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University spillovers in Japan: channels, geography, and policy

Nobuya Fukugawa
Tohoku University
Graduate School of Engineering
nfukugawa@gmail.com

Abstract

This study addresses four research questions: whether university research affects industrial innovations; whether its impact is geographically constrained; whether joint research acts as an effective conduit of university knowledge; and whether policy instruments to promote regional joint research networks are conducive to localized university spillovers. A regional innovation panel consisting of forward citations of patents, industry R&D, university research, and university-industry joint research networks from 1983 to 2002 is established to estimate regional knowledge production function. Estimation results negate the first and second questions while they partially support the third and fully support the fourth statement.

Jelcodes:O33,O38

1 Introduction

Universities play three important roles in national innovation systems (Mowery and Sampat, 2005). First, they educate and provide society with excellent human resources that are critical for economic growth. Second, they engage in basic research that, while not directly associated with any industrial use, can be applied and developed in various technological categories, thereby fostering economic growth in the long run. Third, they act as a source of knowledge for firms that encounter problems in R&D or attempt to extend their R&D capabilities. 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, 2007a; Kneller, 2007b). 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-industry knowledge transfer (Zucker and Darby, 2001). As a result, an informal and long-term relationship between prestigious national universities and large firms, such as the recruitment of competent graduates and voluntary transfer of university inventions, became a significant conduit for transferring university knowledge.

Since the late 1990s, a series of reforms of the national innovation system for the promotion of university spillovers (i.e., the efficient transfer of university knowledge to industrial R&D via various channels) were implemented. The important changes in innovation policy are as follows (Kneller, 2007b). The Technology Licensing Organization (TLO) Act of 1998 legitimized contractual transfers of university inventions to industry. The Japan Bayh-Dole Act (Act on Special Measures for Industrial Revitalization) of 1999 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 Industrial Technology Enhancement Act of 2000 established procedures under which university-based scientists can consult for, establish, and manage companies. The National University Corporation Act of 2004 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. Despite these reforms, some consider that legal and organizational factors recreate the strong relationship between large firms and leading research universities (Kneller, 2007a; Kneller, 2007b), leaving small firms in difficulty tapping into university knowledge.

The aim of this study is to quantitatively examine whether and how university research affected industrial innovations before and under the reform of national innovation systems initiated in the late 1990s. Specifically, using several databases of the Japanese patent, university research, and university-industry joint research between 1983 and 2002, this study examines 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 regional collaborations through joint research particularly matters for university spillovers. The remainder of this paper is organized as follows. Section 2 identifies important perspectives in analyzing university spillovers by reviewing the previous literature on the impact of university research on industrial innovations. Based on several perspectives identified through literature review, Section 3 introduces the econometric model. Section 4 introduces variables and data used for regression analysis. Section 5 presents estimation results and discusses the implications of empirical findings.

2 Previous studies

This section reviews four important issues on university spillovers identified through review of previous studies, that is, recipients, channels, geography, and determinants of university spillovers (Bozeman, 2000; Agrawal, 2001; Breschi and Lissoni, 2001; Rothaermel et al., 2007), which provides a basis for the regression model developed in the next section.

Recipients

Firms with limited internal knowledge resources have a greater potential of tapping into external sources of knowledge. Among them, firms with greater absorptive capacity, that is, R&D-intensive firms, are able to assess, acquire, and exploit complementary knowledge more effectively (Cohen and Levinthal, 1990). Previous empirical studies show that small technology-based firms are likely to achieve technological success (measured as patent productivity) or commercial success (measured as the rate or return to R&D) by tapping into university knowledge better than do their larger counterparts, such as in the USA (Link and

Rees, 1990; Mansfield, 1991), in Italy (Audretsch and Vivarelli, 1996; Piergiovanni et al., 1997), and in Japan (Motohashi, 2004; Fukugawa, 2012). Such tendencies are more salient in technologies where industrial innovations build on scientific advancement, that is, in science-based sectors (Narin et al., 1997). In the pharmaceutical industry, dedicated biotechnology firms (DBFs) are the driving force of new drug discoveries that build on close linkages to universities (e.g., spin-off and coauthorship). DBFs' research productivity is greatly improved through research alliances with universities (Deeds and Hill, 1996; Powell et al., 1996; Zucker et al., 1998; Baum et al., 2000; Rothaermel and Deeds, 2004).

Geography

University-based scientists compete globally, and their achievements are evaluated through the publication of academic papers and the forward citations received by the paper. Their goal is for their research outcomes to be published in international journals as promptly as possible, so that the results can be widely disseminated and cited in the scientific community. In this regard, if university knowledge were to spill over into industry R&D, the geographical range of its impact would not be localized. However, previous studies show that the flow of university knowledge is localized (Jaffe, 1989; Audretsch and Feldman, 1996; Anselin et al., 1997; Piergiovanni et al., 1997; Varga, 1998; Feldman and Audretsch, 1999; Autant-Bernard, 2001; Acs et al., 2002; Romjin and Albaladejo, 2002; Bode, 2004). In other words, university knowledge spills over into the R&D of firms in the region through some channel, but firms in remote regions will not receive such benefits even though firms are able to tap into university knowledge via publication regardless of their location. This implies that for university research to have positive effects on industrial innovations, the transfer of not only codified knowledge via scientific papers but also tacit knowledge is important. One of the main reasons for this lies in the characteristics of university knowledge. 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 communicate closely with the academic inventor in order to identify practical applications of the invention (Mansfield, 1995).

Channels

It is important to investigate not only the presence but also the mechanism of university spillovers, that is, how university knowledge is transferred (Jaffe et al., 1993). Previous empirical studies identify several university spillover channels, such as joint supervision of Ph.D. students (Schartinger et al., 2001), coauthorship (Cockburn and Henderson, 1998), labor mobility (Odagiri et al., 1997), licensing of university patents (Shane, 2002), academic startups (Markman et al., 2004), and consultation as a scientific adviser (Audretsch and Stephan, 1996). Another stream of research examines determining factors in the type of spillover channel (e.g., joint research and consultation) and show that university-specific factors, such as the research quality of faculty staff, and industry-specific factors, such as the employment share of large or small firms, are influential in employing a specific type of spillover channel. Small technology-based firms, seeking for immediate solutions to problems in their core domain, exploit university knowledge via technological consultation and funded research, whereas large firms in resource-intensive industries engage in joint research with universities in firm's peripheral domain to enhance the long-term R&D capabilities

(Perkmann and Walsh, 2008). This is confirmed through empirical evidence from the US (Santoro and Chakrabarti, 2002), Austria (Schartinger et al., 2002), and Japan (Motohashi, 2004; Fukugawa, 2005).

Determinants

A number of empirical studies examine factors that affect the productivity of university-based technology transfer (Phan and Siegel, 2006). These studies typically model university-based technology transfer as a production function, where the output is measured as the number of patented university inventions, the number of licensed university patents, the number of university spin-offs, the total factor productivity of university licensing, and royalty revenue. The input of production function refers to the characteristics of universities and technology transfer organizations (TTOs). Their proxy variables include the research expenditure of the university, the research quality of faculty staff, the size and experience of TTOs, and the incentive mechanisms designed for faculty staff and TTO employees. According to their findings, university-specific factors such as research quality, direction in research (i.e., basic or applied research-oriented), and incentives for academic scientists and faculty, and TTO-related factors, such as size and incentives, are influential in the productivity of university licensing (Henderson et al., 1998; Thursby and Kemp, 2002; Thursby and Thursby, 2002; Siegel et al., 2003; Markman et al., 2004). Furthermore, university-specific factors such as incentive mechanisms represented as reward and property rights, and policies for academic and surrogate entrepreneur are important for the promotion of academic spin-offs (Franklin et al., 2001; DiGregorio and Shane, 2003; Goldfarb and Henrekson, 2003; Lockett et al., 2003).

3 Empirical Analysis

3.1 Model

The previous section reviewed the prior research and identified four issues (i.e., recipients, geography, channels, and determinants) as key theoretical perspectives to understand university spillovers. Based on the theoretical predictions of the last three issues, this section proposes four research questions: whether university research affects industrial innovations; whether its impact is geographically constrained; whether joint research acts as an effective conduit of knowledge transfer; and whether policy instruments to promote regional university-industry joint research are conducive to university spillovers (i.e., the productivity improvement of industrial R&D due to the transfer of university knowledge). Some studies based on the regional knowledge production function addressed the issue of recipients, which was not examined in this study. They typically divide the sample into subgroups according to firm size and technologies to identify who is more advantages in receiving university spillovers. Audretsch and Vivalelli (1996) provides a first evidence from Europe that shows university research is more important for small firm innovations.

The simplest model of the regional knowledge production function, which is a patent production function aggregated at a regional level, can be described as

$$Y_{it} = f(R_{it}, U_{it}) \qquad (1)$$

where Y_{it} is innovation output, R_{it} is industry R&D, U_{it} is university research. Suffixes *t* and *i* denote year and a region (i.e., prefecture), respectively.

Geography

As noted earlier, as far as public channel (e.g., publication) concerned, if university knowledge were to spill over into industry R&D, the geographical range of its impact would not be localized. Previous studies employ the regional knowledge production function to examine whether and how university spillovers are geographically constrained. Jaffe (1989) is the first to employ the regional knowledge production function, using a state level dataset in the USA. Although he introduced a geographic coincidence index (which is an uncentered correlation between vectors of industry R&D and university research across Standard Metropolitan Statistical Areas, and different from a spatially weighted university research represented as US_{it}) to the model, he found no evidence of localized university spillovers. Jaffe's approach was fully developed by Anselin et al. (1997) which incorporated a *ring* variable, that is, concentric circles from a typical geographical unit to measure university research conducted within, near, and remote areas, to represent spatially weighted university research's impact on industrial innovations. They found that university research conducted at remote areas did not increase patents generated by firms in a standard metropolitan statistical area, while that conducted in vicinity increased patents. Using the French data, Autant-Bernard (2001) estimated a modified model of Anselin et al. (1997), which measured the impact of scientific proximity on innovations as well as that of geographical proximity, and found that university research conducted within a region increased patents generated by firms in that region while that conducted in remote and near regions did not affect industrial innovations generated in that region. If tacit nature of university spillovers requires face-to-face communication, it is time distance that matters for the effectiveness of spillovers. With this regard, Ponds et al. (2010) employed an inverse of time distance between NUTS3 regions to generate a spatial weight for university research and found positive impact, suggesting that university research conducted closer areas were more likely to lead industrial innovations.

This study examines localized university spillovers using a regional knowledge production function described as

$$Y_{it+q} = f(R_{it}, U_{it}, US_{it}) \quad (2)$$

where *US* is a spatially weighted variable of *U*, that is, university research conducted in adjacent regions to the region where *U* was conducted. Suffix *q* denotes the time lag that is required for the effect of each innovative input to become visible.

Channels

Recent studies based on a regional knowledge production function addressed the issue of spillover channels. They modify the aforementioned regional knowledge production function to evaluate the impact of university spillover pool that is accessible to firms through joint research. Using a planning region level dataset in Germany, Fritsch and Franke (2004) examined university spillover channels such as use of equipments, joint R&D, coauthorship, and contract research, but found only weak evidence to support the significance of these channels, suggesting that unexamined channels might have been working. Ronde and Hussler (2005) employed R&D partnerships and recruitment as proxy variables for spillover channels and found their positive impacts on patents generated by firms in a department (a geographical unit of governance in France). Using a NUTS3 level dataset of Netherland, Ponds et al. (2010) examined coauthorship as a spillover channel and found a positive impact on patents generated by firms in a region. Using a prefecture level dataset of Japan, Fukugawa (2011) incorporated the university knowledge which is accessible to firms through joint research with national universities into the regression model, and, despite institutional constraints on formal interactions in the empirical period (1983-1996), confirmed university spillovers in many technological categories.

The regional knowledge production function, taking an example of university-industry joint research as a spillover channel, can be written as

$$Y_{it+q} = f(R_{it}, U_{it}, UN_{it}) \quad (3) \quad \text{where } UN_i = \sum_{j=1}^{47} U_j B_{ij} \text{ and } B_{ij} = \frac{A_{ij}}{\sum_{i=1}^{47}\sum_{j=1}^{47} A_{ij}}$$

$$Y_{it+q} = f(R_{it}, U_{it}, UNL_{it}) \quad (3') \quad \text{where } UNL_i = \sum_{j=1}^{47} U_j B_{ij} \ (i = j) \text{ and } B_{ij} = \frac{A_{ij}}{\sum_{i=1}^{47}\sum_{j=1}^{47} A_{ij}} \ (i = j)$$

where A is the number of joint research projects that firms in a region i conducted with national universities in a region j (i.e., regional collaboration is the case where $i=j$), B is a weight for university knowledge utilized by firms in a region i through joint research, and UN is university spillover pool accessible to firms in a region i through joint research with national universities. In order to examine the effect of regional collaborations, UNL, which represents the university spillover pool accessible to firms through regional collaborations (i.e., both a firm and a university are located in the same prefecture), is alternatively added to the regression model. The number of i and j is forty seven, reflecting the number of local units (i.e., prefecture) in Japan.

Policy instruments to promote spillovers

The previous studies show that the productivity of university technology transfer is affected not only by the magnitude and quality of university research, but also by organizations mediating academia and industry, such as TTOs. In many countries, these intermediate organizations (e.g., liaison offices, business incubators, science parks, and technology extension centers) to promote university spillovers are designed and promoted by regional innovation policy. With this regard, some studies have incorporated factors related to regional innovation policy to the model. Ronde and Hussler (2005) employed R&D expenditure by local authorities to represent regional innovation policy and found a negative impact on patents generated by firms in a department, reflecting the regional innovation policy in France to promote less innovative regions. Ponds et al. (2010) employed a semi-public TTO dummy to represent regional innovation policy in Netherland and found its positive impact on patents generated by firms in a region. Both studies incorporated these policy-related factors as control variables for variations of innovative output. However, variables representing policy measures to promote university spillovers are considered to be correlated with university knowledge accessible to firms via some channel, but affect industrial innovations only through the variation of university research weighted by either geography or networks. This is because the aim of intermediate organizations established as innovation policy is to promote university knowledge transfer (then consequently promote industrial innovations), and it may not directly bolster industrial innovations. In an econometric term, innovation policy instruments to promote university spillovers can be dealt with as an instrument which affects *UN* and *UNL*, (i.e., they satisfy the conditions of relevancy) and is uncorrelated with unobservable factors that are influential in *Y* (i.e., they satisfy the conditions of exogeneity).

Therefore, this study incorporates X representing innovation policy to promote university-industry collaborations not only through joint research but also through various channels into the regional knowledge production function as an instrumental variable. As introduced in the next section, X include a binary dummy representing the presence of a liaison office for regional joint research and the number of local public technology centers for technology transfer to small local firms.

$$Y_{it+q} = f(R_{it}, U_{it}, UN_{it}) \quad (4) \quad \text{where } UN_{it} = g(X_{it})$$
$$Y_{it+q} = f(R_{it}, U_{it}, UNL_{it}) \quad (4') \quad \text{where } UNL_{it} = h(X_{it}).$$

Taking log of the aforementioned equations yields the following econometric models (constant terms are omitted).

$$\ln Y_{it+q} = b_{11} \ln R_{it} + b_{12} \ln U_{it} + u1_i + v1_t + \varepsilon 1_{it} \quad (5),$$
$$\ln Y_{it+q} = b_{21} \ln R_{it} + b_{22} \ln U_{it} + b_{23} \ln US_{it} + u2_i + v2_t + \varepsilon 2_{it} \quad (6),$$
$$\ln Y_{it+q} = b_{31} \ln R_{it} + b_{32} \ln U_{it} + b_{33} \ln UN_{it} + u3_i + v3_t + \varepsilon 3_{it} \quad (7),$$
$$\ln Y_{it+q} = b_{41} \ln R_{it} + b_{42} \ln U_{it} + b_{43} \ln UNL_{it} + u4_i + v4_t + \varepsilon 4_{it} \quad (8),$$
$$\ln Y_{it+q} = b_{51} \ln R_{it} + b_{52} \ln U_{it} + b_{53} \ln UN_{it} + u5_i + v5_t + \varepsilon 5_{it} \quad (7') \; where \; \ln UN_{it} = b_{54} X_{it} + u6_i + v6_t + \varepsilon 6_{it},$$
$$\ln Y_{it+q} = b_{61} \ln R_{it} + b_{62} \ln U_{it} + b_{63} \ln UNL_{it} + u7_i + v7_t + \varepsilon 7_{it} \quad (8') \; where \; \ln UNL_{it} = b_{64} X_{it} + u8_i + v8_t + \varepsilon 8_{it}.$$

3.2 Data

Dependent variable

A proxy variable for Y_{it+q} is the number of forward citations, excluding self-citations, received by a patent granted to a Japanese firm by the Japan Patent Office (JPO) from the year of application to 2006; this represents the quality of innovations (Trajtenberg, 1990; Hall et al., 2005). Suffix *t* denotes the year of application and suffix *i* denotes the prefecture in which the inventor resides. Suffix *q*, the time lag that is required for the effect of each innovative input to become visible, is assumed to be one, two, and three. Specifically, taking one year lag against independent variables at the year of 2000 means forward citations between 2001 and 2006. In practice, it is possible for a patent to receive a citation from other patents after being public. In Japan, information of filed patents is disclosed within 18 months or earlier.

Independent variables

A proxy variable for R_{it} is the number of inventors. Suffix *t* denotes the year of application and *r* 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. The patent database of the Institute of Intellectual Property, an external body of JPO, was used to create *Y* and *R*. A proxy variable for U_{it} is the number of research projects in natural sciences with Grant-In-Aid for scientific research from the Japan Society for the Promotion of Science (GIA), conducted by scientists affiliated with national, public (i.e., prefectural or municipal), and private universities. Suffix *i* denotes the prefecture in which the university is located and suffix *t* denotes the year in which the GIA research was commenced. Since GIA is a multi-year contract, observations are limited to the year in which the research was started in order to avoid double counting. Since GIA is the most important peer-review-based research fund for university-based scientists, *U* represents the research quality of the faculty staff which is particularly high in research universities. The coefficients of *U* being significantly positive imply research universities (ex-imperial universities) promote industrial innovations in the region via some channel. Imperial universities in prewar Japan have historically been research universities significant enough to act as sources of industrial innovations; they are Hokkaido University, Kyoto University, Kyushu University, Nagoya University, Osaka University, Tohoku University, and University of Tokyo. A spatial weight for US_{it} is an inverse of physical distance between prefectural capitals so that it will make university research conducted in closer (further) regions more heavily (lightly) weighed. The coefficients of *US* being significantly positive imply localized university spillovers via some channel. A network weight for UN_{it} and UNL_{it} is defined as Equations 3 and 3'. Suffix *i* denotes the prefecture in which the firm is located (i.e., *r* is identical to university location in the case of *UNL*) and suffix *t* denotes the year in which the joint research project was initiated. The coefficient of *UN* being significantly positive implies university spillovers, be they localized or not (since a university partner can be located across the nation), through joint research. The coefficient of *UNL* being significantly positive implies localized university spillovers through joint research. Information on *UN* and *UNL* was collected from a comprehensive survey on university-industry collaborations by the Ministry of Education, Culture, Sports, Science and Technology (NISTEP, 2003). Although this information is limited to national universities, this would not yield a crucial difference in the empirical results because the research universities that have been a source of industrial innovations are national universities in Japan. Proxy variables for X_{it} include a dummy variable representing the presence of a regional joint research center (i.e., national university's liaison offices bridging faculty staff and local firms not only through joint research but also various channels) and the number of local public technology centers that were engaged in technology extension for small local firms, in a prefecture *i* and the year of *t*. Information of the number of local public technology centers was collected from the Nationwide List of Research Institutes in Japan by Lattice. *Y* may vary according to economic size of the region.

Control variables

Control variables for economic size of the region are *GVA*, gross value added and *EST*, the number of establishments. They are added in the regression model alternatively. Suffix *r* denotes the prefecture and suffix *t* denotes the year. Information on *GVA* and *EST* was collected from Census of Manufacturing by the Ministry of Economy, Trade, and Industry. Citations received by a patent dramatically decrease if the application year of the patent exceeds a specific threshold. Therefore, time dummies are included in the regression models to control for truncation of the distribution of forward citations.

The empirical period is from 1983 to 2002, which includes the period of the fundamental reform of the national innovation system initiated in the late 1990s. The geographical unit of analysis is the prefecture, the local unit of governance in Japan, and there are 47 prefectures. The location of innovation was identified at the innovator level instead of the applicant level in order to avoid the geographical distribution of innovations that is wrongly concentrated in Tokyo and Osaka where the headquarters, not the R&D institutes, of large firms are typically located. It should be noted that the absence of commuting bias (Deyle and Grupp, 2005) is assumed here. In other words, the inventor's address listed in the patent documents is assumed to denote exactly where the inventor lives, and the inventor is assumed to work in the prefecture in which he or she lives.

3.3 Results

Table 1 shows the estimation results. The estimated coefficients indicate impacts of each independent variable on innovations in a region after controlling for unobserved region-specific factors. The models including spatially weighted university research (*US*), university research weighted by joint research networks (*UN*), and university research weighted by localized joint research networks (*UNL*) as independent variable were estimated using the instrumental variable method. Applying different lagged structure in a dependent variable does not change the results. Control variables for regional economic size, the number of establishments (*EST*) and gross value added (*GVA*), do not affect the quality of industrial innovations in the region. The inclusion or exclusion of control variables does not change other key findings. The coefficients of industrial R&D (*R*) are significantly positive in most of the models, which implies that the number of inventors can act as an indicator of R&D investment. Implications of key results, that is, the impacts of university research on industrial innovations, are discussed in the next section.

Table 1 about here

4 Discussions

Based on literature review developed in Section 2, this study addressed four research questions: 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 instruments to promote regional university-industry joint research were conducive to university spillovers (i.e., the productivity improvement of industrial R&D due to the transfer of university knowledge). Estimation results negate the first and second questions while they partially support the third and fully support the fourth statement. This section discusses implications of key results.

In all types of the models, university research weighted by university-industry joint research networks (*UN*) does not have significant impacts on regional innovations, which suggests the *absence* of university spillovers via joint research. Among the various channels of university spillovers, this study finds that joint research within a region acts as an effective channel through which university knowledge spills over into industry R&D. This evidence has peculiar implications in the Japanese context. From a legal perspective, joint research was considered as a means for large firms to preempt outcomes of publicly-funded research since most of the research universities in Japan were ex-imperial (national) universities and public grants in aid for scientific research tended to concentrate on these universities (Kneller, 2007a; Kneller, 2007b). Unlike US Patent Law, Japan Patent Law Article 73 does not allow a co-owner (in this case the university) to transfer or license jointly-owned patents to other firms without the permission of other co-owners (in this case the industry partner). This legal environment offers industry partners, large firms in particular, a great advantage to preempt the outcomes of university research through joint research (Kneller, 2007a; Kneller, 2007b). Large firms 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). 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 contribution to the joint invention is null, which suggests the absence of knowledge spillovers rather than the acquisition of complementary knowledge from academic research. The result that university research weighted by university-industry joint research networks shows no impacts on industrial innovations seems to be consistent with this concern.

However, in all types of the models, university research weighted by *regional* joint research networks (*UNL*) has significantly positive impacts on innovations in a region, which means that regional collaborations through joint research were effective in the promotion of industrial innovations. Previous studies find localized spillovers from academic research (Jaffe, 1989; Acs et al., 1992; Mansfield, 1995; Autant-Bernard, 2001). Among channels through which tacit knowledge is transferred, academic spinoffs and labor mobility are considered as typical drivers of localized knowledge spillovers (Almeida and Kogut, 1997; Almeida and Kogut, 1999; Almeida et al., 2003). In this regard, the results show that the firms with localized university linkages through joint research have greater advantages in improving the quality of their knowledge resources, than firms without local ties. The geographical proximity to spillover pools facilitates face-to-face communications with university-based scientists, promoting the efficient transfer of tacit knowledge, which is essential for successful industrial applications of research (von Hippel, 1994; Nooteboom, 1999; Jensen and Thursby, 2001). The significance of geographical proximity in knowledge transfer depends on the nature of innovation that the firm pursues through joint research. The results may reflect that the cognitively distant knowledge that is required for novel innovations can be transferred by close communications.

Although the results of the first step estimation in the instrumental variable method are not reported here, policy instruments, *X*, has a significantly positive impact on spatially weighted university research (*US*) and regional network weighted university research (*UNL*), meaning that liaison offices at national universities and local public technology centers expand university research that local firms can access via joint research and other channels. This is consistent with the fact that liaison offices at national universities have been established since the mid 1980s to promote knowledge transfer from national universities to local firms. However, policy instruments have no impacts on university research weighted by university-industry joint research networks (*UN*), indicating that liaison offices are intermediate organizations for *localized* university-industry collaborations and do not promote joint research in general. The implications of these findings are that helping firms develop knowledge networks can be the key to effective regional innovation policy. This has important implications in regional policy where local authorities attempt to develop regional innovation policies for the promotion of university-industry local ties, such as the development of science parks or knowledge clusters, through research collaborations. The results suggest that human resources which act as gatekeepers who bridge different realms (i.e., business, science, and government) matter for the promotion of industrial innovations by leveraging university knowledge. In this regard, previous studies conducted in various regions suggest that nurturing gatekeepers connecting different realms is the key for the promotion of knowledge interactions between industry and science (Westhead and Batstone, 1999; Frisch and Lukas, 2001; Santoro and Chakrabarti, 2002; Balconi et al., 2004; Cassi et al., 2008; Molina-Morales and Martínez-Fernández, 2010). Therefore, policy instruments to strengthen intermediation between the two, undertaken by coordinators at regional cooperative R&D centers (Collins and Wakoh, 2000), business incubators, and local public technology centers (Fukugawa, 2005), is of high importance.

Contributions and limitations of this study can be summarized as follows. First, the present study is the first to incorporate innovation policies into the regional knowledge production function to examine how policy instruments affect university spillovers, and consequently industrial innovations in a region. Actually, the effect of university-industry joint research, which is promoted by intermediate organizations established as innovation policy instruments, on industrial innovations is contingent on the geographical proximity; this has important policy implications for regional innovation policy. In addition to regional innovation policies address in the present study, other measures to promote university spillovers, such as science parks, should also be evaluated by future studies. Second, by examining the period when the national innovation system has undergone fundamental reform since the late 1990s, this study provides evidence that formal university-industry connections through joint research agreements were not effective in general. However, the empirical period of the study (1983-2002) was limited due to the availability of data on university-industry joint research and the truncation problem in patent citation. Dividing the empirical period before and after the late 1990s reduces the number of observations, which makes estimated results unstable and difficult to interpret. Future studies should expand the empirical period to investigate how the impacts of university research and university-industry knowledge interactions on industrial innovations in a region have changed after the reform.

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Table 1 Regional knowledge production function, fixed-effects model estimation: dependent variable: ln(*Y*)

Equation	5	5	5	6	6	6
Lagged structure	1	2	3	1	2	3
ln(*R*)	0.6544**	0.5395**	0.4587**	0.6589**	0.5400**	0.4584**
	0.0418	0.0410	0.0424	0.0418	0.0411	0.0425
ln(*U*)	0.0986	0.0175	0.1283	-0.2548	-0.0235	0.1460
	0.0720	0.0707	0.0730	0.1897	0.1867	0.1927
ln(*US*)				0.6252*	0.0725	-0.0312
				0.3105	0.3055	0.3155
ln(*UN*)						
ln(*UNL*)						
ln(EST)	-0.2325	-0.4120	-0.2748	-0.2488	-0.4139	-0.2740
	0.2363	0.2319	0.2394	0.2360	0.2322	0.2397
ln(GVA)	-0.0647	0.1130	0.0933	-0.0724	0.1121	0.0937
	0.1542	0.1514	0.1563	0.1540	0.1515	0.1564
Constant	5.3571*	5.0213*	3.3612	3.9890	4.8626	3.4295
	2.5037	2.4576	2.5373	2.5901	2.5482	2.6309
N	940	940	940	940	940	940
Method	FE	FE	FE	FE	FE	FE
Rho	0.908	0.937	0.929	0.878	0.936	0.930

Equation	7	7	7	8	8	8
Lagged structure	1	2	3	1	2	3
ln(*R*)	0.6538**	0.5390**	0.4601**	0.6544**	0.5395**	0.4587**
	0.0420	0.0412	0.0426	0.0418	0.0411	0.0424
ln(*U*)	0.0984	0.0173	0.1290	0.0952	0.0199	0.1278
	0.0721	0.0708	0.0730	0.0723	0.0710	0.0733
ln(*US*)						
ln(*UN*)	0.0034	0.0033	-0.0091			
	0.0233	0.0229	0.0236			
ln(*UNL*)				0.0193	-0.0132	0.0026
				0.0339	0.0333	0.0344
ln(EST)	-0.2364	-0.4158	-0.2643	-0.2312	-0.4130	-0.2746
	0.2379	0.2335	0.2411	0.2364	0.2321	0.2396
ln(GVA)	-0.0626	0.1150	0.0878	-0.0671	0.1147	0.0930
	0.1549	0.1521	0.1570	0.1543	0.1515	0.1564
Constant	5.9775*	5.7902*	4.1382	5.9937*	5.7675*	4.1601
	2.5040	2.4579	2.5374	2.5034	2.4576	2.5375
N	940	940	940	940	940	940
Method	FE	FE	FE	FE	FE	FE
Rho	0.907	0.937	0.929	0.906	0.938	0.929

Equation	7'	7'	7'	8'	8'	8'
Lagged structure	1	2	3	1	2	3
ln(*R*)	0.5284**	0.3173	0.1555	0.6557**	0.5414**	0.4606**
	0.1558	0.2306	0.3035	0.0444	0.0468	0.0481
ln(*U*)	0.0426	-0.0814	-0.0066	0.0309	-0.0769	0.0306
	0.1266	0.1873	0.2465	0.0829	0.0874	0.0897
ln(*US*)						
ln(*UN*)	0.7915	1.3965	1.9055			
	0.8939	1.3231	1.7413			
ln(*UNL*)				0.3769*	0.5250**	0.5436**
				0.1775	0.1872	0.1921
ln(EST)	-1.1376	-2.0088	-2.4535	-0.2059	-0.3750	-0.2364
	1.0835	1.6037	2.1106	0.2513	0.2650	0.2719
ln(GVA)	0.4111	0.9524	1.2386	-0.1115	0.0478	0.0258
	0.5863	0.8678	1.1421	0.1653	0.1743	0.1788
Constant	7.0133	7.9433	7.3481	5.8124*	5.6555*	4.0178
	4.2447	6.2828	8.2687	2.6687	2.8134	2.8873
N	940	940	940	940	940	940
Method	IV	IV	IV	IV	IV	IV
Rho	0.791	0.744	0.708	0.878	0.898	0.890

Notes

1. Number of observations=940.
2. Number of groups (prefectures)=47.
3. Empirical period: 1983-2002.
4. ** p<.01; * p<.05.
5. Results of time dummies are not reported. Standard errors are below coefficients.
6. *Y*: forward citations, excluding self-citations, received by JPO patents granted to the Japanese firm; *R*: industry R&D; *U*: university research in natural sciences; *US*: spatially weighted university research; *UN*: university knowledge accessible to firms through joint research with universities; *UNL*: university knowledge accessible to firms through joint research with local universities; *EST*: the number of establishments; *GVA*: gross value added.
7. Estimation method: Fixed effect model (FE); panel instrumental variable method (IV)
8. Instrumented: *UN*; *UNL*.
9. Instruments: a liaison office dummy; the number of local public technology centers.