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Impact of national university patenting on innovation: Researcher analysis in Japan☆

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ABSTRACT

This study addresses the impact of national university ownership of patents on the quantity and quality of university patents. We constructed researcher-level patent data with detailed information on their affiliations, and the difference-in-differences (DID) model was applied to determine the change in patent characteristics of national university researchers when the institutional ownership of intellectual property rights at national universities was allowed in 2004. An increase in university patenting has a significant impact on subsequent innovation, as observed by its forward citation, particularly by firms without prior university collaborations.

1. Introduction

The impact of patenting on university research on science and technology knowledge spillovers is a long-standing controversy. Whether patenting of university research hinders or facilitates knowledge spillover to subsequent research and industrial applications is at the heart of this debate. Some studies have demonstrated that the anticommons nature of university patenting hinders knowledge spillover from university research activities ([1]; Fabrizino, 2007; [2]). However, a positive impact of university patenting on innovation has been demonstrated by requiring university scientists to disclose the details of their findings [3] and encouraging firms to engage in follow-on innovation [4–6].

The impact of university patenting on subsequent innovations is determined by the balance between the patenting propriety nature (negative) and the information disclosure effect (positive); thus, empirical results are influenced by the scientific field. In addition, the national institutional setting, including the university system's governance mechanism and academic patenting policy, also matters in empirical findings. Mowrey and Sampat [7] described the significant institutional differences between the United States (US) and continental European countries.

This study addresses this issue by examining the incorporation of national universities in Japan in 2004 to identify the marginal effect of university patenting. This reform involves the incorporation of national universities in Japan as independent entities transformed from government organizations under the Ministry of Education. Such organizational change allows national universities to patent their discoveries as independent legal entities [8]. However, this policy did not affect Japan's private and local government-affiliated universities, in which patenting was allowed as an institution even before this reform. Therefore, this institutional reform provides us an opportunity to evaluate the marginal impact of university patenting (before and after the reform) in different settings (national vs. nonnational universities).

In this study, we created a unique dataset by linking disambiguated patent inventors and research paper authors at the researcher level, covering all science disciplines. Controlling researcher-level heterogeneity across capability and discipline, this study complements past empirical studies with mixed results. Additionally, we contribute to the understanding of the relationship between university patenting and knowledge spillovers in Japan by adding more geographic contexts, whereas almost all past studies dealt with US or European cases.

The remainder of this paper is organized as follows. Section 2 introduces previous studies on patent applications and examines

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qualitative changes in patents and inventions in the context of institutional ownership of university patents. Section 3 describes the method of extracting patents held by university faculty members from the database employed, specifically the IIP Patent based on published patent applications of the Japan Patent Office. Section 4 presents the results of the quantitative analysis of the impact of the national university corporation reform on university patents. Finally, Section 5 summarizes the policy implications and presents issues for future research.

2. Literature review and position of the current study

Concerns that patenting university research outcomes may hinder subsequent scientific inquiry and industrial applications have been well conceptualized by the "Tragedy of the Anticommons" [9,10]. Several studies have provided supportive evidence. For example, Henderson et al. [11] demonstrated that the propensity of university patents to be cited by patents in diverse technical fields has been declining since the mid-1980s because of the Bayh–Dole Act of 1980. Additionally, the attribution of research findings funded by public research funds to universities has led to an increase in the number of university patents but a decline in their quality. This finding implies that university ownership of patents derived from government-funded research may restrict knowledge spillover while generating economically less valuable patents.

Murray and Stern [1] investigated the impact of patenting on scientific research. Analyzing 169 patent–paper pairs, they found a decline of approximately 10%–20 % in the research paper citations after the patent on scientific research was granted, indicating a potential slowing down of knowledge spillover to subsequent research. This study directly tested the tragedy of the anticommons hypothesis, providing an empirical foundation for further discussion about the impact of university patenting in science. It also called for studies on how university patenting may affect industrial innovation. Chaves et al. (2023) confirmed a similar pattern in the Chilean context, demonstrating that university patenting hinders open science through publication delays and refusal to share research.

Fabrizio [12] attempted to respond to this call by analyzing the relationship between university patenting and the pace of industrial innovation development using patent citation information. The analysis demonstrated that as university patenting increases, the lag in creating a firm-patented invention becomes longer. This pattern was particularly strong in fields where scientific knowledge is the key input for firm innovation. The findings imply that university patenting may slow down knowledge spillover from university research to industry, resulting in a deceleration of industrial innovation. The two studies summarized above revealed that university patenting may deter knowledge diffusion not only to science but also to industry, supporting concerns about the undesirable impacts of university patenting on innovation.

However, other research strands have found somewhat inconsistent or even opposite evidence to this conclusion, arguing that university patenting may facilitate both scientific and technological progress because of the information disclosure function of patenting. This function incentivizes university researchers to explore industrial applications more actively while enhancing the impact of university research [3,13–15].

Various pieces of evidence support this view. For example, using the same data as those of Henderson et al., Mowery and Ziedonis [16] found that universities with a higher concentration of patents had an increased number of citations, whereas the number of citations decreased in universities with fewer patents after the Bayh–Dole Act in the US. This indicates that the impact of university patenting on industrial spillovers of university research varies by institution.

Shane [5] offered more contextualized evidence supporting Mowery and Ziedonis' [16] conclusion. By analyzing patents assigned to the Massachusetts Institute of Technology, this study demonstrated that university inventions with effective patent protections are more frequently licensed to firms. This implies that university patenting may help promote knowledge spillovers to industry from university researchers. Although the generalizability of this finding is limited, as it was based only on the case of one academic institution, the findings imply that the relationship between university patenting and industrial innovation through knowledge spillover is likely more complicated than prior theoretical discussions have indicated.

Magerman et al. [17] analyzed patent–paper pairs to examine whether patenting scientific findings deter scientific and technological spillovers in biotechnology. In contrast to the findings of Murray and Stern [1], they found no evidence of a negative impact of patenting scientific research on scientific knowledge spillover.

Sampat and Williams [6] extended this investigation by examining whether patenting gene research deters follow-up scientific research and the development of gene-based pharmaceutical products in the US. They found that follow-on research was more significant for patented genes than for nonpatented genes, indicating a systematic "selection" in gene patenting. Considering the selection, their further analysis found no evidence that gene patenting discouraged follow-on innovation. These findings imply that even in science-driven domains, such as gene-based research and pharmaceutical product development, patenting scientific research outcomes may not uniformly discourage the development of industrial applications. The authors revealed that researchers' selection of research findings for patenting may further complicate our understanding of the relationship between patenting science and industrial innovation. In the context of university research and patenting, this implies that university researchers may selectively patent their research, thus making the impacts of university patenting on industrial innovation ambiguous.

Researchers have also elaborated on the relationship between university patenting and industrial innovation by examining the channels of knowledge spillover from university to industry and the role of university "ownership" of patented research. Scholars in Europe have made significant contributions to this field by examining the impact of institutional changes that enable universities to own patents from university researchers. For example, Lissoni et al. [18] explored how institutional changes that introduced the "professor's privilege" while expanding the autonomy of universities' management affected university patenting activities in Italy. Using European patent data, the researchers found that these changes resulted in a significant increase in university patenting mainly because universities established rules to override professors' privileges to secure their ownership of faculty inventions. This finding implies that institutional changes granting universities autonomy over their intellectual property rights (IPRs) may encourage their patenting activities by enabling them to develop internal rules to control university researchers' patent ownership.

Schoen and Buenstorf [19] reached a similar conclusion by providing evidence of a significant increase in university-owned patents after the abolition of the professor's privilege. These two studies revealed that institutional changes that enable universities to own their patents result in a substantial increase in the number of university patents.

Other scholars have examined how such institutional changes affect the spillover of university research. For instance, Giuri et al. [4] examined how universities' patent ownership is associated with the commercialization of university research using data on over 800 patents owned by universities or public research organizations and filed with the European Patent Office in 22 countries. Their analysis revealed that universities' patent ownership is positively associated with the likelihood of the patent being licensed. This reveals that university patent ownership facilitates the channel for the commercialization of university knowledge, at least through patent licensing. In the European region, Caviggioli et al. [20] established the pattern of technology specialization via university patenting.

As patent licensing is one of the major channels for transforming university research into industrial applications, Callaert et al. [21] examined whether policies encouraging university patenting deteriorate

the technological spillover of university knowledge and whether this effect differs by patent ownership (i.e., owned by university or firm). Using data on the patenting activities of Flemish universities from 1991 to 2001, their analysis revealed that policies encouraging university patenting have led to a substantial increase in university involvement in patenting their research. Interestingly, the study found no evidence of worsened technological spillover of university knowledge due to patenting. Their findings demonstrated that encouraging university patenting (ownership) through policy changes does not necessarily result in aggravation of the tragedy of the anticommons.

Martínez and Sterzi [2] explored a more complex relationship between university patent ownership and spillover by examining the change in technological spillovers after the abolition of the professor's privilege in Europe. Their analysis revealed that after universities began owning faculty patents, the size of the technological spillover of academic patents declined (measured by patent forward citations), whereas when firms owned university patents, the spillover increased significantly. Ljungberg et al. [22] further elaborated by comparing the difference in forward patent citations between academic patents owned by Swedish firms and firm-invented patents. The authors examined whether the size of technological spillovers differed based on the origin of firm patents (i.e., academic or non-academic). Their analysis revealed that the short-term technological spillover of academic patents owned by universities was smaller than that of firm-owned academic patents. However, this difference eventually disappeared.

The complication was further highlighted by Penin [23], who demonstrated that university patenting is positively associated with the size of knowledge spillover to industry, and may induce university scientists' strategic behavior in publication. By analyzing survey data on 280 French academic inventors, the author revealed that university patenting accelerates the transfer of university technology to industry while delaying the publication of scientific discoveries. The positive spillover effect of university collaboration on firms is also confirmed in the Chinese context [24]. Table 1 summarizes our literature review.

Although the studies summarized above have contributed to extending our understanding of the relationship between university patenting and knowledge spillover, they also revealed notable empirical irregularities stemming from various contexts in which university patenting occurs. Specifically, the empirical settings of these studies vary in terms of geographical context, being predominantly concentrated in the US and Europe. As regions and countries have distinctive characteristics in their local innovation systems, knowledge spillovers from science to technology and their relationship with university patenting may vary by region, which may explain why the evidence in the US is not consistent with what has been observed in Europe. This underscores the importance of further empirical studies in more diverse regional contexts, such as Asia.

Motohashi and Muramatsu (2010) and Kwon et al. [25] responded to this call. Motohashi and Muramatsu (2010) analyzed the changes in the quality of industry–academia collaboration patents in Japan before and after 2000, as Japan introduced the Bayh–Dole-like act in 1999. They analyzed the impact of a series of industry–academia collaboration policies, including the Technology Licensing Organization (TLO) Act in 1998, the enforcement of the Japanese version of the Bayh–Dole Act in 1999, and the reform of national corporations in 2004, in terms of changes in the characteristics of patents held by universities, including private universities, compared with those held by corporations. Their results revealed the effectiveness of the industry–academia collaboration policy regarding the number and quality of patents since 2000 according to the generality index, which measures the diversification of technology classes of cited patents. However, an analysis from the perspective of the partner companies in industry–academia collaborations indicated a tendency for companies to make more significant inventions independently. Moreover, universities began to assert their

Table 1
Literature summary.

Authors (Year)	Context of patenting on scientific research	Sample	Country	Destination of Knowledge Spillover	Findings
Shane [5]	Scientists' choice	Survey data	U.S.	Industry	Effective IPR protection induces greater knowledge spillovers to firms
Murray and Stern [1]	Scientists' choice	Patent-Paper pairs	U.S.	Science	Decreased level of knowledge spillover to subsequent research
Fabrizio [12]	Previously existing university patents	Patent data	U.S.	Industry	The greater the university patenting, the slower the industrial invention in the field where science serves as critical input for innovation
Penin [23]	Patenting by university researchers	Survey data	France	Industry	Facilitate the technology transfer from universities to industry Delayed publication of research
Giuri et al. [4]	Patents owned by universities	Patent data	Europe	Industry	Positive association between university patent ownership and knowledge spillover to industry through "licensing"
Callaert et al. [21]	Policy encouraging university patenting	Patent data	Belgium	Industry	University patenting increased No detrimental impact on the spillover the university research to industry
Ljungberg et al. [22]	Firm-owning academic patents	Patent data	Sweden	Industry	Technological spillover of university-owned patents are comparable to that of the firm-owning academic patents
Magerman et al. [17]	Patenting on scientific findings	Patent-paper pairs	–	Science	No negative impact of patenting on scientific knowledge spillovers Greater academic reputation of scientists involving in patenting activities
Sampat and Williams [6]	Scientists' choice	Patent data	U.S.	Science & Industry	Strong selection of patenting on technological/scientific impact of gene research for patenting No causal impact of gene patenting on spillovers to industry/science
Martínez and Sterzi [2]	Institutional change of abolishing professor privilege	Patent data	Europe	Industry	-Industry spillover academic patents owned by universities decreased -Industry spillover of academic patents owned by firms
Kwon et al. [25]	Policy encouraging university patenting	Patent + paper data	Japan	Science & Industry	No change in the scientific spillover Accelerated technological spillover
Caviggioli et al. [20]	University collaboration's impact on specialization	Patent	Europe	Industry	Accelerated technological specialization
Liu et al. [24]	University collaboration's impact on firm innovation	Patent	China	Industry	Accelerated technological spillover
Chávez-Bustamante et al. [32]	Openness of scientific publication	Patent + paper data	Chili	Science & Industry	Patenting hinders scientific openness, such as delay of publication, refusal to share research

patent rights. The study by Motohashi and Muramatsu (2010) was helpful in empirically examining how one channel of diffusing university knowledge to industry (i.e., university–industry collaboration) is possibly shaped by the institutional change that enabled and encouraged university patenting in Japan.

A more recent study by Kwon et al. [25] analyzed the case of the national university reform in Japan in 2004 and revealed that institutional changes encouraging universities to explore the commercial potential of their research outcomes, including enabling university patenting, did not have a negative impact on the research productivity of university scientists or scientific knowledge spillovers. By investigating how the institutional change encouraging the commercial use of university knowledge, including enabling university patent ownership in Asia, affects their scientists' research activities, it hints at how university patenting (more broadly strengthening academic entrepreneurship) shapes the scientific and technological endeavor of academic scientists.

Although Kwon et al. [25] partially answered the question of how such institutional change encouraging university patenting impacted the spillover of university "knowledge" to industry, the questions of how it shaped the spillover of university "inventions" to industry and whether university patent ownership of research outcome indeed spurs diffusion of university inventions to industry and in what mechanism are unanswered.

In the next section, we describe our empirical strategy to explore the answers to these questions by examining the relationship between institutionally enabled patenting of university research and knowledge spillover in Japan.

3. Research context: National university reforms in Japan

In April 2004, the national university reform transformed independent higher education entities into national university corporations, which had previously been part of the national government's administrative structure. The corporations were granted administrative autonomy, including fund allocation and personnel management. Each corporation was required to establish its own mid-term goals and plans for six years and manage itself according to its objectives, whereby institutional funding was allocated based on performance evaluations. In addition to education and research, universities were assigned a third mission of contributing to society by commercializing research outputs. Government funding was reduced by a certain percentage, and more budget was allocated to competitive funding projects to encourage research competition among universities [8,25].

Since the establishment of independent administrative agencies for each university in 2004, universities have claimed their own IPRs instead of being considered government entities; thus, national university corporations file applications and register for IPRs. The University Intellectual Property Office Creation Program was launched in 2003 to support the development of a strategic system for universities' creation, acquisition, management, and use of intellectual property (IP). This program provides grants to universities and public research institutes, including national universities. Furthermore, as the Japanese version of the Bayh–Dole Act was enacted in 1999, it allowed institutions that fund their research with government funds to attribute the resulting patents to themselves. There have been a growth in patents resulting from industry–academia collaborations due to measures to support such collaboration, starting with the TLO Act in 1998 [8].

In principle, patents filed by faculty members of national universities before the incorporation system in 2004 were attributed to the faculty member responsible for the invention under the "principle of individual attribution." Regarding inventions resulting from university–industry collaboration, patents were usually applied for solely by the company funding the research as compensation or by the academic inventor involved in the joint project. As an exception, the head of the university may act as the applicant if the research was funded by special government measures or conducted using special large-scale research equipment installed for research purposes by the government [26].

The number of patent applications from national university corporations has increased rapidly since 2004 due to universities' authorization of institutional ownership. The case studies of patent applications and their management at the University of Tsukuba, Hiroshima University, and Tohoku University [27] provide a detailed analysis of individual universities. The experiences of the three national universities in Japan indicate that a sharp increase in patent applications is driven by internal systems, such as creating an IP office, supported by the University Intellectual Property Headquarters Development Program Ministry funded by the government.

Despite the lack of patenting by national universities before this reform, these universities have been actively engaged in research collaborations with private firms [28]. The firms applied for patents from such activities because the national university was not an independent legal entity that could claim its patent rights. A university professor can jointly claim her rights with the collaborating firm as a joint patent application; however, such cases are rare [8].

4. Dataset

In this study, we use the inventor disambiguation results [29], that is, the identification of the same person across all Japan Patent Office (JPO) patents published until 2017 (IIP Patent Database, Goto and Motohashi, 2017), to construct researcher-level data on invention patents to investigate the impact of national university reform in 2004 on patent quality and its spillover effects. The affiliation of the inventor is estimated by comparing the inventor's address with that of the applicant(s) of the patent. For patents involving a university professor as the inventor but in which a firm is the applicant, the professor's affiliation cannot be identified. However, if the professor holds a patent after the university reform, she can be identified as a university inventor (via an address match). As these two patents belong to the same inventor, the former can be identified as a university–industry joint invention patent with a firm solo application. If the inventor's affiliate is not a national university, her affiliation can be identified based on the applicant information for each patent, regardless of the timing of the national university reform.

We identify "joint invention patent" as an academic patent involving a university professor in invention activities but owned solely by industry (mainly before national university incorporation). In contrast, "joint application patent" is when both the university and firm are identified as applicants [8]. Fig. 1 depicts the trend of both patents by type of university (national vs. nonnational), indicating that the joint invention patents for national universities were replaced by joint application patents after the incorporation of the national university system in 2004. Interestingly, joint invention patents can be found in nonnational universities as well since institutional ownership of patents was not strongly implemented at private or local government universities in the 1990s. However, the shift from joint inventions to joint applications occurred slowly for nonnational universities, in contrast to national universities where a more abrupt change was found, driven by the institutional reform in 2004.

Fig. 2 depicts the trend of university-related patents, including university-only patents. Here, we add both types of university–industry collaboration patents as an "industry–university joint patent." The data reveal a significant surge in the number of patents held by national universities since the implementation of institutional ownership in 2004. Other universities have also witnessed a gradual increase in patent numbers since 2000, influenced by policies promoting the commercialization of academic activities, such as the TLO Act of 1998 and the University Intellectual Property Headquarters Development Program in 2013. However, the upward trend for nonnational universities is comparatively smoother and less dramatic than that for national universities. Regarding industry–university joint patents, an upward trend is observed for national universities but not for other universities.

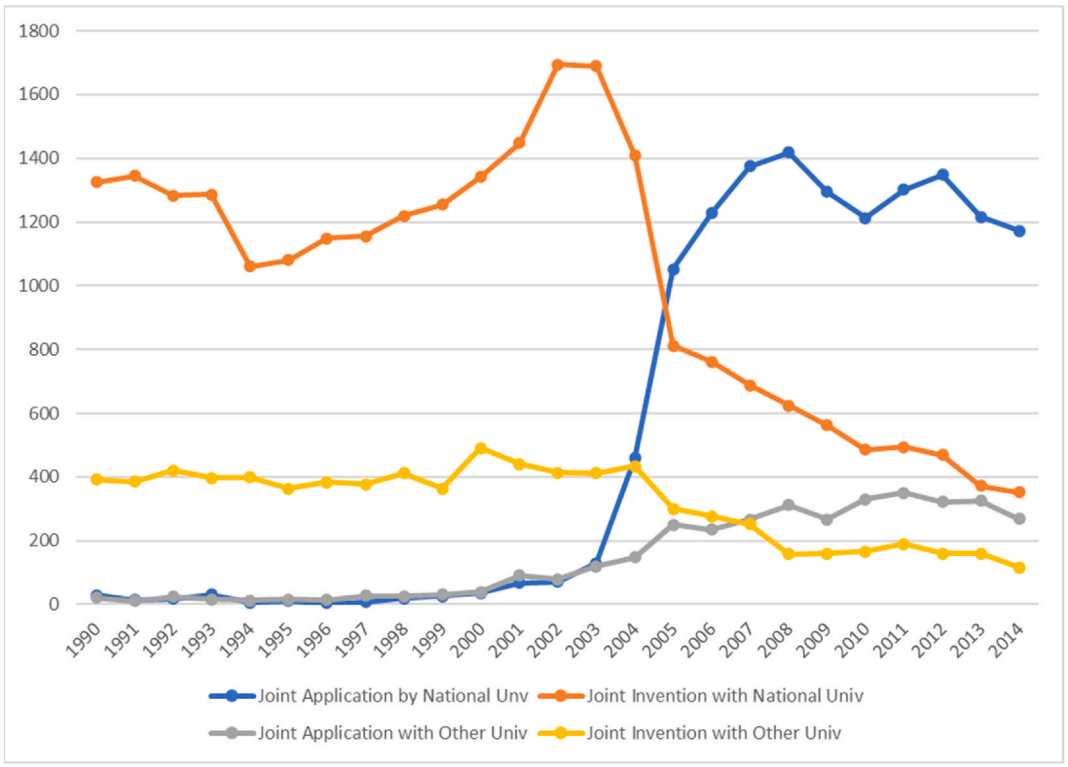

Fig. 1. Joint application vs joint invention patents.

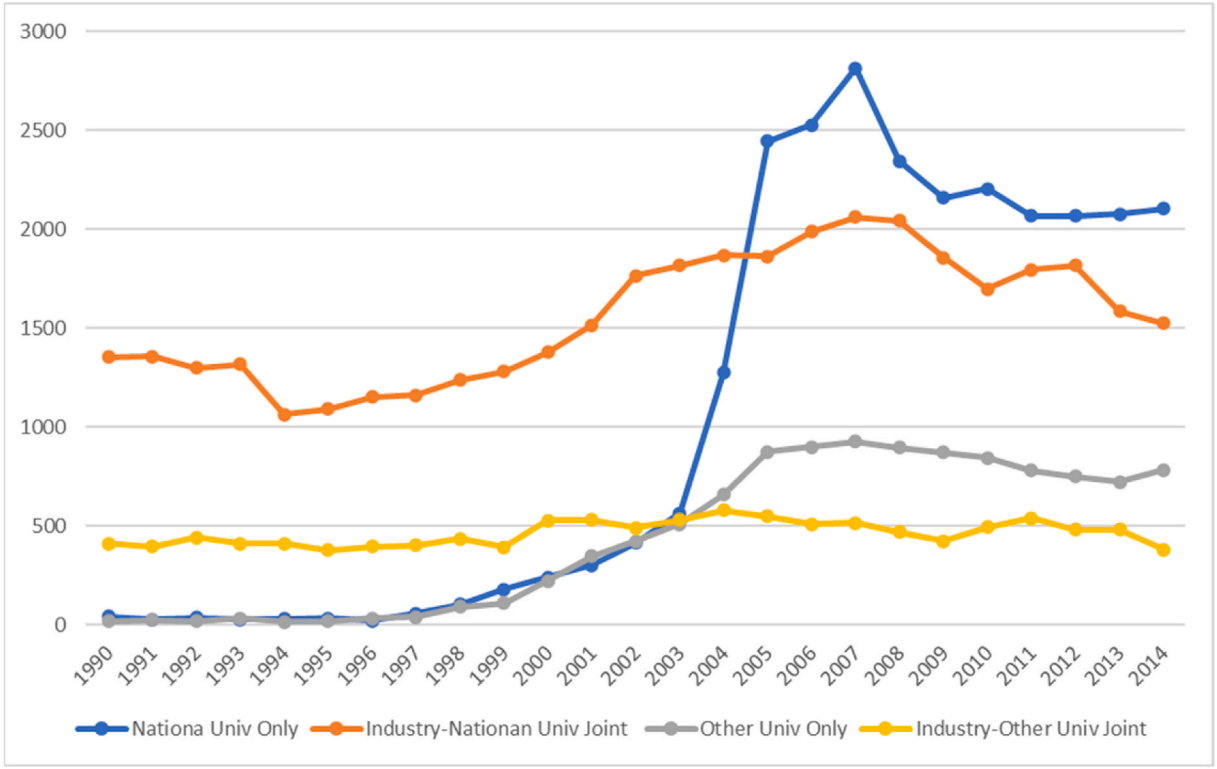

Fig. 2. Number of patent applications filed by national and other universities.

5. Empirical analysis and results

This section empirically analyzes the impact of incorporating national universities on the quantity and quality of patents using the university patent database, as described in the previous section. We use the difference-in-differences (DID) method to compare changes in the number of patent applications and citations between researchers at national and private universities before and after 2004.

Using the results of identifying patent inventors as described in the previous section, we construct panel data at the researcher level, patent counts by a researcher, and application year. We selected researchers with academic activities before and after 2004. Academic activities are measured by research paper publications based on linking the research paper author with the patent inventor for academic researchers [30]. Using research paper information, we identified researchers with no patent applications before and after 2004.

We used four-year windows around 2004, that is, before the incorporation of national universities (2000–2003) and after incorporation (2005–2008)[1]. In our empirical setting, it is essential to find university researchers whose affiliation information can be identified through patents or research papers. Thus, we only included researchers who met any of the following three criteria in the sample.

- Researchers with at least one patented invention within four years before and four years after incorporation
- Researchers with at least one patented invention within four years before incorporation and at least one published paper within four years after incorporation
- Researchers with at least one published paper within four years before incorporation and at least one patented invention within four years after incorporation.

Table 2 presents the transition matrix of the changes in patent application activities of the university researchers analyzed in this study during the four years before and after the incorporation of national universities. The analysis covers 9,965 researchers—7,355 and 2,610 affiliated with national and private universities, respectively. Approximately half of these researchers applied for patents after the national universities were incorporated. A total of 55.5 % of researchers who applied for patents after the incorporation of national universities were affiliated with national universities and 45.0 % were affiliated with private universities.

Table 2
The number of researchers by the status of patent inventions before and after national university incorporation.

All types		2005–2008				
		No patent	Univ only	Univ & Collab	Collab only	Total
2000–2003	No patent	0	4,177	813	264	5,254
	Univ only	1,008	649	191	110	1,958
	Univ & Collab	144	159	279	110	692
	Collab only	156	593	1,037	275	2,061
	Total	1,308	5,578	2,320	759	9,965
National Univ		2005–2008				
		No patent	Univ only	Univ & Collab	Collab only	Total
2000–2003	No patent	0	3,192	680	208	4,080
	Univ only	620	332	136	79	1,167
	Univ & Collab	106	85	198	77	466
	Collab only	109	460	864	209	1,642
	Total	835	4,069	1,878	573	7,355
Private Univ		2005–2008				
		No patent	Univ only	Univ & Collab	Collab only	Total
2000–2003	No patent	0	985	133	56	1,174
	Univ only	388	317	55	31	791
	Univ & Collab	38	74	81	33	226
	Collab only	47	133	173	66	419
	Total	473	1,509	442	186	2,610

Before the incorporation, when patent applicants in national universities were divided into solo university applications and applications from industry–academia collaborations, the ratio of researchers who only applied for industry–academia collaboration patents was the highest (22.3 %), followed by those who only applied for university-alone patents at (15.9 %). After incorporation, 55.3 % of the researchers were involved only in solo university patenting applications, whereas 25.5 % had experience in both solo university patenting and industry–academia applications. Therefore, the number of researchers who applied for solo university patents increased after incorporation, and the ratio of researchers who applied for patents through industry–academia collaborations decreased substantially by 7.8 %. Although this trend is more evident at national universities, it is also observed among private university researchers.

Next, using data at the researcher level, we analyze the effect of the incorporation of national universities on the quantity and quality of university patents. The model used for the estimation is as follows:

$$E[y_{it}] = \alpha_i + \beta \times after2004_t + \gamma \times national_i \times after2004_t + \sum_k \theta_k I(age_i = k) + \varepsilon_{it} \quad (1)$$

where the explained variable y_{it} is the number of patents or the aggregated number of citations accrued to patents filed by researcher i in period t and is assumed to follow a negative binominal distribution. In addition, the analysis covers two periods—2000–2003 and 2005–2008. $after2004_t$ is a dummy variable that takes the value of 1 if period t is after 2004 (i.e., after incorporation) and 0 otherwise. $national_i$ is a dummy variable that takes the value of 1 if researcher i belongs to a national university and 0 if the researcher belongs to a nonnational university. γ is a coefficient indicating the treatment effect of national university incorporation. Age dummies for each researcher's number of years, from the first publication/patent year to 2005, is added as explanatory variables. Finally, we control for individual researcher-level time-invariant heterogeneity by α_i so that there is no national dummy in our model. A researcher's quality regarding research activities at a university affects the patent quality and quantity. Here, we control for both time-invariant individual research quality (α) and the changes in her quality by her tenure in academia (age dummy).

In addition to the total number of patent applications, an analysis using the number of patent applications for each type of applicant is conducted as the explained variable y_{it}. In addition to the total number of times a patent is cited, an analysis of whether the patent is self-cited based on the applicant and inventor information of the patent from which it is cited is also conducted. Table 3 provides details on the variables used in the analysis. Self-citations by firms are based on applicant information, whereas self-citations by universities are defined based on inventor information.

Table 4 presents the results of the analysis on the impact of the incorporation of national universities on the number of patent applications. In each estimation formula, the coefficient (γ in Equation (1)) of the cross term between the dummy for national university affiliation (*national*) and the dummy for postincorporation (*after2004*) indicates the treatment effect of national university incorporation. The incorporation of national universities has a significant effect on increasing the overall number of patent applications (*npat_all*). Furthermore, incorporating national universities led to a significant increase in the number of patents related to industry–academia collaborations (*npat_ui*), industry–academia joint application patents among industry–academia collaborations (*npat_ui_univapp*), and the number of patents filed independently by universities (*npat_univonly*). In contrast, there was a significant negative effect on the number of patents applied for by companies alone (patents in which university researchers are involved as inventors but the university is not an applicant (*npat_ui_firmonly*))

Table 3
Variable definitions and descriptive statistics.

Varriable	Definition	N	Mean	SD	Min	Max
national	Dummy for national university	19,930	0.74	0.44	0.00	1.00
after2004	Dummy for years after 2004	19,930	0.50	0.50	0.00	1.00
npat_all	Number of patent applications	19,930	2.26	4.76	0.00	215.00
npat_ui	Number of university industry collaborative (UI) patents	19,930	1.07	3.90	0.00	215.00
npat_ui_univapp	Number of UI patents with university as an applicant	19,930	0.38	1.78	0.00	120.00
npat_ui_firmonlyapp	Number of UI patents with only firm as an applicant	19,930	0.70	3.33	0.00	213.00
npat_univonly	Number of patents by solo university application	19,930	1.18	2.15	0.00	55.00
ncited_all	Forward citation count	19,930	5.59	17.90	0.00	651.00
ncited_std	Normalized forward citation count by application year and IPC subclass	19,930	1.93	5.92	0.00	215.86
ncited_nonself_firm	Non self-citation counts, cited by firm	19,930	3.63	12.75	0.00	505.00
ncited_nonself_univ	Non self-citation counts, cited by university	19,930	1.09	2.95	0.00	107.00
ncited_self_firm	Self-citation counts, cited by firm	19,930	0.69	4.05	0.00	216.00
ncited_self_univ	Self-citation counts, cited by university	19,930	0.18	0.89	0.00	19.00

Table 4
Results of DID negative binomial distribution regression analysis of the effect of national university incorporation on the number of patent applications.

	[1]	[2]	[3]	[4]	[5]
	npat_all	npat_ui	npat_ui_univapp	npat_ui_firmonly	npat_univonly
after2004	0.125***	−0.396***	0.722***	−0.899***	0.860***
	[0.0412]	[0.0611]	[0.122]	[0.0790]	[0.0570]
national × after2004	0.457***	0.216***	1.758***	−0.283***	0.743***
	[0.0361]	[0.0571]	[0.120]	[0.0747]	[0.0473]
Age fixed effects	Yes	Yes	Yes	Yes	Yes
N	19,930	8,262	5,012	6,014	18,540
χ^2 test statistics	3190.2	353.8	1237.5	982.6	3662.3
p-value for χ^2 test	0.000	0.000	0.000	0.000	0.000

Robust standard errors in parentheses.
*p < 0.1, **p < 0.05, ***p < 0.01.

among patents resulting from industry–academia collaborations[2]. These results are consistent with the trend presented in Table 1, indicating that compared with researchers at private universities, researchers at national universities increased their number of patent applications around the time of the national universities' incorporation. Additionally, while patents applied for by universities themselves significantly increased, the number of industry–academia patents filed solely by companies decreased.

Table 5 presents the effect of incorporating national universities on the quality (number of citations) of patents. Here, by normalizing the raw numbers by dividing the average of citation counts by application year and IPC subclass, we use two types of citation counts—the raw numbers (*ncited_all*) and the standardized ones (*ncited_std*). As discussed earlier, because the incorporation of national universities has a positive effect on patent applications, the natural logarithm of the number of patent applications is added as an explanatory variable to control the effect of changes in the overall number of applications. The analysis results depict the effect on the average number of citations of patents filed by researchers.

For the heterogeneity of each researcher unit, we control the ratio of industry–academia collaboration patents for each researcher for the entire period (*npat_ui_shr*) and the point in time when researchers started their research (i.e., the year when they first applied for a patent or a paper (age-fixed effect)). The subjects of the analysis are researchers who applied for at least one patent in both periods.

In the results of the analysis using the total number of citations (*ncited_all*) as the explained variable, the coefficient of the cross term between the dummy for national university affiliation (*national*) and the

Table 5
Results of DID negative binomial distribution regression analysis of the effect of national university incorporation on patent quality.

	[1]	[2]	[3]	[4]	[5]	[6]
	ncited_all	ncited_std	ncited_nonself_firm	ncited_nonself_univ	ncited_self_firm	ncited_self_univ
ln_npat_all	0.900***	0.930***	0.889***	0.908***	1.011***	0.858***
	[0.0172]	[0.0195]	[0.0195]	[0.0306]	[0.0403]	[0.0717]
npat_ui_shr	−0.021	−0.0348	−0.0451	−0.249***	1.501***	−2.301***
	[0.0375]	[0.0425]	[0.0424]	[0.0665]	[0.105]	[0.189]
after2004	−0.524***	−0.625***	−0.557***	−0.574***	−0.179*	−0.554**
	[0.0461]	[0.0630]	[0.0530]	[0.0867]	[0.108]	[0.225]
national × after2004	0.0665*	0.0894**	0.0764*	0.113	0.0169	0.18
	[0.0398]	[0.0436]	[0.0457]	[0.0700]	[0.101]	[0.150]
Age fixed effects	Yes	Yes	Yes	Yes	Yes	Yes
N	6,500	6,500	6,104	4,810	3,274	1,508
χ^2 test statistics	3194.8	2896.1	2418.4	1376.8	710.2	237.2
p-value for χ^2 test	0.000	0.000	0.000	0.000	0.000	0.000

Robust standard errors in parentheses.
*p < 0.1, **p < 0.05, ***p < 0.01.

dummy for postincorporation of national universities (*after2004*) was positive and significant at the 10 % level. Additionally, there was a significant positive effect of national university incorporation at the 5 % level for the number of citations (*ncited_std*) and nonself-citations by universities (*ncited_nonself_univ*), standardized by IPC four digits and application year.

Models 3–6 set the explanatory variables as nonself-citation by firms (*ncited_nonself_firm*), nonself-citation by universities (*ncited_nonself_univ*), self-citation by firms (*ncited_self_firm*), and self-citation by universities (*ncited_self_univ*). The coefficients of the cross terms of the national university affiliation dummy (*national*) and the national university postincorporation dummy (*after2004*) are positive and significant only for the nonself-citation by firms in Model 3 but not significant for the others. Thus, according to the DID model of private universities, other than national universities as comparison groups, the qualitative increase in patents at national universities was due to their patents being cited by more companies.

Thus, the activation of IP activities at universities following the national university reform made university research activities more visible, particularly for firms that did not have a previous relationship with the university. Although a national university researcher disseminates her research through publications, patented technology, as a commercial research output, must attract more private firms' attention [31].

6. Conclusion

After national universities were incorporated in 2004, they could claim patent rights, resulting in a significant increase in the number of patents held by universities. This study examined the quantity and quality of university patents before and after incorporation. Prior to incorporation, most patents resulting from industry–academia collaborations were filed independently by companies and were not considered university patents. However, by examining the invention information, patents can be identified as industry–academia collaboration patents when faculty members are listed as inventors. Since 2004, the number of patents from national universities, including university-only patents and industry–academia joint application patents, has increased. However, there is insignificant change in the number of industry–academia collaboration patents when considering single-application patents from companies in which universities are involved.

Moreover, there were some patents in which the head of the university was the applicant, even before the incorporation of national universities. However, these patents were rare and resulted from government or other organizations' extensive research and development (R&D) projects. The significant increase in patents involving national universities after incorporation is mainly attributed to universities filing patents independently, which was made possible by changes to patent ownership regulations.

This study examined the impact of incorporation on university patents by comparing patents involving researchers from national universities before and after incorporation with those involving researchers from other types of universities during the same period. It was found that 55.5 % of national university researchers who had at least one patent from 2001 to 2008 had not applied for a patent before 2003, implying that they only began to participate in patenting activities after incorporation. Over 80 % of these researchers were only involved in patents filed solely by the university after incorporation, indicating that approximately 43.4 % of all researchers began to apply for university-alone patents for research results not involving industry–academia collaboration after incorporation.

However, the remaining 44.5 % of researchers at national universities involved in patenting before incorporation can be classified into three categories—only university applicant patents (15.9 %), only in industry–academia joint invention patents (22.3 %), and both (6.3 %). Most researchers solely involved in university-alone patent applications were not involved in industry–academia collaboration patents after incorporation. On the contrary, 75 % of researchers involved in patents related to industry–academia collaborations before incorporation continued to be involved in such collaborations after incorporation.

Furthermore, we estimated a DID model to quantitatively analyze the changes in the quantity and quality of patents before and after the reform, using the patenting activities of private universities and other institutions that were not affected by the national university reform authorizing patent ownership as a control sample. The results revealed that after the reform, national university patents increased in quantity and quality, as measured by the number of patent applications and citations.

It was also found that the quality improvement was caused mainly by an increase in the number of citations from the private sector. Thus, the increase in the number of university patents due to national university reforms may have increased research benefits for society. This implies that university ownership of IP may facilitate the diffusion of university knowledge to industry—one of the primary objectives of science policy across countries (especially for the tech transfer community). We argue that this finding is due to the following reasons.

The first relates to the nature of the patent system in its role of encouraging follow-on inventions. Documenting/disclosing the detailed technical information of existing inventions helps inventors learn about existing inventions and build their inventions on them. This mechanism can work well for firms that seek commercially valuable university knowledge to support their R&D. Before the reform, most national university researchers did not patent their research outcomes even if they had strong commercial potential. In contrast, after the reform, national universities were authorized to engage in standalone patenting and researchers were encouraged to file patents (as it was one of the criteria for researcher performance evaluation). Thus, national universities' research outcomes with commercial potential are revealed to the world via patenting, and firms could be better informed by searching for university knowledge with commercial potential. This can increase firms' patent citations of university patents.

Second, the reform could have induced national university researchers to engage more in research with academic and commercial potential as university and researcher patenting became part of the performance criteria after the reform [25]. This change could generate more academic research with commercial potential than that before the reform, which naturally draws firms' attention to academic research for its R&D relevance.

In either case, we argue that the reform contributed to improve the diffusion of university knowledge to industry—a science policy objective in many countries. The impact of institutional ownership of university patents and technology transfer through TLO activities varies by national innovation systems, and the level of activity in European countries is less positive than in the US [7]. Unlike in the US, Japan's innovation system is more similar to that of European countries, where national and other public universities have a greater influence. However, industry–academia collaboration policies, mainly through the reform of national university corporations, have produced some positive results. Compared with Sweden, where patents cannot be attributed to universities [13], and Italy, where changes in the system are more frequent, Japan's major institutional reform, which makes national universities continue to be the core of its innovation system, is the backdrop of its innovation system.

Our findings only implicate the policy impact over a short period. For the four-year window, the reform might have been close to an external shock, but from a long-term perspective, universities and firms could have considered the reform and reflected it in their patenting decisions and invention activities. After 20 years of national universities' incorporation in 2004, the reform of the national university system is still an important policy agenda, in which a series of changes have been introduced. For example, an evaluation system to consider the heterogeneity of each university was introduced in 2016. All national universities are

categorized into three types: Type 1: local leading university; Type 2: specialized university, such as medical schools; and Type 3: national-level leading universities. This opens new research opportunities by examining the different impacts of university patents according to university objectives.

In addition, although our analysis implied that university patents increasingly served as inputs for firms' invention activities after the reform, whether and to what extent the reform encouraged firms to invest more in (formally) incorporating university knowledge into their R&D processes remains unclear. An analysis of the changes in the portion of university research in the composition of knowledge sources for Japanese firms' R&D after the reform with firm-level survey data can help answer this question. By complementing the research on behavioral changes on the firm side with our analysis of university patents, it is possible to examine the structural impact of the national university reforms of Japan on its national innovation system.

CRediT authorship contribution statement

Kazuyuki Motohashi: Writing – review & editing, Supervision, Methodology, Funding acquisition, Formal analysis, Data curation, Conceptualization. **Kenta Ikeuchi:** Writing – original draft, Methodology, Data curation, Conceptualization. **Seokbeom Kwon:** Writing – review & editing, Methodology, Conceptualization.

Data availability

Data will be made available on request.

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