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# Chasing Two Hares at Once? Effect of Joint Institutional Change for Promoting Commercial Use of University Knowledge and Scientific Research*

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Abstract

Stimulating the university's scientific research while encouraging the commercial use of the resulting knowledge is one of the foremost missions of science policymakers. The present research examines the short-term impact of joint institutional changes for facilitating the commercial use of university knowledge and stimulating scientific research activities through the introduction of a research performance evaluation system on university scientists' research outcomes. Our empirical analysis is based on Japan's national university reform in 2004, which introduced institutional measures to support the income-generating activities of academic staff while implementing a regular evaluation of their performance. Our analysis of over 5000 scientists in Japan's national and private universities finds that this joint institutional change increased the research productivity of national university scientists without significant change in research quality. Also, we find evidence showing that the reform encouraged more of them to engage in research that serves as a knowledge input for developing technological applications. These short-term effects are specific to the scientists who were in the Life Science domain and those who were inactive in developing technical applications before the reform. Contributions to the literature on how an institutional change to encourage commercial use of university knowledge affects science and implications for science policy are discussed.

Keywords: University corporatization; University policy; Pasteur Quadrant; Commercialization
JEL classification: D02, I23, O34, O38



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## 1. Introduction

Although universities play a pivotal role in technological innovation by serving a locus of basic science and knowledge spillover (Nelson, 1993), university knowledge is often difficult to be utilized for its embryonic stage of development (Jensen and Thursby, 2001; Thursby and Thursby, 2003). The underutilization of university knowledge is a salient public policy issue because universities' research is often supported by the public research funds for its positive externality to innovation and economic growth (Jaffe, 1989; Youtie and Shapira, 2008).

To foster the use of university knowledge, a range of public policy measures has been attempted. The Bayh-dole act in the U.S. and similar laws in other countries are an example. The provision of tax exemptions or subsidies to firms that collaborate with universities for R&D (Szücs, 2018; Veugelers and Cassiman, 2005) is another example. Yet, these efforts were accompanied by a long-standing controversy over their consequence in science.

Most of all, encouraging commercial use of university knowledge may induce university scientists to allocate fewer resources for fundamental research while increasing their efforts toward applied research (Henderson et al., 1998). Such resource diversion may result in decreased fundamental research activities by leading university scientists to pursue the research that can bring more economic profits (see, Lach and Schankerman, 2008) while undermining their efforts to basic science (Cohen et al., 1998; Partha and David, 1994).

Also, emphasis on generating profit from university knowledge may weaken the scientific reward system that has been a key driver for scientists to disclose and disseminate their knowledge (Rhoten and Powell, 2007) in exchange for peer's recognition of the contribution to the science (Merton, 1973; Partha and David, 1994).

This concern has drawn a large volume of empirical studies on how institutional change for encouraging commercial use of university knowledge shapes university research, or more broadly, science for the recent decades. Yet, the conclusion remains somewhat indefinite.

Some researchers find evidence showing that pursuing commercial use of university knowledge does not necessarily impede (Mowery et al., 2004; Nelson, 2001) but can be compatible with (Shibayama, 2012) or even complementary to stimulating fundamental research (among others, Agrawal and Henderson, 2002; Azoulay et al., 2009; Fabrizio and Di Minin, 2008; Goldfarb et al., 2009; Van Looy et al., 2006). Azoulay et al. (2009) explained that such compatibility/complementarity presents because commercial technology development could be a "byproduct" of scientific research while the collaborative research between academic and industrial scientists for technology development can inspire the academic scientist's fundamental research later. In contrast, others found that the institutional change diverted university scientists' efforts from diffusing their knowledge or deter them from engaging in basic research, which slows down the cumulative process of science (e.g., Agrawal and Henderson, 2002; Murray and Stern, 2007).

The presence of the mixed empirical findings is perhaps due to the complementarity and substitutability between pursuing commercial use of university knowledge and provision of incentive for fundamental research coexist. To this complication, how to mitigate the probable substitution effect is an important policy inquiry.

Several organizational measures to incentivize scientists' engagement in scientific research activities and disclosing/diffusing their scientific findings can be considered. For instance, formalizing evaluation of individual scientists' performance using their research outcomes (e.g., number of publications, research impact, etc.) can enhance the universities' research strategy (Hicks, 2009) while stimulating individual scientist's research activities. Yet, because the performance-based evaluation may induce the scientist's strategic behavior (e.g., gaming the metric) in resource allocation for research (Frost and Brockmann, 2014; Geuna and Martin, 2003; Smith, 1993; Yamamoto, 2004), whether and to what extent such institutional device functions as a complementary measure to the policy for encouraging commercial use of university knowledge remains as an empirical question.

Exploring the answer is not obvious because most of the relevant institutional changes were mainly for encouraging commercial use of university knowledge with no explicit consideration of the countermeasure to mitigate the induced dissuasion of scientists from basic research. Even if the policymakers recognize its importance and usefulness, placing it into practice is subject to another challenge in reality due to the complications in university governance (Goldfarb and Henrekson, 2003) or conflicts among the stakeholders of the university policy (Argyres and Liebeskind, 1998).

Existing studies offer partial clues by focusing on analyzing the case of the U.S. where the government's role in university governance is relatively weak or continental Europe where higher education systems have been traditionally governed by governmental authority. Accordingly, the question of how the institutional change toward encouraging commercial use of university knowledge and the introduction of the performance evaluation system at individual universities, which needs the joint initiatives of the government and individual universities, have been remained largely unaddressed. This gap is particularly acute to stakeholders of university research in some countries where transformed (or will transform) the university governance system (e.g., Japan, South Korea) based on such joint initiatives.

The present study takes a step toward bridging this gap by addressing the above-briefed challenges to examine ***how if at all, a joint institutional change for facilitating commercial use of university knowledge and the introduction of university policy for stimulating scientific research affect the university scientists' research outcomes***.

Our empirical analysis is based on Japan's university reform in 2004. By this reform, the status of national universities of Japan changed from governmental organizations to corporate entities. The goal of this change was to enhance the efficiency of national universities' operations by conferring more autonomy and flexibility in the management (Kang and Motohashi, 2020; Motohashi and Muramatsu, 2012; Oba, 2007; Yamamoto, 2004). As it transformed the legal status of the national universities to corporate entities, the reform was accompanied by various organizational changes for encouraging income-generating activities of academic staff, which placed substantial emphasis on the commercial use of the university knowledge. At the same time, this reform enabled the national universities of Japan to regularly evaluate individual scientists' performance, which was expected to encourage their scientific research activities.

The case of the policy change in Japan in 2004 is also useful for formulating a research design for a causal analysis because the reform was close to an exogenous event to the individual university scientists. There were long-standing politics and debate across stakeholders in the national university reform along with repeated setbacks and the advance of the discussion as the dominant political party changed (Christensen, 2011; Yamamoto, 2004). Accordingly, the timing of the reform was difficult to be expected by individual university scientists beforehand, which mitigates the concern of the typical endogeneity issue in making causal inferences on the impact of the reform.

Our data consists of over 5000 scientists in Japan's national or private universities, who were active in research from 2000 to 2008. Given that the reform was specific to the national universities and the institutional change was an exogenous event to the individual scientists, we consider the scientists in national universities as the treatment group and the counterpart in the private universities as the comparison group.

Our panel difference-in-difference (DiD) analysis finds that, for a short period, the reform positively influenced university scientist's research productivity with no significant change in the research impact. Also, after the reform, more national university scientists engaged in research that serves knowledge inputs for developing technological applications than private university scientists did. Further analysis revealed that the observed findings were particular to the scientists in the Life Science domain. It was also shown that the impact was specific to those who were not active in developing technical applications based on their knowledge before the reform. These findings suggest that the impact of such institutional changes unlikely to be even across the science domain and may depend on the individual's prior interests in the commercial use of their knowledge.

The contribution of our study is twofold. First, we extend the strain of literature on how institutional change toward facilitating the commercial use of university knowledge affects science. Our study expands the scope of the previous discussion to the science-policy options that may be worthy of consideration as a supplementary measure when commercial use of university knowledge is institutionalized.

Second, in addition to revealing individual scientist's strategic tradeoff between the volume and quality of research in responding to the institutional change, we provide more nuanced policy implications by showing that the impact of such institutional change may differ by various factors including research domain and scientist's prior interest in the commercial use of scientific knowledge.

The remainder of this paper is structured as follows. In section 2, we provide background information about the national university reform in Japan. Then, we review empirical studies on how the institutionally encouraged commercial use of university knowledge shapes the scientist's research activities and the scholarly works on the performance evaluation of individual university researchers and its probable consequences in their behaviors. Section 3 illustrates our empirical research design, and section 4 presents the data. In section 5, we illustrate the econometric model for the analysis of the data. Section 6 reports the analysis results and section 7 discusses the implications of the findings with concluding remarks.

## 2. Background

### 2.1. National University Reform of Japan in 2004

Following the New Public Management (NPM) movement (Christensen, 2011), the Japanese government enacted a law that changes the status of national universities of Japan from governmental organizations to corporate entities in April 2004. The primary purpose of this reform was to promote inter-university competition by relaxing the governmental restriction on the operation of national universities. Toward this end, the change expanded the autonomy and flexibility in the management of national university operations. The change of national universities' status to the "corporate" entities was accompanied by various measures for economizing their operating cost and promoting the income-generating activities of the academic staff in the national universities.

For instance, by steadily reducing the central government's institutional fund, scientists in the national universities were encouraged to seek external research funds including funding from private sectors or competitive funding (Kneller, 2003; Shibayama, 2011; Watanabe, 2011), which later influenced on invention and research activities of the university scientists (e.g., Kang and Motohashi, 2020; Wang et al., 2018). As a result, the number and size of university-industry joint research projects dramatically increased.

Also, the governmental restriction on national universities' patent ownership and their enforcement were substantially relaxed (Motohashi and Muramatsu, 2012). Before the reform, national universities could own patents for some exceptional cases (Shimoda, 2004). By the reform, national universities became free to own patents, and as a result, there was a four-fold increase in the number of patent applications filed by the national universities after four years from the reform (Motohashi and Muramatsu, 2012).

Along with this change, the operations of Technology Licensing Offices (TLOs) of the national universities were reinforced to support the university scientists' income-generating activities (Oba, 2007; Woolgar, 2007).

Another notable organizational change was the introduction of the regular performance review of academic staff. To enhance the efficiency in human resource management, some national universities began evaluating the performance of faculties, researchers, and administrative staff. With this change, the national universities could equip with a system to design their internal policy for managing the human resource more flexibly. Some national universities used the evaluation result to relocate faculty positions within the institute. Although there are some variations across the universities, by and large, the number of research papers published, external funding acquisitions, contribution to society through such as collaboration with industry, etc. have been incorporated as the criteria for the performance evaluation.

These changes by the national university reform of Japan were expected to enhance the operational efficiency of the national universities while fostering the research activities of university scientists as we as the commercial use of the research outcomes.

### 2.2. Commercialization of University Knowledge and Its Consequence in Science

This section provides an overview of the prior studies on the association between university scientists' activities for seeking the commercial value of research and their research activities. A large volume of studies focused on investigating the relationship between the patenting activities of university scientists and the scientists' research outcomes, considering academic patenting as a proxy for the interest of university scientists in the commercial use of their knowledge.

Henderson et al. (1998) examined the probable consequence of the increased patenting activities of US universities after the Bayh-dole act in 1980 in the average technical importance of university patents. Their analysis showed that before the mid-1980s (around the Bayh-dole act), the US university patents were more cited and cited by subsequent patents in a wide range of technology domains than random-sampled patents. Yet, this finding disappeared in the later period. Based on the findings, the authors argued that in contrast to the expectation, the Bayh-dole act in the U.S. was not effective in driving university scientists to develop commercially valuable inventions, which may suggest that promoting academic patenting may not be effective to shift the academic scientists' interest toward commercial inventions.

Nelson (2001) and Mowery et al. (2004) extend this conclusion by shedding light on the effect of the Bayh dole act on the research activities of the university scientists. Their studies using the case of the University of California, Stanford University, and Columbia University showed no evidence on which the Bayh-dole act diverted university scientists from basic research. Although there was a surge in patenting and licensing of universities after the Bayh-dole act, these were mainly caused by prior time trends rather than the consequence of the act.

Agrawal and Henderson (2002) more directly examined the relationship between university scientists' patenting activities and their research performance. Through quantitative and qualitative analysis on the patenting activities of faculty of the department of mechanical engineering at the Massachusetts Institute of Technology (MIT), the study showed that only a minor portion of the faculty patented on their research outcomes. More interestingly, the analysis found no systematic correlation between the MIT faculty's patenting activities and the number of publications, but it was positively associated with the citation impact of the research papers. These findings suggest that university scientists' patenting activities may not divert their endeavors from fundamental research.

Fabrizio and Di Minin (2008) advanced this conclusion with empirical evidence showing that the university faculty's patenting is complementary to their research publication activities. By using inventor name information in the NBER patent dataset in conjunction with a manual web search of inventor's personal information (e.g., affiliation), they analyzed the correlation between faculty's patenting and two measures of their research activities- number of published research papers and the citation rate of the papers. Their analysis revealed that faculties published more research papers after they file patents. Yet, the citation rates of the research papers were not either significantly, or negatively correlated with the number of patents the faculty filed. These findings agree on the conclusion that academic patenting activities are not substituting for fundamental research activities.

The study by Azoulay et al. (2009) extends this conclusion. Their analysis using the data on Ph.D. degree recipients in biomedical fields found that the scientists' patenting activities are positively associated with their research productivity and the citation rate (moderately). More interestingly, the analysis revealed a positive relationship between the extent to which a scientist's research paper contains patentable ideas and the scientist's patenting activity. From the findings, it was concluded that academic patenting is a complementary activity to basic research, and it shifts the research of academic scientists to the area of commercial interest.

Through an Event History Analysis on the patenting activities of material science researchers in universities or public research organizations of Italy, Calderini et al. (2007) showed that academic scientists' hazard to file patents increased with the number of publications and their citations rates on average. Their additional analyses revealed that the relations take inverted U-shapes, indicating that the association between scientist's commercial interest in their research and scientific research activities may not be in linear relationships.

Besides, some studies focused on the impact of academic patenting on the dissemination of university knowledge. In theory, scholars argued that academic patenting hampers university knowledge dissemination by inducing the so-called tragedy of anticommons (Argyres and Liebeskind, 1998; David, 2004; Henderson et al., 1998; Nelson, 2004) because the patent protection restricts the access to the outcome of university research with an excessive cost for acquiring them, which could discourage innovation in return.

Subsequent studies empirically tested this concern. For example, Murray and Stern (2007) investigated whether patenting on scientific discoveries restricted the knowledge dissemination by analyzing the patent-paper pair data. By utilizing the time difference between the timing of research paper publication and patent grants, they estimated the change in the citation rate to the patent-paired research papers after the corresponding patent is granted. Their analysis showed that after a patent is granted, the citation rate to the corresponding research paper decreased by 10 to 20 percent, implying that the patenting on research hampers the scientific knowledge flow.

A study by Rosell and Agrawal (2009) attempted to shed empirical light on how the increasing patenting activities of universities associates with the narrowness of the dissemination of university knowledge. They estimated the diversity of entities whose inventions became the knowledge input for university inventions (inflow) and the breadth of the entities whose inventions were influenced by the university inventions (outflow) over time. Their analysis using the US universities' patents revealed that the inflow and outflow of the university knowledge measured by patent citations decreased over time.

They conclude that the knowledge dissemination by the university has narrowed down by the increased academic patenting.

Interestingly, Magerman et al. (2015) draw the opposite conclusion. Their analysis of patent-paper pairs in biotechnology showed that the citation rate of the publications having patent pairs was greater than those without the patent pairs. Their author-level analyses further showed that the H-indices of authors having publication-patent pairs were greater than their counterparts. These findings suggested that academic patenting may not hamper knowledge dissemination in the biotechnology domain.

### 2.3. Performance Evaluation and Its Impact on Scientists' Behavior

Evaluating the performance of academic staff in universities takes an important part in examining the socio-economic and scientific impact of university research while being an important ground for designing the university policy. By evaluating the university researcher's performance, stakeholders of university policy are informed about the public value that the university contributes, the research projects that need supports, and the ways that the impact of university research is delivered (Penfield et al., 2014). Yet, scholars in public administration and management suggest that the evaluation of scientists' performance may distort their incentive for research and, eventually, result in unintended consequences. According to Smith (1993) and follow-on studies (e.g., Bevan and Hood, 2006; Heinrich and Marschke, 2010; Van Thiel and Leeuw, 2002), the introduction of performance evaluation system into public organizations may lead the employees to concentrate on tasks that are directly related to the performance evaluation criteria, to purse the tasks for their narrow purpose instead of pursuing the organizational goal, while trying not to be an "outlier" from the evaluation perspective. As a result, the employees are disincentivized for bringing innovative ideas into the job place.

In the university context, a similar concern has been raised. In the U.K., it has been a widely perceived concern that university research performance evaluation leads the scientists to selectively engage in research projects of which the economic impact is visible and relatively easy to be credited in evaluated while dissuading them from the curiosity-driven research projects.[1] This concern led to a petition against legalizing the university performance evaluation in the U.K, later. Scholars in the science policy domain provide some supportive evidence by showing that the novel research projects are often recognized as

[1] See, Statement on the research excellence framework proposal by University and College Union (2011). Available at https://www.ucu.org.uk/media/3600/Statement-on-the-Research-Excellence-Framework-proposals/pdf/ucu_REFstatement_finalsignatures.pdf

"risky project" under the research performance evaluation criteria (Butler, 2003; Hicks, 2012) and, thus, biased against in funding decision (Boudreau et al., 2016; Wang et al., 2017).

Yamamoto (2004) argued that the introduction of the regular performance evaluation for academic staff in the national universities of Japan may dissuade the scientists from novel /innovative research projects that require a longer time to invest to concentrate on the research subject that they can publish (relatively) easily and quickly.

Alvesson and Sandberg (2013) made a somewhat similar argument by discussing why the impactful research in management studies decreases although there has been substantial growth in the volume of published research papers. They argued that the institutional condition that universities assess the performance of university researchers with their number of publications is one of the reasons. Under this evaluation criterion, the faculty and researchers are incentivized to invest their resources in maximizing the number of publications rather than investing their resources in conducting highly impactful research.

Frost and Brockmann (2014) provide qualitative evidence of this argument by interviewing German university faculty. Their study showed that the outcome-related performance indicator and evaluation of the faculty performance in German universities based on it led the faculty to behave strategically to meet the performance review criteria with less concern about the quality or impact of their research outcomes.

Geuna and Martin (2003) situate this concern in the research funding allocation practice. They argue that when the performance-evaluation result is linked to the allocation of research findings, it may "homogenize" the research and university activities by motivating the scientists to choose research projects that likely to safely receive the research funding. Also, it may drive the scientists to find "safe ground" in being evaluated for their performance, which will cause so-called "publication inflation" while discouraging their engagements in innovative/risky research projects.

As a relevant study, Tapinos et al. (2005) focused on the relationship between the introduction of the performance measurement system and the setting of organizational direction (i.e., organizational mission, strategic goal, etc.) in the university context. Their study based on the case of the University of Warwick in the U.K. reveals that the university performance measurement systems enabled the top managers in the University of Warwick to identify their strengths and weakness in achieving academic excellence. Also, the individual employees at the University of Warwick interpreted the university's direction based on the way that their performances are evaluated. This study suggests that the introduction of the performance review system for evaluating the academic staff in the universities may impact on setting the direction of the university and it, in return, influences on individual academic staffs' behavior by leading them to interpret the university's organizational setting.

In the next section, we describe our empirical research design to examine how joint institutional change for promoting commercial use of university knowledge and the research activities affect the university scientist's research activities.

## 3. Data

### 3.1. Sample

Our sample consists of scientists in national or private universities of Japan, who were active in publishing original research articles in SCIE journals from 2000 to 2008. Our empirical strategy is a short-term comparison of national and private university scientists in their research productivity, research quality, and whether the research outcome serves as a knowledge input for developing technological applications. Because the reform was specific to the national universities, we consider scientists in the national universities as the treated group whereas the scientists in the private universities as the comparison group.

### 3.2. Identifying the Researchers and Retrieving the Researcher-Level Information

By considering an original research article as a body of new scientific knowledge and its first author as the key scientist who contributed to the research, we start by selecting the first authors of the journal papers, who were affiliated to either national or private universities of Japan before the reform. Our sampling strategy is to choose the university scientists who continued scientific research while staying in the same university during the period between 2000 and 2008.

**Individuating Scientists in Japan:** One of the empirical challenges in conducting scientist-level analysis is to precisely identify the scientists and individuate their information. We address this challenge by using the JGlobal Data that is a registry of researchers in Japan. This data is provided by the Japan Science and Technology Agency, linking the Identifier of scientists in public research organizations or universities in Japan to their Clarivate's Web of Science (WoS) indexed SCI(E) journal papers. Although this registry is based on self-registration, the coverage is surprisingly high. Our crosscheck using the WoS authorship information indicates that about 80% of the first authors of SCI(E) journal papers published in Japanese universities appeared in the JGLOBAL data.

**Affiliation Data:** National Institute of Science and Technology Policy (NISTEP) of Japan provides data that links WoS-indexed journal papers to the authors' affiliation information when the affiliated organizations are in Japan. We identify the university scientists in Japan by using this data.

**Metadata of SCI(E) Journal Papers**: Next, from the WoS core collection database, we retrieve metadata of the SCI(E) journal papers that were published from 2000 to 2008 by the university scientists identified above.

**Non-patent literature Citation Data:** One of the variables that we employ in analysis measures whether a scientist of interest published research papers that were cited by patents. We obtain the paper-patent citation information from the Clarivate WoS patent citation information.

**Academic Inventor:** To identify the scientists who were involved in patenting as inventors, we used the WoS author name-patent inventor name matching data provided by Ikeuchi and Motohashi (2020).

We start with the scientist who published research papers as the first author in 2004. This is to narrowly identify the scientists who were in Japan's national or private universities around the reform timing. As a result, 9665 university scientists were identified. Among these, we select the scientists who have published research papers from 2000 through 2003 as well as from 2005 to 2008, without changing the affiliation. This strategy allows us to choose the active university scientists in research who stayed in the same universities from 2000 to 2008. Our data contains 5679 university scientists in total. Among them, 4529 (80%) scientists were in the national universities (treated group) and 1150 (20%) were private university scientists (comparison group).

## 4. Measures

### 4.1. Dependent Variables

We use three dependent variables. The first variable is the number of SCI(E) journal papers published by each scientist in the sample (***nPubs***). This variable is to measure the research productivity of the scientist.

The second dependent variable is the mean value of the paper-age-normalized citation counts that accrued to the research articles published by the scientist in question, considering the citation impact as a measure of the research quality. We take the natural log value of it with the addition of 1 (***ln(PerYrCite+1)***) to take into account the right-skewed distribution of this variable.

The third dependent variable is the measurement of the extent to which university scientist's research serves a knowledge input for developing technological applications. Patents are granted for technologically novel, non-obvious, and industrially useful inventions, while patent's citation to research paper can be considered as a paper trail of knowledge flow from scientific research to technical applications (Narin et al., 1997; Narin and Noma, 1985; Verbeek et al., 2002). Following this notion, we consider that scientific knowledge in a research article contributed to developing technological applications if the research article was cited by patents. To rule out an obvious mechanical relationship that is driven by the fact that scientists in national universities were encouraged to file patents after the reform and those patents cite the scientist's own research works (i.e., self-citation), we count the nonself-patent citations only. Our third dependent variable ***CiteFrmPat*** is a binary variable that takes the value 1 if the focal scientist published at least one research paper that was cited by patents, 0 for otherwise.

### 4.2. Independent Variables

In our analysis, we fit our data to the scientist-fixed effect (FE) panel DiD model. Toward this end, we first generate a binary variable that takes the value of 1 for the scientists in national universities of Japan, 0 for the private university scientists (***National***). Then, we create another binary variable that takes the value of 1 for the observation for the post-reform period (***Post04***). Last, we generate the interaction term between ***National*** and ***Post04*** (***NationalxPost04***). The regression coefficient of ***NationalxPost04*** is the DiD estimator that quantifies the causal impact of the reform.

### 4.3. Control Variables

Several control variables are employed in regression to rule out probable spurious relationships between the dependent and independent variables. First, we control for scientist's research network size. In Japan, the national university serves as the main venue for basic science (Kneller, 2003; Oba, 2007; Shibayama, 2011). Thus, it is plausible that scientists in national universities may have a broader research network than those in private universities. Meanwhile, the research network size relates to the scientist's research activities as explored by a myriad number of studies. To rule out the research network size effect, we introduce the number of coauthors of the focal scientist's research articles. Because this variable is mechanically dependent upon the number of papers that the focal researcher published, we use the "average number of coauthors" per paper (***AvgCouathors***).

Next, we control for scientist's cross-disciplinarity in research. In Japan, national universities are often established with diverse academic disciplinary whereas private universities specialize in certain academic fields in general. Accordingly, scientists in national universities may have greater opportunities to communicate and collaborate with researchers in various science disciplines. Given that combination of existing knowledge in a variety of fields in a novel way is one of the sources of scientific creativity (Uzzi et al., 2013) while the research collaboration across the disciplines grows over time, scientists in the national university might have engaged more in cross-disciplinary research than the scientists in private universities while it could drive the differential pattern in the dependent variables as time goes. To capture this compounding effect, we control for the cross-disciplinarity of scientists' research by using the number of associated research areas (WoS Subject categories) to each scientists' research papers (***BreadthRes***).

By the university reform, the governmental restriction on national universities' ownership over intellectual property rights such as patents was substantially relaxed. As a result, scientists in national universities are likely to increasingly appear as the inventor in patents. Indeed, our data show that after the reform 50% more national university scientists filed patents than before the reform. Meanwhile, scientists who involve in the patenting process are perhaps those who have a particular interest in developing technical applications using their research and this personal tendency could associate with the nature of the research the scientist's conduct. For instance, scientists who are active in patenting may have a strong self-motivation for commercializing the research outcomes than others. To take into account this, we introduce a binary variable that takes the value of 1 for scientists who filed patents as an inventor, and 0 otherwise (***InventorDummy***).

Studies found that scientists' career age is associated with their research activities. For instance, Zeng et al. (2019) showed the extent to which a scientist switches research topics increases with the career age at decreasing rate. It is also plausible that the higher the career age of a scientist, the more the established research environment and the higher the career status in general. As studies discussed, the status of university scientists (i.e., professorship) is likely to associate with the extent to which the scientist's research activity is influenced by external components such as funding source (Arora and Gambardella, 2005; Goldfarb, 2008; Wang et al., 2018). Meanwhile, because the mandatory retiree age is longer for academic staff in private universities than the national universities, the average academic age of researchers in private universities could higher than that for the scientists in national universities. This probable systematic difference may generate a heterogeneous distribution of the academic age of scientists in national and private universities. To rule out this probable compounding effect, we control for scientist's career age fixed effect (***Age FE***). In our data, the career age of a scientist in the pre-reform term is calculated as the year difference between 2004 and the earliest year of publication. For the post-reform period, the academic age is calculated into the year difference between 2008 and the earliest year of publication of the scientist.

We control for the extent to which the journals where a scientist published papers are related to the applied research fields. We measure this based on the journal commercial impact factor (JCIF) that quantifies the extent to which papers published in a journal are cited by patents. We create a binary variable ***JCIFDummy*** that takes the value of 1 if the journals where the scientist of interest published the research papers have positive JCIFs. We obtain this data from the recently disclosed data Marx and Fuegi (2019).

Last, ***CiteFrmPat*** is mechanically correlated with the number of research papers that a scientist published. To rule out the probable compounding effect driven by this mechanical relationship, we control for ***nPubs*** in addition to the other control variables in regressing ***CiteFrmPat***.

### 4.4. Descriptive Analysis

Table 1 presents the summary statistics of the key variables for the treated and comparison groups. The data shows notable changes in the average of ***nPubs*** and ***CiteFrmPat*** for national university scientists after the reform—the average of ***nPubs*** and ***CiteFrmPat*** increased for the national university scientists after 2004 more than those for the private university scientists. This observation suggests that the reform might have boosted national university scientists' research productivity and the extent to which their research outcomes serve knowledge input for technological application development.

[Insert Table 1 about here]

A comparison of the average change in ***AvgCouathors*** shows that, after the reform, the size of the research collaboration network increased more for national university scientists than for private university scientists. As expected, the mean of ***InventorDummy*** for national university scientists became larger than that for private university scientists after 2004.

Table 2 presents the pairwise correlation among the variables. The absolute values of all the correlations are below 0.5. No critical multi-collinearity issue is indicated.

[Insert Table 2 about here]

Figure 1 displays the top 10 science disciplines of the national and private university scientists. Scientist's discipline was operationalized into the most frequently appeared Web of Science Research Area (WoS RA) of research papers that the scientist published from 200 to 2004.

[Insert Figure 1 about here]

Chemistry is the most populated field both for national and private university scientists followed by Life Science. For a macro-level comparison, we aggregate the research areas into three groups based on the WoS categorization scheme[2]— Life Science & Biomedicine, Physical Science, and Technology. Figure 2 profiles the distribution. In national universities, Physical Science was the most populated field and Life Science follows. However, Life Science was the most prominent area among private university scientists and Physical Science follows.

[Insert Figure 2 about here]

Figure 3 visualizes the mean values of the three dependent variables from 2000 to 2008 for each group of university scientists. Figure 3-(a) presents that the average of ***nPubs*** of national university scientists is greater than that of the private university scientist before the reform. This difference appears to be widened after the reform.

[Insert Figure 3 about here]

Figure 3-(b) compares the mean values of ***ln(PerYrCite+1)*** between the two groups of scientists. In both pre- and post-reform periods, the mean value for national university scientists is greater than that for private university scientists. Whether the observed difference in the pre-reform period changes in the post-reform period is not evident.

Figure 3-(c) compares the mean of ***CiteFrmPat.*** The mean values of the national university scientists are seemingly overlapped with that of private university scientists in the pre-reform period. Yet, from 2005, the mean for national university scientists becomes greater than that for private university scientists and this difference persists.

#### 4.5. Regression Model

We fit our data to the two-term panel Difference-in-Difference (DiD) model. The variables are calculated by aggregating scientists' research articles published in 2000-2003 (pre-reform) and 2005-2008 (post-reform), respectively. We control for the scientist-fixed effect to eliminate the effect of scientist-level time-invariant characteristics. The following equation presents our main regression model.

$$Y_{i,t} = \beta_1 National_i \times Post04_{i,t} + \beta_2 Post04_{i,t} + \gamma_1 AvgCoauthors_{i,t} + \gamma_2 BreadthRes_{i,t} \\ + \gamma_3 InventorDummy_{i,t} + \gamma_4 AgeFE_{i,t} + \gamma_5 JCIFDummy_{i,t} + \gamma_6 nPubs_{i,t} + \tau_i + \epsilon_{i,t}$$

[2] Because the research papers published by the university scientists in our sample are limited to those published in SCI(E) journals, the research areas of scientists in our data do not include Social Sciences or Arts & Humanities. https://images.webofknowledge.com/images/help/WOS/hp_research_areas_easca.html

Where $\tau_i$ is the term for scientist-fixed effect and $\epsilon_{i,t}$ is an idiosyncratic error. We choose to fit our data to the conditional negative binomial model for regressing ***nPubs***. For ***ln(PerYrCite+1)*** and ***CiteFrmPat***, we use the OLS regression models. Note that $nPubs_{i,t}$ is introduced as a control variable only when regressing ***CiteFrmPat***. To take into account the heteroskedasticity, we use the robust standard.

## 5. Results

### 5.1. Difference-in-Difference Analysis

Table 3 presents the main regression results. The DiD regression results without control variables are reported in the first three columns. The estimation results with the full set of control variables are shown from the fourth to the sixth columns.

[Insert Table 3 about here]

The results indicate that scientists in the national universities of Japan published more research papers than comparable private university scientists after the reform. According to our estimation, a national university scientist published 1.14 more research papers than a comparable private university scientist. The coefficients of ***NationalxPost04*** are statistically insignificant at the 0.1 significance level for ***ln(PerYrCite+1)***. We found no evidence showing that the reform influenced the average research quality of national university scientists.[3]

Meanwhile, a national university scientist's research papers were more likely to be cited by patents than a comparable private university scientist after the reform. According to the estimation presented in the third and sixth columns, 3~4% more national university scientists' research papers were cited by patents than private university scientists, and this was statistically significant at the (at least) 0.1 significance level. We found modest evidence showing that the reform induced more national university scientists to engage in research that serves the knowledge input for developing technological applications.

### 5.2. Multi-Term DiD with Matching

The key assumption of DiD for causal inference is that the time trend of outcome variables for treated and comparison groups are parallel in the pre-treatment period. To ensure this assumption is not severely violated, we conduct an additional analysis using a matched sample of scientists in national and private universities of Japan. Our matching variables are all the three dependent variables and the control

[3] We also tested whether the maximum value of the paper age-normalized citation has changed after the reform for robustness check. Our analysis finds no evidence on the change in the citation impact.

variables that were measured pre-reform period (i.e., from 2000 to 2003). Our matching combines the exact matching for the binary variables and the nearest neighborhood matching for the continuous variables.

For each of the national university scientists, we search for private university scientists that have the same ***ResearchArea***, ***AcademicAge***, ***InventorDummy***, ***JCIFDummy***, and ***nPubs*** in 2004 as the national university scientist. Among the matched private university scientists, we select one who is the nearest neighborhood, calculated based on the Euclidean distance for ***BreadthRes***, ***AvgCouathors***, ***ln(PerYrCite+1)*** measured for the period between 2000 and 2003. This matching procedure reduced our sample size to 2966 (1483 scientists in national and private universities, for each). Because our matching criteria include all the covariates, we run regression without control variables. We fit our matched sample of university scientists to the multi-period DiD regression model as follows.

$$Y_{i,t} = \sum_{j=00}^{03} \beta_j \times YR_{j,i,t} \times National_{i,t} + \sum_{k=05}^{08} \theta_j \times YR_{j,i,t} \times National_{i,t} + \sum_{j=00}^{03} \gamma_j \times YR_{j,i,t}$$
$$+ \sum_{j=05}^{08} \eta_j \times YR_{j.i,t} + \tau_i + \epsilon_{i,t}$$

Where $\tau_i$ is the term for scientists fixed effect, $YR_{j.i,t}$ is a binary variable taking the value of 1 if the datapoint corresponds to observation is for year j, and $\epsilon_{i,t}$ is an idiosyncratic error. Table 4 reports the regression result using the matched scientist sample.

[Insert Table 4 about here]

The coefficients $\beta_j$ are, by and large, not far from 0. Especially, $\beta_{02}$ and $\beta_{03}$ (i.e., just before the reform) are statistically insignificant at the 0.1 significance level except for the ***CiteFromPat***. For the ***CiteFrmpat***, the coefficient of ***YR03xNational*** was significant at the 0.1 significance level.

In the first column, the coefficient of ***YR05xNational*** is positively significant at the 0.1 significance level and the coefficient of ***YR06xNational*** is positive and statistically significant at the 0.01 significance level. However, the coefficients of ***YR07xNational*** and ***YR08xNational*** are statistically insignificant at the 0.1 significance level. The short-term positive effect of the reform on research productivity is confirmed. In the second column, the coefficients of all the interaction terms from ***YR05xNational*** to ***YR08xNational*** are statistically insignificant at the 0.1 significance level. Consistent with our main regression analysis results, there is no evidence showing that the reform affected the average research quality of national university scientists. In the third column, the coefficients of ***YR05xNational*** and ***YR07xNational*** are positive and statistically significant at the 0.01 and 0.05 significance levels, respectively. Yet, the coefficient of ***YR08xNational*** is statistically insignificant at the 0.1 significance level. The short-lived positive effect of the reform on the extent to which research outcome serves knowledge input for technological application development is confirmed. All in all, our additional analysis yields consistent findings with the main regression analysis while additionally revealing that the observed impact of the reform was rather short-lived. We discuss the probable reason in the discussion section.

### 5.3. Selection by Scientist Mobility

We used the data that includes the university scientists who were active in publishing while staying in the same universities from 2000 to 2008. Yet, the use of this data could cause a sample selection for the differential mobility of scientists. By the national university reform, the status of scientists in the national universities changed to non-civil servants, which could lead some of the national university scientists to leave the universities. By triggered mobilization of national university scientists, our sample may retain the national university scientists who decided to stay in the same universities even after the reform whereas private university scientists were unlikely to be subject to this self-selection issue. To empirically check whether the scientist's mobility differs between the national and private universities after the reform, we conducted a simple exercise by using the samples of university scientists who were in the national or private universities of Japan before 2004. Then, we identify the scientists who changed their affiliations after 2004 by referring to author affiliation information in the research articles that were published after the reform.

Our data shows that about 6.1% of the national university scientists moved to different institutes after the reform, whereas 5.5% of private university scientists did so. The difference was 0.6% point. Our t-test indicates that this difference is statistically insignificant at the 0.1 significance level ($t=0.89$, the p-value: 0.37). There is no evidence of the differential mobility of scientists between the national and private universities.

### 5.4. Selection by Performance Evaluation

Our sampling strategy selected the scientists who published at least one research paper before as well as after the reform. A probable bias by this sampling strategy is that it could disproportionally exclude the national university scientists who were not "active" in research in the post-reform period compared to the private university scientists because the academic staff's performance evaluation was implemented in the national universities after the reform. To test if this selection bias was behind our findings, we examine whether a national university scientist less likely to be retained than a private university scientist when applying our sampling strategy. We start by identifying all the university scientists who published at least one research paper from 2000 to 2003. Then, we investigate how many of the national and private university scientists are excluded when we restrict our sample to those who also published research papers in the post-reform period.

Our test shows that 80.2% of private university scientists and 80.5% of the national university scientists remained in the data. The t-test result presents that the difference is virtually zero (p-value=0.79, t=-0.26), indicating no evidence of the selection bias.

## 5.5. Heterogeneous Effect

### 5.5.1. By Previous Experience in Patenting

Our main analysis found that the national university reform in Japan enhanced university scientists' productivity while stimulating them to engage in research that contributes to developing technological applications without deteriorating their research quality.

Which scientists were particularly influenced by the reform? Was the reform influential to scientists who were not previously active in utilizing their knowledge for technical application or effective to researchers who were active in developing technical applications before the reform, or both? We believe that exploring the answer to this question can draw more nuanced policy implications to understand "how" the joint institutional changes shape the university research overall. If the impact was specific to the scientists who were already active in developing technical applications, it implies that the scope of the policy impact was somewhat targeted for helping those who had an interest in the commercial use of their knowledge. In contrast, if the impact was specific to scientists who were inactive in developing technical applications beforehand, it indicates that the change induced spreading the culture of commercialization among university scientists.

Considering that an academic researcher's patenting is a revealed interest of the researcher in developing the technological applications, we operationalize a scientist's activeness in developing technological applications before the reform by employing the information of whether the scientist appeared in patent applications as an inventor from 2000 to 2003.

Then, we run separate regression for the group of scientists who were and were not appeared as inventors of patents before the reform, respectively. Table 5 and Table 6 present the regression results for each group of scientists.

[Insert Table 5 and Table 6 about here]

In Table 5, the coefficients of the ***Post04xNational*** are statistically insignificant at the 0.1 significance level. In contrast, in Table 6, the coefficients of ***Post04xNational*** are positive and statistically significant at the 0.01 significance level for ***nPubs*** and the 0.05 significance level for ***CiteFrmPat***. These findings imply that that the impact of the reform was specific to the national university scientists who were inactive in developing technological applications before the reform.

### 5.5.2. By Research Field

Because the extent to which scientific knowledge has a close interface with technical application differs by the domain of research, the impact of the university reform in Japan is likely to differ by the research field. In the meantime, the field-level difference may also associate with the degree and the way that individual scientists respond to the institutional environment change. For instance, in some fields, individual scientist's performance and reputation are evaluated based on their scientific research achievements (e.g., research paper publication, citations, etc.) while, in other fields, the impact of research realized through commercialization the knowledge, establishing startups, and the collaboration with the industrial partners, etc., could be also importantly considered. To elucidate the probable heterogeneity by the research domain, we conduct an additional analysis by dividing the scientists into three research domains – Life Science, Physical Science, and Technology. [4]In our data, 2175, 2599, and 905 scientists were in the Life Science, Physical Science, and Technology domain, respectively.

Table 7 to Table 9 report the regression results for the scientists in each of the three domains. In Table 7, the signs and statistical significances of the interaction terms ***NationalxPost04*** are consistent with the main regression results in Table 3. In Table 8, the coefficient of ***NationalxPost04*** is positive and statistically significant at the 0.1 significance level only for the ***nPubs***. The rest of the regression shows no statistically significant coefficients of the interaction terms at the 0.1 significance level. For the scientists in the Technology domain (Table 9), all the coefficients of the ***NationalxPost04*** are statistically insignificant at the 0.1 significance level.

[Insert Table 7, Table 8, and Table 9 about here]

Our separate regression analyses by the research domain find that the impact of the university reform in Japan was specific to the scientists in the Life Science domain.

[4] See section 4.4 for the details of field categorization and scientists grouping.

In sum, we showed that the joint institutional change for encouraging the commercial use of university knowledge as well as promoting the research activities of university scientists (1) stimulated their research productivity, and led more of them to (2) engage in research that serves knowledge inputs for technological application development. Yet, (3) These effects were specific to scientists who were inactive in developing technological applications before the reform and those who were in the Life Science domain.

## 6. Discussion and Conclusion

The present study examined how university research is shaped by the joint institutional changes for promoting the commercial use of university knowledge and scientific research by university scientists. Our empirical analysis was based on Japan's national university reform in 2004. The reform changed the status of national universities to corporate entities, and as a result, various institutional measures for supporting scientists' "income-generating activities" were implemented. Also, as a result of the reform, the national universities of Japan could devise a system for evaluating the academic staff's research performance.

To estimate the causal effect of this joint institutional change, we conducted a DiD analysis using the novel data on scientists in Japan's national and private universities. Our analysis found that the reform enhanced the research productivity of the national university scientists. This reform also induced more national university scientists to engage in the research that later served as a knowledge input for developing technical applications. Additional analysis revealed that the observed effects were specific to the scientists who were previously inactive in developing technological applications and those who were in the Life Science domain.

Our first two findings imply that encouraged commercial use of the university knowledge could improve their research productivity while helping them to pursue the research that has commercial value when an institutional device for promoting their research activities is supplemented.

Our analysis results also suggest that such institutional changes may direct university scientists to engage more in research that has a closer interface with technical application development. Given that this effect was particular to those who were inactive in developing technical applications before the reform, we argue that the reform has drawn more scientists to consider the commercial value of their research.

We also observed that the impact of the joint institutional changes was specific to the scientists in Life Science, which indicates the substantial field-level heterogeneity in the way and the extent to which individual scientists respond to such external environment change for their research activities. This finding is aligned with the prior studies that showed the complementary relationship between scientific research activity and effort toward commercial use of the resulting knowledge in the Life Science domain (Azoulay et al., 2009; Magerman et al., 2015). In the meantime, our findings suggest that the presence of the complementary relationship is unlikely to be omnipresent but depends on research fields, which calls for accounting for such field-level heterogeneity in further relevant policy and scholarly discussion.

The concept of Pasteur Quadrant (Stokes, 1997) is useful for reasoning our findings. Stokes (1997) explains that scientists can pursue the quest for a fundamental understanding of scientific principles while considering the potential “use” of the resulting research outcomes (i.e., Pasteur domain). Scientists in the Life Science domain are often positioned in this environment as they pursue fundamental scientific understanding while the research outcome is often turned into practical applications such as pharmaceutical products, medical devices, etc. (i.e., the duality of knowledge). To the scientists in this domain, the joint institutional change for promoting commercial use of their knowledge and for implementation of a performance evaluation system might have functioned to simulate their research activities while leading more of them to actively consider the commercial use of the research outcomes.

In our analysis, we could not find evidence of the changed quality/impact of research by the reform. This does not conclude the absence of reform’s effect on the average research quality/impact because our analysis was only for the short-term effect (i.e., for four years after the reform). Instead, this observation suggests that there is no empirical evidence supporting the concern that the reform could divert scientist’s effort for basic science and retrograde the quality of research as a consequence.

In our multi-term DID analysis presented in Table 4, we additionally found that the impact of the reform on national university researchers fades away as time goes. Although there could be many probable explanations, we argue that the emergence of the spill-over effect of the reform over time could be one of the reasons. As the national and private universities researchers likely to be interconnected in the research community (e.g., research collaboration), the impact of the reform to the national universities’ researchers could have diffused to the private university researchers as time goes and, hence, the observed differences between national and private universities in their research performance indicators after the reform have faded away.

The contribution of our study is twofold. First, our study expands the scope of the long-standing discussion about how institutional change to facilitate the commercial use of university knowledge affects science. The previous studies focused on empirical examination on whether promoting commercial use of university knowledge diverts scientists from engaging in fundamental research. In addition to these studies, our study empirically showed that a joint introduction of an institutional measure for incentivizing the university scientists' research activities may be worthy of consideration to mitigate the probable unintended consequence of promotion of the commercial use of university knowledge in science.

Second, our finding that the impact of the reform was specific to scientists who were previously inactive in developing technological applications provides a more nuanced university policy implication. Studies have found that the institutional environment where university scientists locate in shapes the scientists' commercial endeavors (Bercovitz and Feldman, 2008; Owen-Smith and Powell, 2001). Our study contributes to advancing this conclusion by empirically showing that national-wide university policy change for establishing a supportive institutional environment for the commercial endeavor of university scientists along with incentivizing their scientific research activities can stimulate "more" university scientists to consider the commercial potential of the university knowledge while not deteriorating their research activities.

The present study has limitations that we wish the future study to address. First, for the lack of data, we could not untangle the effect of the institutional change for promoting commercial use of university from the effect of institutionalizing the research performance evaluation. We believe that elucidating how each of the changes worked and to what extent they become complementary to one another is helpful to elaborate on the underlying dynamics.

Second, studies suggested that scientists' characteristics such as age, gender, socio-economic status, etc. are associated with their research outcomes (e.g., Bercovitz and Feldman, 2008; Wang et al., 2018). For the lack of data, our study could not explore what characteristics of individual scientists moderate the impact of the reform. Exploring the moderators can provide nuanced implications for designing a better university policy to promote science and the commercial use of its knowledge.

Third, the joint institutional change by the national university reform in Japan could influence the mobility of the researchers as we discussed in section 5.3 (i.e., change in entry and exit of the researchers.) Because researchers' mobilization is a channel for knowledge transfer (Criscuolo, 2005) and an important fact of inducing research collaboration (Kato and Ando, 2017), examining how the reform might have impacted the researchers' mobility and their performance (e.g., Payumo et al., 2018) could provide additional implications for a more comprehensive evaluation of the impact of the national university reform in Japan.

**FIGURES**

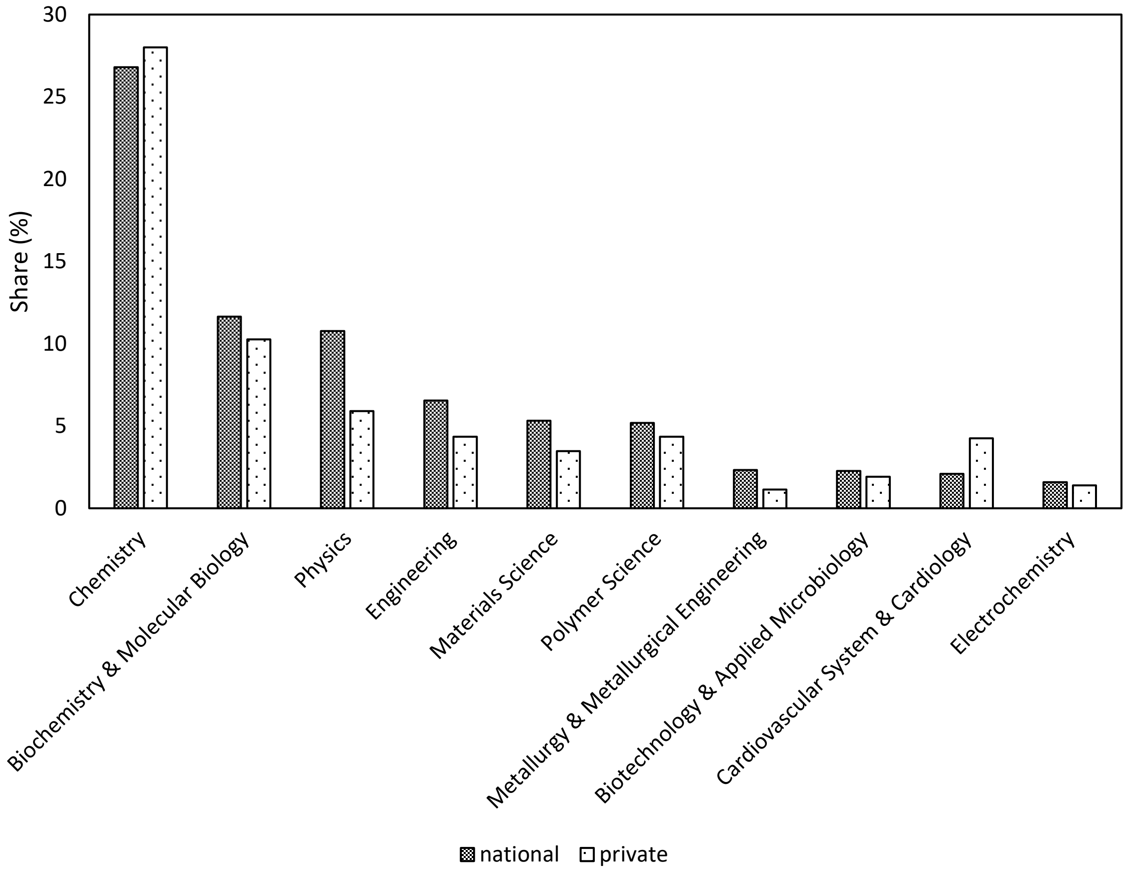



*Figure 1. Top10 Research Area*

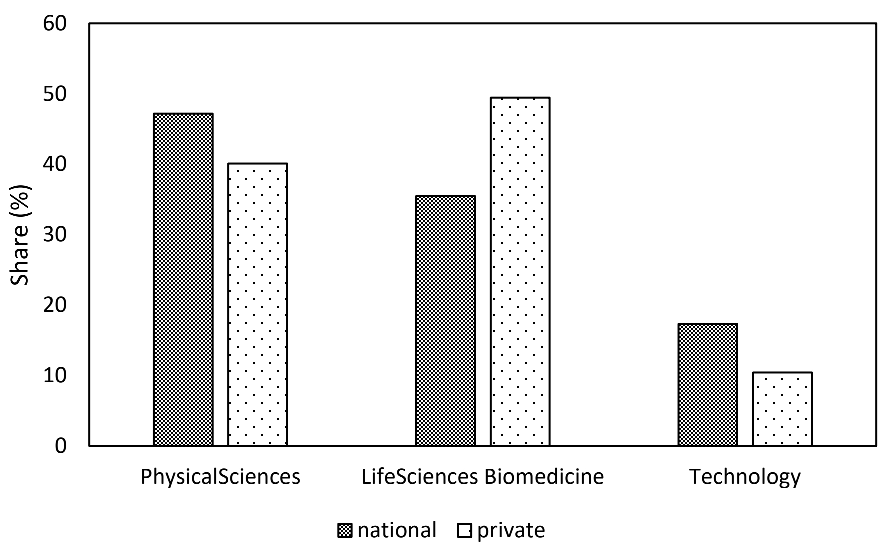
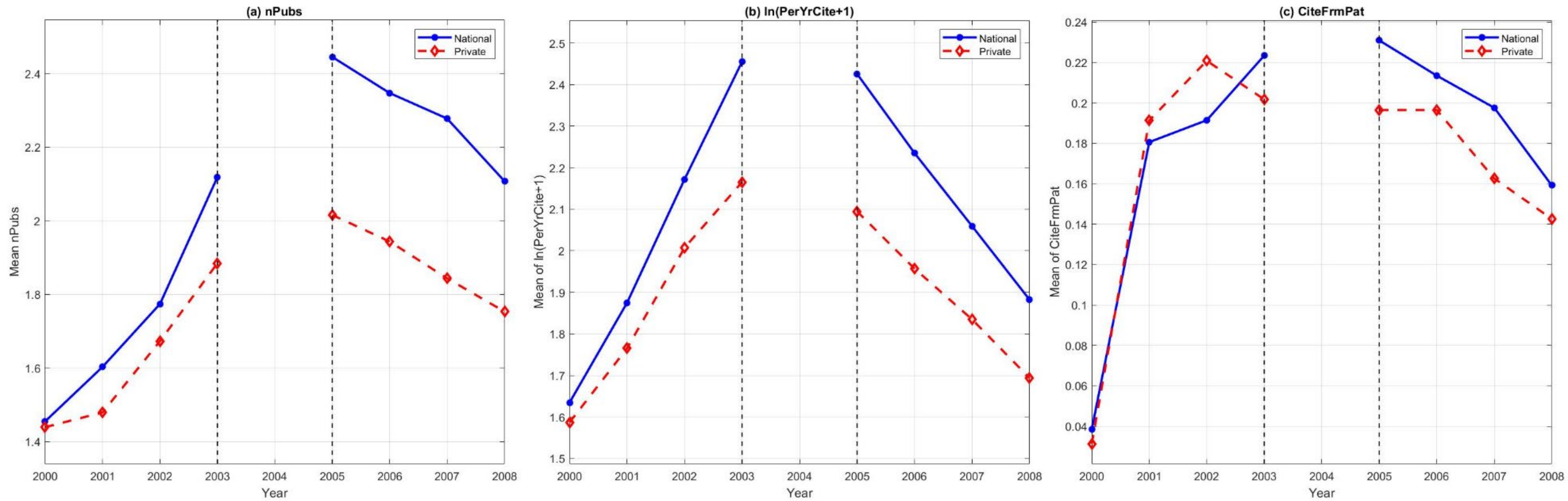



*Figure 2. Distribution of the Aggregated-Level Research Area*




*Note: (a): nPbus, (b):ln(PerYrCite+1), (c): CiteFrmPat, -- Policy Window*

*Figure 3. Time Trend of Means of Dependent Variables*

## TABLES

*Table 1. Summary Statistics*

| All (00-08) | National Univ Researchers (n=4529) | | | | | Private Univ Researchers (n=1150) | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| Variables | mean | s.d | min | max | Obs. | mean | s.d | min | max | Obs. |
| nPubs | 8.06 | 10.24 | 1 | 304 | 9058 | 7.02 | 8.18 | 1 | 116 | 2300 |
| ln(PerYrCite+1) | 1.05 | 0.58 | 0 | 4.26 | 9058 | 0.90 | 0.53 | 0 | 3.64 | 2300 |
| CiteFrmPat | 0.44 | 0.50 | 0 | 1 | 9058 | 0.42 | 0.49 | 0 | 1 | 2300 |
| AvgCoauthors | 3.02 | 2.18 | 0 | 45 | 9058 | 3.34 | 2.28 | 0 | 38 | 2300 |
| BreadthRes | 3.50 | 2.23 | 1 | 17 | 9058 | 3.27 | 2.12 | 1 | 14 | 2300 |
| InventorDummy | 0.20 | 0.40 | 0 | 1 | 9058 | 0.15 | 0.35 | 0 | 1 | 2300 |
| Age | 10.02 | 6.62 | 1 | 27 | 9058 | 10.94 | 6.97 | 1 | 27 | 2300 |
| JCIFDummy | 0.95 | 0.23 | 0 | 1 | 9058 | 0.96 | 0.19 | 0 | 1 | 2300 |

| Pre2004(00-03) | National Univ Researchers (n=4529) | | | | | Private Univ Researchers (n=1150) | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| Variables | mean | s.d | min | max | Obs. | mean | s.d | min | max | Obs. |
| nPubs | 6.95 | 9.30 | 1 | 304 | 4529 | 6.48 | 7.38 | 1 | 71 | 1150 |
| ln(PerYrCite+1) | 1.02 | 0.58 | 0 | 4.08 | 4529 | 0.86 | 0.51 | 0 | 3.58 | 1150 |
| CiteFrmPat | 0.42 | 0.49 | 0 | 1 | 4529 | 0.43 | 0.50 | 0 | 1 | 1150 |
| AvgCoauthors | 2.79 | 1.77 | 0 | 16 | 4529 | 3.03 | 1.69 | 0 | 9 | 1150 |
| BreadthRes | 3.41 | 2.08 | 1 | 15 | 4529 | 3.27 | 2.01 | 1 | 14 | 1150 |
| InventorDummy | 0.16 | 0.37 | 0 | 1 | 4529 | 0.14 | 0.35 | 0 | 1 | 1150 |
| Age | 8.02 | 6.31 | 1 | 23 | 4529 | 8.94 | 6.68 | 1 | 23 | 1150 |
| JCIFDummy | 0.94 | 0.25 | 0 | 1 | 4529 | 0.97 | 0.18 | 0 | 1 | 1150 |

| Post2004 (05-08) | National Univ Researchers (n=4529) | | | | | Private Univ Researchers (n=1150) | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| Variables | mean | s.d | min | max | Obs. | mean | s.d | min | max | Obs. |
| nPubs | 9.18 | 10.99 | 1 | 287 | 4529 | 7.56 | 8.88 | 1 | 116 | 1150 |
| ln(PerYrCite+1) | 1.09 | 0.58 | 0 | 4.26 | 4529 | 0.94 | 0.54 | 0 | 3.64 | 1150 |
| CiteFrmPat | 0.46 | 0.50 | 0 | 1 | 4529 | 0.42 | 0.49 | 0 | 1 | 1150 |
| AvgCoauthors | 3.25 | 2.50 | 0 | 45 | 4529 | 3.64 | 2.71 | 0 | 38 | 1150 |
| BreadthRes | 3.59 | 2.36 | 1 | 17 | 4529 | 3.27 | 2.22 | 1 | 14 | 1150 |
| InventorDummy | 0.24 | 0.42 | 0 | 1 | 4529 | 0.15 | 0.36 | 0 | 1 | 1150 |
| Age | 12.02 | 6.31 | 5 | 27 | 4529 | 12.94 | 6.68 | 5 | 27 | 1150 |
| JCIFDummy | 0.96 | 0.21 | 0 | 1 | 4529 | 0.96 | 0.19 | 0 | 1 | 1150 |

*Table 2. Correlation*

| | nPubs | ln(PerYrCite+1) | CiteFrmPat | AvgCoauthors* | BreadthRes | InventorDum | Age | JCIDum |
|---|---|---|---|---|---|---|---|---|
| nPubs | 1.00 | | | | | | | |
| ln(PerYrCite+1) | 0.13 | 1.00 | | | | | | |
| CiteFrmPat | 0.35 | 0.38 | 1.00 | | | | | |
| AvgCoauthors | -0.26 | 0.10 | -0.10 | 1.00 | | | | |
| BreadthRes | 0.44 | 0.17 | 0.32 | -0.08 | 1.00 | | | |
| InventorDummy | 0.19 | 0.05 | 0.14 | -0.09 | 0.17 | 1.00 | | |
| Age | 0.41 | -0.05 | 0.16 | -0.14 | 0.24 | 0.17 | 1.00 | |
| JCIFDummy | 0.12 | 0.16 | 0.19 | 0.00 | 0.15 | 0.05 | 0.08 | 1.00 |
| Mean | 7.85 | 1.02 | 0.44 | 3.09 | 3.45 | 0.19 | 10.20 | 0.95 |
| S.D | 9.87 | 0.57 | 0.50 | 2.20 | 2.21 | 0.39 | 6.70 | 0.22 |
| Min | 1 | 0 | 0 | 0 | 1 | 0 | 1 | 0 |
| Max | 304 | 4.26 | 1 | 45 | 17 | 1 | 27 | 1 |
| Obs. (Scientist) | 5679 | 5679 | 5679 | 5679 | 5679 | 5679 | 5679 | 5679 |
| Obs. (Panel) | 11358 | 11358 | 11358 | 11358 | 11358 | 11358 | 11358 | 11358 |

*The value is 0 for the scientists who published research articles only as a solo author in 2004.

*Table 3. Panel DiD Estimation*

| | (1) | (2) | (3) | (4) | (5) | (6) |
|---|---|---|---|---|---|---|
| VARIABLES | nPubs | ln(PerYrCite+1) | CiteFrmPat | nPubs | ln(PerYrCite+1) | CiteFrmPat |
| NationalxPost04 | **0.122*** ** | -0.0111 | **0.0392** ** | **0.0703*** ** | -0.0148 | **0.0365* ** |
| | **(0.0274)** | (0.0180) | **(0.0187)** | **(0.0232)** | (0.0180) | **(0.0187)** |
| Post04 | 0.135*** | 0.0777*** | -0.0342** | 0.395*** | 0.0761*** | -0.0376 |
| | (0.0247) | (0.0160) | (0.0168) | (0.0397) | (0.0206) | (0.0242) |
| BreadthRes | | | | 0.141*** | 0.0191*** | 0.0222*** |
| | | | | (0.00404) | (0.00384) | (0.00412) |
| InventorDummy | | | | 0.00651 | 0.0386* | 0.00408 |
| | | | | (0.0255) | (0.0220) | (0.0222) |
| AvgCoauthors | | | | -0.155*** | 0.0203*** | -0.00751** |
| | | | | (0.00611) | (0.00467) | (0.00322) |
| JCIFDummy | | | | 0.362*** | 0.191*** | 0.0605*** |
| | | | | (0.0467) | (0.0275) | (0.0191) |
| nPubs | | | 0.0180*** | | | 0.0146*** |
| | | | (0.00104) | | | (0.00111) |
| Constant | 1.653*** | 0.987*** | 0.295*** | 2.320*** | 0.690*** | 0.209*** |
| | (0.0355) | (0.00371) | (0.00798) | (0.155) | (0.0636) | (0.0680) |
| Observations | 11,358 | 11,358 | 11,358 | 11,358 | 11,358 | 11,358 |
| Number of Scientists | 5,679 | 5,679 | 5,679 | 5,679 | 5,679 | 5,679 |
| R-squared | | 0.015 | 0.059 | | 0.040 | 0.070 |
| Adjusted R-squared | | 0.0149 | 0.0585 | | 0.0378 | 0.0678 |
| Age FE | YES | YES | YES | YES | YES | YES |
| Scientist FE | YES | YES | YES | YES | YES | YES |
| Sample | All | All | All | All | All | All |
| Model | NBREG | OLS | OLS | NBREG | OLS | OLS |

Robust standard errors in parentheses (Standard error for the negative binomial regression)
*** p<0.01, ** p<0.05, * p<0.1

*Table 4. Multi-Term DiD Estimation using Matched Scientists Sample*

| VARIABLES | (1)<br>nPubs | (2)<br>ln(PerYrCite+1) | (3)<br>CiteFrmPat |
|---|---|---|---|
| YR00xNational | -0.220*** | -0.250*** | 0.00674 |
| | (0.0570) | (0.0695) | (0.0161) |
| YR01xNational | 0.0325 | -0.120* | -0.0189 |
| | (0.0547) | (0.0692) | (0.0173) |
| YR02xNational | -0.0200 | -0.0147 | -0.0290 |
| | (0.0487) | (0.0668) | (0.0177) |
| YR03xNational | -0.00163 | -0.0625 | -0.0310* |
| | (0.0443) | (0.0602) | (0.0182) |
| YR05xNational | **0.0733*** | 0.0499 | **0.0499***** |
| | **(0.0432)** | (0.0612) | **(0.0189)** |
| YR06xNational | **0.128***** | 0.0957 | 0.0229 |
| | **(0.0449)** | (0.0631) | (0.0188) |
| YR07xNational | 0.0711 | 0.0499 | **0.0425**** |
| | (0.0463) | (0.0642) | **(0.0186)** |
| YR08xNational | -0.0228 | -0.0708 | -0.00202 |
| | (0.0475) | (0.0621) | (0.0185) |
| YR00 | -0.869*** | -1.744*** | -0.239*** |
| | (0.0383) | (0.0486) | (0.0114) |
| YR01 | -0.941*** | -1.664*** | -0.155*** |
| | (0.0385) | (0.0484) | (0.0123) |
| YR02 | -0.599*** | -1.261*** | -0.126*** |
| | (0.0340) | (0.0451) | (0.0122) |
| YR03 | -0.328*** | -0.747*** | -0.0910*** |
| | (0.0309) | (0.0400) | (0.0128) |
| YR05 | -0.256*** | -0.864*** | -0.106*** |
| | (0.0304) | (0.0419) | (0.0130) |
| YR06 | -0.381*** | -1.197*** | -0.0978*** |
| | (0.0319) | (0.0426) | (0.0130) |
| YR07 | -0.437*** | -1.422*** | -0.147*** |
| | (0.0326) | (0.0444) | (0.0130) |
| YR08 | -0.454*** | -1.525*** | -0.135*** |
| | (0.0329) | (0.0424) | (0.0134) |
| Constant | 2.676*** | 3.015*** | 0.244*** |
| | (0.0967) | (0.0178) | (0.00666) |
| Observations | 26,694 | 26,694 | 26,694 |
| Number of Scientists | 2,966 | 2,966 | 2,966 |
| R-squared | | 0.140 | 0.045 |
| Adjusted R-squared | | 0.140 | 0.0445 |
| Scientist FE | YES | YES | YES |
| Sample | Matched Researchers | Matched Researchers | Matched Researchers |

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

*Table 5. Regression with Scientists having Experience in Patenting before the reform (from 2000 to 2003)*

| VARIABLES | (1)<br>nPubs | (2)<br>ln(PerYrCite+1) | (3)<br>CiteFrmPat | (4)<br>nPubs | (5)<br>ln(PerYrCite+1) | (6)<br>CiteFrmPat |
|---|---|---|---|---|---|---|
| NationalxPost04 | -0.0542 | -0.0293 | -0.0121 | -0.0582 | -0.0385 | -0.0233 |
| | (0.0660) | (0.0508) | (0.0476) | (0.0557) | (0.0517) | (0.0476) |
| Post04 | 0.301*** | 0.0798* | 0.0180 | 0.437*** | 0.0880 | 0.0817 |
| | (0.0602) | (0.0463) | (0.0434) | (0.0874) | (0.0539) | (0.0558) |
| BreadthRes | | | | 0.132*** | 0.0313*** | 0.0359*** |
| | | | | (0.00869) | (0.00943) | (0.00961) |
| AvgCoauthors | | | | -0.177*** | 0.0342** | -0.0262** |
| | | | | (0.0172) | (0.0159) | (0.0102) |
| JCIFDummy | | | | 0.366** | 0.0927 | 0.0707 |
| | | | | (0.159) | (0.0923) | (0.0568) |
| nPubs | | | 0.0136*** | | | 0.00835*** |
| | | | (0.00173) | | | (0.00184) |
| Constant | 1.685*** | 1.038*** | 0.407*** | 1.943*** | 0.675*** | 0.172 |
| | (0.0808) | (0.00952) | (0.0190) | (0.367) | (0.158) | (0.142) |
| Observations | 1,794 | 1,794 | 1,794 | 1,794 | 1,794 | 1,794 |
| Number of Scientists | 897 | 897 | 897 | 897 | 897 | 897 |
| R-squared | | 0.010 | 0.056 | | 0.053 | 0.098 |
| Adjusted R-squared | | 0.00880 | 0.0546 | | 0.0386 | 0.0840 |
| Scientist FE | YES | YES | YES | YES | YES | YES |
| Age FE | YES | YES | YES | YES | YES | YES |
| Sample | Inventor bf04=1 | Inventor bf04=1 | Inventor bf04=1 | Inventor bf04=1 | Inventor bf04=1 | Inventor bf04=1 |
| Model | NBREG | OLS | OLS | NBREG | OLS | OLS |

Robust standard errors in parentheses (Standard error for the negative binomial regression)
*** p<0.01, ** p<0.05, * p<0.1

*Table 6. Regression with Scientists having No Experience in Patenting before the reform*

| | (1) | (2) | (3) | (4) | (5) | (6) |
|---|---|---|---|---|---|---|
| VARIABLES | nPubs | ln(PerYrCite+1) | CiteFrmPat | nPubs | ln(PerYrCite+1) | CiteFrmPat |
| NationalxPost04 | **0.155***** | -0.00767 | **0.0462**** | **0.102***** | -0.00696 | **0.0451**** |
| | **(0.0301)** | (0.0193) | **(0.0203)** | **(0.0253)** | (0.0192) | **(0.0202)** |
| Post04 | 0.104*** | 0.0774*** | -0.0421** | 0.374*** | 0.0724*** | -0.0571** |
| | (0.0270) | (0.0170) | (0.0183) | (0.0456) | (0.0228) | (0.0270) |
| BreadthRes | | | | 0.144*** | 0.0170*** | 0.0186*** |
| | | | | (0.00457) | (0.00420) | (0.00459) |
| AvgCoauthors | | | | -0.153*** | 0.0185*** | -0.00563* |
| | | | | (0.00654) | (0.00481) | (0.00340) |
| JCIFDummy | | | | 0.360*** | 0.201*** | 0.0548*** |
| | | | | (0.0488) | (0.0288) | (0.0203) |
| nPubs | | | 0.0195*** | | | 0.0165*** |
| | | | (0.00128) | | | (0.00139) |
| Constant | 1.648*** | 0.977*** | 0.273*** | 2.460*** | 0.717*** | 0.231*** |
| | (0.0396) | (0.00402) | (0.00895) | (0.181) | (0.0708) | (0.0779) |
| Observations | 9,564 | 9,564 | 9,564 | 9,564 | 9,564 | 9,564 |
| R-squared | | 0.016 | 0.061 | | 0.042 | 0.071 |
| Adjusted R-squared | | 0.0160 | 0.0606 | | 0.0393 | 0.0683 |
| Number of Scientists | 4,782 | 4,782 | 4,782 | 4,782 | 4,782 | 4,782 |
| Scientist FE | YES | YES | YES | YES | YES | YES |
| Age FE | YES | YES | YES | YES | YES | YES |
| Sample | Inventor bf04=0 | Inventor bf04=0 | Inventor bf04=0 | Inventor bf04=0 | Inventor bf04=0 | Inventor bf04=0 |
| Model | NBREG | OLS | OLS | NBREG | OLS | OLS |

Robust standard errors in parentheses (Standard error for the negative binomial regression)
*** p<0.01, ** p<0.05, * p<0.1

*Table 7. Regression with Scientists in Life Science domain*

| VARIABLES | (1)<br>nPubs | (2)<br>ln(PerYrCite+1) | (3)<br>CiteFrmPat | (4)<br>nPubs | (5)<br>ln(PerYrCite+1) | (6)<br>CiteFrmPat |
|---|---|---|---|---|---|---|
| NationalxPost04 | **0.208*****<br>**(0.0408)** | -0.0237<br>(0.0278) | **0.0570****<br>**(0.0274)** | **0.148*****<br>**(0.0347)** | -0.0169<br>(0.0280) | **0.0584****<br>**(0.0275)** |
| Post04 | 0.0432 | 0.0970*** | -0.0565** | 0.583*** | 0.0778** | -0.0927** |
| | (0.0353) | (0.0233) | (0.0235) | (0.107) | (0.0356) | (0.0422) |
| BreadthRes | | | | 0.144*** | 0.0124** | 0.0142** |
| | | | | (0.00609) | (0.00584) | (0.00619) |
| InventorDummy | | | | -0.0556 | 0.00519 | 0.0326 |
| | | | | (0.0483) | (0.0411) | (0.0394) |
| AvgCoauthors | | | | -0.113*** | 0.0210*** | -0.00429 |
| | | | | (0.00731) | (0.00601) | (0.00430) |
| JCIFDummy | | | | 0.327*** | 0.193*** | 0.0660* |
| | | | | (0.0711) | (0.0452) | (0.0338) |
| nPubs | | | 0.0287*** | | | 0.0245*** |
| | | | (0.00225) | | | (0.00256) |
| Constant | 1.875*** | 1.038*** | 0.278*** | 3.687*** | 0.751*** | 0.319** |
| | (0.0696) | (0.00637) | (0.0128) | (0.520) | (0.128) | (0.138) |
| Observations | 4,350 | 4,350 | 4,350 | 4,350 | 4,350 | 4,350 |
| R-squared | | 0.018 | 0.076 | | 0.051 | 0.089 |
| Adjusted R-squared | | 0.0175 | 0.0749 | | 0.0446 | 0.0830 |
| Number of Scientists | 2,175 | 2,175 | 2,175 | 2,175 | 2,175 | 2,175 |
| Age FE | YES | YES | YES | YES | YES | YES |
| Scientist FE | YES | YES | YES | YES | YES | YES |
| Sample | LifeSci | LifeSci | LifeSci | LifeSci | LifeSci | LifeSci |
| Model | NBREG | OLS | OLS | NBREG | OLS | OLS |

Robust standard errors in parentheses (Standard error for the negative binomial regression)
*** p<0.01, ** p<0.05, * p<0.1

*Table 8. Regression with Scientists in Physical Science domain*

| VARIABLES | (1)<br>nPubs | (2)<br>ln(PerYrCite+1) | (3)<br>CiteFrmPat | (4)<br>nPubs | (5)<br>ln(PerYrCite+1) | (6)<br>CiteFrmPat |
|---|---|---|---|---|---|---|
| NationalxPost04 | 0.0691* | 0.00692 | 0.0186 | 0.0541 | 0.000494 | 0.0215 |
| | (0.0415) | (0.0258) | (0.0302) | (0.0341) | (0.0257) | (0.0303) |
| Post04 | 0.194*** | 0.0524** | -0.0229 | 0.293*** | 0.0579** | -0.0385 |
| | (0.0378) | (0.0230) | (0.0278) | (0.0526) | (0.0293) | (0.0348) |
| BreadthRes | | | | 0.138*** | 0.0206*** | 0.0234*** |
| | | | | (0.00634) | (0.00611) | (0.00670) |
| InventorDummy | | | | 0.0256 | 0.0517* | -0.00135 |
| | | | | (0.0345) | (0.0302) | (0.0311) |
| AvgCoauthors | | | | -0.223*** | 0.0169** | -0.0104* |
| | | | | (0.0112) | (0.00840) | (0.00548) |
| JCIFDummy | | | | 0.543*** | 0.263*** | 0.0463 |
| | | | | (0.0858) | (0.0500) | (0.0353) |
| nPubs | | | 0.0157*** | | | 0.0130*** |
| | | | (0.00128) | | | (0.00137) |
| Constant | 1.553*** | 1.004*** | 0.331*** | 1.829*** | 0.630*** | 0.259*** |
| | (0.0481) | (0.00526) | (0.0116) | (0.198) | (0.0924) | (0.0931) |
| Observations | 5,198 | 5,198 | 5,198 | 5,198 | 5,198 | 5,198 |
| R-squared | | 0.012 | 0.057 | | 0.040 | 0.072 |
| Adjusted R-squared | | 0.0112 | 0.0565 | | 0.0347 | 0.0665 |
| Number of Scientist | 2,599 | 2,599 | 2,599 | 2,599 | 2,599 | 2,599 |
| Age FE | YES | YES | YES | YES | YES | YES |
| Scientist FE | YES | YES | YES | YES | YES | YES |
| Sample | PhysicalSci | PhysicalSci | PhysicalSci | PhysicalSci | PhysicalSci | PhysicalSci |
| Model | NBREG | OLS | OLS | NBREG | OLS | OLS |

Robust standard errors in parentheses (Standard error for the negative binomial regression)
*** p<0.01, ** p<0.05, * p<0.1

*Table 9. Regression with Scientists in Technology Domain*

| VARIABLES | (1)<br>nPubs | (2)<br>ln(PerYrCite+1) | (3)<br>CiteFrmPat | (4)<br>nPubs | (5)<br>ln(PerYrCite+1) | (6)<br>CiteFrmPat |
|---|---|---|---|---|---|---|
| NationalxPost04 | -0.0279 | -0.0109 | -0.00836 | -0.0156 | -0.0386 | -0.0192 |
| | (0.0818) | (0.0607) | (0.0489) | (0.0684) | (0.0595) | (0.0478) |
| Post04 | 0.276*** | 0.0837 | 0.0387 | 0.519*** | 0.0744 | 0.0700 |
| | (0.0765) | (0.0578) | (0.0451) | (0.116) | (0.0592) | (0.0636) |
| BreadthRes | | | | 0.145*** | 0.0443*** | 0.0256** |
| | | | | (0.0103) | (0.00968) | (0.0108) |
| InventorDummy | | | | 0.0298 | 0.0572 | -0.00176 |
| | | | | (0.0616) | (0.0535) | (0.0548) |
| AvgCoauthors | | | | -0.230*** | 0.0130 | -0.00118 |
| | | | | (0.0211) | (0.0145) | (0.0111) |
| JCIFDummy | | | | 0.225** | 0.0902* | 0.0595* |
| | | | | (0.0894) | (0.0466) | (0.0304) |
| nPubs | | | 0.0145*** | | | 0.0112*** |
| | | | (0.00230) | | | (0.00266) |
| Constant | 1.608*** | 0.813*** | 0.186*** | 3.142*** | 0.652*** | -0.00181 |
| | (0.0866) | (0.00884) | (0.0192) | (0.491) | (0.126) | (0.150) |
| Observations | 1,810 | 1,810 | 1,810 | 1,810 | 1,810 | 1,810 |
| R-squared | | 0.019 | 0.058 | | 0.070 | 0.077 |
| Adjusted R-squared | | 0.0181 | 0.0562 | | 0.0552 | 0.0620 |
| Number of Scientists | 905 | 905 | 905 | 905 | 905 | 905 |
| Age FE | YES | YES | YES | YES | YES | YES |
| Scientist FE | YES | YES | YES | YES | YES | YES |
| Sample | Technology | Technology | Technology | Technology | Technology | Technology |
| Model | NBREG | OLS | OLS | NBREG | OLS | OLS |

Robust standard errors in parentheses (Standard error for the negative binomial regression)
*** p<0.01, ** p<0.05, * p<0.1

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