 by the Japanese firms located in the same prefecture (i.e., $Y_{i2002}$). Information of $Y$ was collected from the NBER patent database (Hall et al. 2001) which contained the data from 1976 to 2006.

It is difficult to establish panel data of expenditures on innovative activities by the private sector and universities at the prefectural level. This study operationalized innovative inputs of the regional knowledge production function as follows. Among components of R&D inputs, such as labor, materials, and tangible fixed assets used for innovative activities, personnel expenses for scientists normally account for the largest proportion of R&D expenditure. $^{14}$ In light of this fact, this study captures private R&D as the number of inventors listed in patent documents. $^{15}$ Suffix $t$ denotes the year of application and $i$ denotes the prefecture in which the inventor resides. In the case of joint invention, the inverse of the number of inventors is used as a weight in order to avoid double counting. It is necessary to obtain a depreciation rate of technological knowledge to compute R&D stock. Science and Technology Agency (1985) shows that the depreciation rate by technological category was 7.9% for chemicals, 14.5% for

$^{12}$ An average prefecture is approximately 8000 sq km, which is even smaller than an average state in the US (approximately 196500 sq km) and larger than an average department in metropolitan France (approximately 5700 sq km).

$^{13}$ Empirical studies show that forward citations, scope, claims, oppositions, renewals, and international application have positive impacts on firms' market value (Lerner, 1994, 1995; Hall et al., 2005; van Zeebroeck, 2011).

$^{14}$ According to the Survey of Research and Development by the Ministry of Internal Affairs and Communications, the proportion of labor costs in R&D expenditure is approximately 45%.

$^{15}$ Most of the innovative attempts are doomed to fail, thus are not patented. Furthermore, not all the inventions are patented since patent propensity greatly varies according to sectors and firm size. Regardless of these potential shortcomings, this proxy variable is selected because of the comprehensiveness of the IIP patent database in representing innovative activities by the Japanese firms.
computers, 10% for drugs, 12.9% for electronics, and 7.2% for mechanical arts. As it was not possible to establish dataset by technological category, this study employed the depreciation rate of ten percent. Information of R was collected from the IIP patent database (Goto and Motohashi 2007).\(^\text{16}\)

A proxy variable for university research is the amount of research grant (i.e., grant-in-aid for scientific research from the Japan Society for the Promotion of Science) that university scientists received. Suffix i denotes the prefecture in which the university is located and suffix t denotes the year in which the grant-in-aid (GIA) research was commenced. As GIA research is a multi-year project, observations are limited to the year in which the GIA research was started in order to avoid double counting. GIA for scientific research from the Japan Society for the Promotion of Science is the most important peer-review-based research fund for university scientists. Therefore, U represents the faculty's research quality which is particularly high in research universities (Fritsch and Franke 2004). No depreciation rate was applied to create university research stock as scientific knowledge was assumed to be useful for industry even for a long period after discovery. Information of U was collected from the GIA database by the National Institute of Informatics.

This study employs two types of weighted university research in terms of physical distance between the user and provider of knowledge and joint research networks between firms and national universities. The geographically weighted university spillover pool is incorporated into the regression model described as

\[
\ln Y_{it+q} = \alpha + \beta_1 \ln R_q + \beta_2 \ln US _i + \beta_3 \ln X_{it} + \varepsilon_{it} \tag{2}
\]

where \(US_i = \sum_{j=1}^{47} U_j B_{ij}\) denotes university research conducted in distant regions from the region in which firms are located. \(B_{ij}\) denotes a spatial weight for university spillover pool. This is an inverse of physical distance (km) between prefectural capitals of a prefecture i in which firms are located and a prefecture j in which universities are located. In the case of \(i=j\), a spatial weight is assumed to be one. The idea is that the further (closer) a university is located from a prefecture in which a firm is located, the less (more) likely that university knowledge can have a positive impact on R&D productivity of firms in a prefecture through some channel.

University spillover pool weighted by joint research networks is incorporated into the regression model described as

\[
\ln Y_{it+q} = \alpha + \beta_1 \ln R_q + \beta_2 \ln UN _i + \beta_3 \ln X_{it} + \varepsilon_{it} \tag{3}
\]

where \(UN_i = \sum_{j=1}^{47} U_j D_{ij}\) denotes university spillover pool accessible to firms in a prefecture i through joint research with national universities, \(D_{ij} = C_{ij} / \sum_{i=1}^{47} \sum_{j=1}^{47} C_{ij}\) denotes a weight for university knowledge utilized by firms in a prefecture i through joint research, and \(C\) denotes the number of joint research projects that firms in a

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16 The Institute of Intellectual Property (IIP) is an external body of the Japan Patent Office that conducts research on issues concerning IP.
prefecture $i$ conducted with national universities in a prefecture $j$ (i.e., regional collaboration is the case where $i=j$). The idea is that the more (less) joint research projects have been conducted between firms in a prefecture $i$ and universities in a prefecture $j$, the greater (smaller) weight the university research conducted in a prefecture $j$ will have. This variable represents the potential spillover pool that could improve R&D productivity of firms in a prefecture $i$ through joint research with universities in a prefecture $j$. Suffix $t$ denotes the year in which the joint research project was initiated. If the coefficient of $UN$ is significantly positive, it implies the presence of university spillover, be it localized or not, since a university partner can be located across the nation, through joint research. Information of this variable was collected from NISTEP (2003). Although this information is limited to national universities, this would not yield a crucial difference in the empirical results because most of the research universities that could act as significant sources of industrial innovations are national universities.

An innovation intermediary as a part of regional innovation policy is incorporated into the regression model described as

$$
\ln Y_{it} = \alpha + \beta_1 \ln R_{it} + \beta_2 \ln U_{it} + \beta_3 \ln TECHC_{it} + \beta_4 \ln X_{it} + \varepsilon_{it} \tag{4}
$$

where $TECHC$ denotes the number of local public technology centers in a prefecture. Corresponding to Equations 2 and 3, regression models where $U$ is replaced by $US$ and $UN$ alternatively with other independent variables intact will be estimated individually. Local public technology centers play three key roles in regional innovation systems: technology diffusion; knowledge creation; and intermediation. Technology diffusion and knowledge creation could directly improve firms’ R&D productivity while intermediation could improve accessibility of firms to university knowledge. It is not possible in the pre-reform period to collect information of their activities representing technology diffusion and knowledge creation individually. Thus, the coefficients of $TECHC$ are considered to indicate contributions of technology diffusion and knowledge creation to regional innovations. As for the effects of intermediation, it is predicted that they help local firms collaborate with universities in research, which would eventually lead to larger university research accessible to local firms through joint research. Thus, I estimate another model where a dependent variable is $UN$ and independent variables are the same as previous models.

$$
\ln UN_{it} = \alpha + \beta_1 \ln R_{it} + \beta_2 \ln U_{it} + \beta_3 \ln TECHC_{it} + \beta_4 \ln X_{it} + \varepsilon_{it} \tag{5}
$$

To control for regional economic size, the number of employees in the non-agricultural and government sectors ($EMP$) is introduced to the regression models. Information was collected from the Establishment Census by the Ministry of Internal Affairs and Communications. The location of a dependent variable was identified at the applicant level, and not at the inventor level due to data constraints. Since larger firms with greater managerial resources are more likely to patent their inventions globally, the geographical distribution of a dependent variable tends to be concentrated on Tokyo and Osaka where headquarters of most large firms are located. To control for such tendencies, binary variables representing Tokyo and Osaka ($TOKYO$, $OSAKA$) are included in the regression models. To control for sectoral characteristics of regions, location quotient of the respective industries’ employment relative to the whole
manufacturing employment is introduced to the regression models.\textsuperscript{17} Industrial classification is two-digit level, and location quotients in fifteen manufacturing industries are included in the regression models. Information was collected from the Establishment Census of Japan by the Management and Coordination Agency. Lastly, time dummies are included in the regression models to control for the variations in the number of US patents filed by the Japanese firms over time. Table 1 shows definitions and descriptive statistics of variables.

Table 1 here

4. Results
Table 2 shows the estimation results. Random effect model was selected since the null hypothesis of random individual effect could not be rejected by Hausman test. Independent variables such as university research ($U$), spatially weighted university research ($US$), and university research weighted by joint research networks ($UN$) are included in the model alternatively due to high correlation among these variables.

Table 2 here

Applying different lagged structure in a dependent variable does affect the main findings. The results of the one-year and five-year lag models are shown so that they will exhibit a clear contrast. In the one-year lag models, the coefficients of industrial R&D are significantly positive whereas those of university research are insignificant. The elasticity of industrial innovations to industry R&D is approximately 0.45, which is close to the estimation results of the regional knowledge production function in the US (Anselin et al. 1997), in France (Autant-Barnerd 2001), and in Germany (Fritsch and Franke 2004). In contrast, in the five-year lag models, the coefficients of university research are significantly positive whereas those of industrial R&D are insignificant. The elasticity of industrial innovations to university research is approximately 0.09, which is lower than the cases of France (Autant-Barnerd 2001) and Spain (Buesa et al. 2006), close to the case of the US (Anselin et al. 1997), and higher than the case of Germany (Fritsch and Franke 2004). As this index represents the efficiency of university spillover, it can be said that university knowledge somehow spilled over into industry R&D with effect even in the pre-reform period when there were little public support for formal university-industry collaborations.

The results also imply that industry R&D has an immediate impact on innovative outputs and its impact disappears over time because of the obsolescence of technological knowledge. Specifically, the coefficients of industrial R&D are significantly positive in the three-year lag models and they become insignificant in the four-year lag models. This may show that the rate of obsolescence of technological knowledge which can yield valuable innovations is high. In contrast, the coefficients of university research are insignificant up to the four-year lag models and they become

\textsuperscript{17} Suppose $X$ is the specific manufacturing sector's employment in a prefecture, and $Y$ is the manufacturing employment in the prefecture. If $X'$ and $Y'$ are that manufacturing sector's employment in Japan and manufacturing employment in Japan, respectively, then the location quotient is $(X/Y) / (X'/Y')$. 

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significant in the five-year lag models. The results imply that it takes university knowledge time to have its effect on firms' R&D productivity because universities engage in basic research and it takes more time for firms to identify practical applications of academic inventions and develop them. The results seem consistent with the previous findings in Japan that the impacts of university-industry research collaborations on firms' R&D productivity become visible in three years (Motohashi 2005; Fukugawa 2013).

In the five-year lag models, the coefficients of university research conducted in a specific prefecture (\(U\)) are significantly positive, which implies that regional university research has a positive effect on regional industrial R&D. Furthermore, those of spatially weighted university research (\(US\)) are significantly positive, which implies that the shorter the geographical distance between a firm and a university is, the more likely that knowledge created at the university will have an effect on R&D productivity of the firm. The results are consonant with those of the previous literature that incorporated spatially weighted university research into the regional knowledge production function (Anselin et al. 1997; Autant-Bernard 2001; Acs et al. 2002; Ponds et al. 2010). That the coefficients of \(US\) do not greatly differ from those of \(U\) implies that the impacts of university research outside the region is marginal and those of regional university knowledge dominate. As for mechanisms of localized knowledge spillover, previous studies identified new firm creation and labor mobility as key factors (Almeida and Kogut 1997; Almeida and Kogut 1999; Almeida et al. 2003). Since academic entrepreneurship was not allowed and the labor market for university scientists was inflexible in the pre-reform period, university research in a region is deemed to have affected industrial innovations in the region through other channels, which will be discussed in detail later.

Another important issue on localized spillover is the relationship between geographical proximity and the nature of innovation that the firm pursues through university linkages. The results may reflect that the cognitively distant knowledge that is required for valuable innovations, measured as US patents filed by the Japanese firms, requires close communications for its efficient transfer. The geographical proximity to spillover pools may have facilitated face-to-face communications with university scientists, promoting the efficient transfer of tacit knowledge, which was essential for successful industrial applications of research (von Hippel 1994; Nooteboom 1999; Jensen and Thursby 2001).

In all models, the coefficients of university research weighted by joint research networks (\(UN\)) are insignificant. This implies that joint research did not act as effective conduit for university research in the period before the reform of national innovation system. In light of the finding that university research somehow affected industrial innovations, the results imply that university knowledge spilt over into private R&D through channels other than joint research. As stated in Section 2, previous studies in the pre-reform provide anecdotal evidence that the informal and long-term relationships, represented as donation, voluntary transfer of academic inventions, and recruitment of excellent graduates, could work as a route of transmitting university tacit knowledge, even in the absence of formalized business relations where university scientists consulted for private companies like in the US (Hicks 1993; Odagiri, 1999; Yoshihara
This study contributes to the previous literature by providing statistical evidence regarding this type of informal linkages as important channels of university spillover in the pre-reform period. However, it should be noted that the type of spillover channels available for firms is contingent on their size (Fukugawa 2005). It is normally difficult for small firms with less financial resources to make a donation so that they can maintain the long-term relationships with research universities as their larger counterparts do. Thus, the results may show that institutional obstacles for formal university-industry collaborations in the pre-reform period may have had small firms face greater difficulties in tapping into university knowledge.

The results show that university-industry joint research had been ineffective as a channel of university spillover in the pre-reform period. From a legal perspective, joint research is considered as a means for large firms to preempt outcomes of publicly-funded research (Kneller 2007), which is of high importance when the outcomes of university-industry joint research frequently take a form of joint patents. Unlike the US Patent Law, the Japan Patent Law (Article 73) does not allow a co-owner (university) to transfer or license jointly-owned patents to other firms without the permission of other co-owners (the industry partner). This legal environment offers industry partners a great advantage to preempt the outcomes of university research through joint research. Industry partners may not intend to use a joint invention internally. Rather, they may want to exploit a channel of joint research as a means to block competitors, to use its own patents (defensive patenting), or to expand the patent portfolio in preparation for negotiations with other firms (cross licensing). It should be noted that such strategic patenting to maintain the market power is typically observed in larger firms as smaller firms are unlikely to patent their inventions for the purpose of blocking (Giuri 2005). In order to be a joint owner of outcomes of academic research (and to take advantage of legal settings described above), large firms may attempt to get their R&D staff listed as co-inventors even though their actual contribution to the joint invention is negligible, which suggests the absence of knowledge spillovers rather than the acquisition of complementary knowledge from academic research. This issue is serious all the more because key research universities were ex-imperial universities and public support for scientific research tended to concentrate on these universities. The results that university research weighted by university-industry joint research networks shows no impacts on industrial innovations seem to be consistent with this concern.

As stated in Section 2, local public technology centers play three key roles in regional innovation systems: technology diffusion (e.g., technical guidance and consultation); knowledge creation (e.g., conducting own research); and intermediation (e.g., connecting innovative firms to universities). As for the third role, the results of Equation

18 Preemption refers to the joint research partner receiving exclusive control over not only discoveries made within the scope of the joint research project, but also a wider range of project-related inventions that originally comes from publicly-funded research (Kneller 2007).
19 The proportion of joint patents in university patents is approximately 60% in 2000s (Tohoku University 2010; Suzuki et al. 2013).
20 Previous studies show that small firms tend to tap into university knowledge in seeking an immediate solution to a clearly defined problem in their core technological field (Santoro and Chakrabarti 2002; Perkmann and Walsh 2008). This suggests that they are likely to collaborate with universities in research for spillover, rather than for creating patent fence.
5 in Table 2 show that TECHC does not have a significant impact on UN, which means that local public technology centers did not help local firms expand knowledge networks to universities via joint research. Shapira (1992) argues that one of the important roles of local public technology centers is to organize small firm networks that aim for joint product development which are known as interindustry groups among small firms for information exchange and innovation (igyoshu-koryu-groups). Examining this type of innovative networks by small firms, Fukugawa (2006) shows that local public technology centers improve the probability of the technological success of such joint innovations. In light of these findings, local public technology centers are deemed as intermediaries for interfirm networks, rather than for university-industry networks. However, it should be noted that this study operationalized university research (U) by using a comprehensive dataset of the peer-review-based grant-in-aid for scientific research, which means that U represents not only the amount of university research but also the quality of faculty. Thus, the results do not necessarily imply that local public technology centers did not act as intermediaries, and it is possible for them to have helped small firms collaborate with universities with less research quality corresponding to absorptive capacity of small firms, which may not have been detected from the dataset.  

Estimation results that have been discussed in this study seem to highlight the advantage of large firms in benefiting from university spillover in the pre-reform period. In this regard, the results of Equation 4 in the five-year lag models imply that local public technology centers fostered valuable innovations through other routes than the promotion of university-industry joint research, that is, technology diffusion and knowledge creation. This suggests the importance of intermediaries that have more functions than intermediation (Howells 2006). The results are consonant with previous anecdotal evidence that local public technology centers contributed to the improvement in the product quality and the introduction of new processes and technologies (Shapira 1992).  

The results also imply that policy evaluation of local public technology centers should take into consideration the time that it would take for their technology transfer activities to exert an effect on innovations.

5. Conclusion

In the knowledge-based economy, universities play three key roles in the long-term economic growth: they provide excellent human resources through education; conduct basic research; and act as a source of knowledge for innovative firms and as a seedbed for high-tech entrepreneurship. This study examined the third role of universities in the period before the national innovation system reform (1983-1997) when university spillover has been considered as inefficient because of institutional impediments but little statistical evidence has been provided. With a comprehensive dataset representing

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21 Fukugawa (2005) shows that the research quality of faculty, represented as forward citations to publications, is significantly correlated with firm size of industrial partners, and local public technology centers are important intermediaries for smaller firms to initiate collaborations with university scientists.

22 Amid serious concerns over decreasing competitive advantage in the manufacturing industry, the US government benchmarked local public technology centers in its industrial modernization program (OTA 1990).
regional innovation systems, this study made a significant contribution to the previous research by depicting a whole picture of knowledge flows in the national innovation system before the fundamental reform where I found different types of sources of knowledge, with different channels of knowledge transfer, for firms with different levels of absorptive capacity, according to firms' accessibility to university knowledge. That is to say, large firms with greater absorptive capacity seem to have received spillover from university research via the long-term, personal, and informal relationships while small firms with lower absorptive capacity seem to have received spillover from technology diffusion by local public technology centers.

What did this study add to the current understanding in the innovation studies? First, this study shed light on the temporal and geographical constraints of university spillover, which has been observed from other countries and periods. The results show that it took time for university research to exert an effect on industrial R&D due to its basic nature and its impact was localized presumably because valuable innovations required cognitively distant knowledge which could be transferred more efficiently with actors' being located in vicinity. Second, this study clarified how university research spilled over into private R&D. The way it affected firms' R&D productivity was not via formal channels, such as joint research, but via informal channels, such as donation, voluntary transfer of academic inventions, and recruitment of excellent graduates as previously suggested by anecdotal evidence. Third, this study is the first to provide statistical evidences of the role played by local public technology centers as intermediaries in regional innovation systems. Previous studies show that intermediaries have more functions than intermediation (Howells 2006) and their diversified roles have been verified through anecdotal evidence in sectoral innovation system studies (Intarakumnerd and Chaoroenporn 2013), but seldom been quantitatively examined with a comprehensive dataset representing regional innovation systems.

What lessons could be learned by other economies in different phases of development from the findings of this study that focused on the pre-reform period in Japan? That national universities could play the third role as a source of knowledge for innovative incumbents even without sufficient policy initiatives to promote university-industry collaborations may have some implications for the catching-up economies where most of the research universities are national universities, the quality of university research has been improved\(^\text{23}\), and less autonomy has been granted to national universities. Informal channels, such as donation, are deemed working as a solution for large firms to circumvent restrictions on collaborations, such as consultation, with national universities that could act as a significant source of knowledge for industrial innovations.

Next, local public technology centers assisted small firms in creating valuable innovations through other channels than intermediation (i.e., helping small local firms expand knowledge networks to universities via joint research), that is, technology diffusion (e.g., consultation and workshops to introduce new technologies). Technology diffusion programs to enhance absorptive capacity of small firms prevail in many

\(^{23}\) The share of high-impact scientific papers in natural sciences and engineering was 0.8% (16th in the world) for South Korea and 0.5% (21st) for Taiwan in 2000 while they ranked 13th (1.5%) and 17th (1.0%), respectively, in 2010 (NISTEP 2013).
knowledge-based economies as a part of regional innovation policy. Examples include manufacturing technology centers (MTC) and manufacturing extension partnerships (MEP) in the US, the Steinbeis Foundation in Germany, Regional Board for Economic Development (ERVET) in Emilia-Romagna of Italy, Technology Innovation Centers (TIC) in the UK, and TNO in the Netherlands, some of which have been quantitatively evaluated and reported to have positive impacts on program participants' productivity growth (Luria and Wiarda 1996; Oldsman 1996; Dziczek et al. 1997; Jarmin 1999; Ponds et al. 2010). This study adds another statistical evidence on positive impacts of technology diffusion programs in the knowledge-based economy and highlights the significance of further examination of the design of this policy initiative and its impact on regional innovations. It is also suggested that technology diffusion programs to help small local firms enhance absorptive capacity are of high importance in the catching-up economies where small firms have greater presence in the business ecosystem. In the catch-up phase, it is relatively easy for firms to identify benchmarks in R&D (since they are unlikely at the leading edge of technological progress), which makes knowledge dissemination, rather than knowledge creation, more significant for economic growth. Furthermore, the improvement in small firms' productivity has positive implications for the growth of big businesses as well, particularly in discrete process industries where small firms could undertake a significant proportion of production processes, such as automotive.

It must be remembered that the dominance of informal channels could pose risk of having smaller firms encounter greater difficulties tapping into university knowledge. As discussed in Section 4, it is more difficult for smaller firms to establish and maintain the personal and long-term relationships with university laboratories, compared to their larger counterparts. Although large firms seem to have received spillover from university research via recruiting excellent graduates and voluntary transfer of academic inventions, it seems unlikely that smaller firms also enjoyed such benefits. Furthermore, the absence of spillover via joint research suggests preemption by joint research partners of the outcomes of publicly-funded research. That is, large firms take advantage of legal settings on joint patents that are characteristic of the Japan Patent Law and exploit joint research not as a means of the acquisition of complementary knowledge from universities but as a means of blocking competitors through strategic patenting. Since this type of strategy is exclusively available for large firms, this may have caused overuse of university research by large firms without spillover at the risk of entrepreneurial firms' having faced difficulties tapping into university knowledge via joint research.

The picture of knowledge flows in the pre-reform period also suggests weakness in the third role of universities as a seedbed for high-tech entrepreneurship. High-tech entrepreneurship leveraging university knowledge that is particularly important in biotechnology encountered difficulties in the pre-reform period because of regulations and overaccess to university research by large firms without spillover where they preempt universities' research outcomes on which high-tech startups could possibly build. Although some of the local public technology centers have incubators, they are basically expected to support small-sized incumbents. This relates to agenda for further

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24 Fukugawa (2008) evaluates how technology transfer activities have been developed by local public technology centers in accordance with regional innovation systems in which they are located.
research. Future research will expand the empirical period in order to investigate how the impacts of university research and university-industry collaborations on regional innovations changed after the national innovation system reform. Despite the reform of national innovation system, some consider that legal and organizational factors recreate the strong relationship between large firms and leading research universities (Kneller 2007), leaving high-tech entrepreneurship in difficulties benefitting from university research. Future research will examine whether this is characteristic to the pre-reform period, and changed after the reform of national innovation system.

Another agenda for future research is about sectoral innovation systems. Previous studies suggest that industrial innovations exhibit distinct sectoral patterns in terms of technological opportunities and appropriability conditions (Nelson and Winter 1982; Pavitt 1984; Malerba 2002). Patents are more effective as a means of appropriating return to R&D in drugs where innovations are standalone, which suggests the sectoral variations in $Y$ and $R$ in this study. Scientific advancement matters more for industrial innovations in biotechnology, which suggests the sectoral variations in the impacts of $U$ on $Y$. Furthermore, recent studies on sectoral innovation systems suggest that different knowledge bases require different modes of transfer (Asheim et al. 2007; Dornbusch and Brenner 2013). For instance, analytical knowledge which is dominant in biotechnology could be transferred via public channels (e.g., publications and patents) which face no geographical constraints, while synthetic knowledge which is important in mechanical engineering requires close communication for efficient transfer, which prefers the geographical proximity. This suggests the sectoral variations in effective transfer channels (e.g., joint research, consultation, and licensing) from universities and local public technology centers. Future research will collect information on R&D, innovation, and technology transfer activities by technological category in order to evaluate how sectoral innovation systems or knowledge bases affect the localization and mechanisms of knowledge transfer from universities and local public technology centers.

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Table 2 Estimated random effect models

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Dependent variable: $Y$
Number of groups (prefectures)=47. Empirical period: 1983-1997. The number of observations=705.
The level of statistical significance is 1% for (_a), 5% for (_b), and 10% for (_c).
Standard errors are shown below the coefficients.
The results of time dummies are not reported.
Equation denotes the number of equations in Section 3.
Figure 1 Joint research between national universities and industry

Source: MEXT, Annual report of university-industry collaborations
Vertical axis on the right-hand side denotes research budget received by universities (billion JPY) and that on the left-hand side denotes the number of projects.