NBER WORKING PAPER SERIES

THE IMPACT OF UNIVERSITY PATENT OWNERSHIP ON COMMERCIALIZATION

Jun Wang
Yi Qian

Working Paper 31021
http://www.nber.org/papers/w31021

NATIONAL BUREAU OF ECONOMIC RESEARCH
1050 Massachusetts Avenue
Cambridge, MA 02138
March 2023, revised August 2023

We acknowledge the support by the Social Sciences and Humanities Research Council of Canada [grant 435-2018-0519] and National Natural Science Foundation of China [grant 72003161]. All inferences, opinions, and conclusions drawn in this study are those of the authors, and do not reflect the opinions or policies of the funding agencies and data stewards. No personal identifying information was made available as part of this study. Procedures used were in compliance with British Columbia's Freedom in Information and Privacy Protection Act. The views expressed herein are those of the authors and do not necessarily reflect the views of the National Bureau of Economic Research.

The Impact of University Patent Ownership on Commercialization
Jun Wang and Yi Qian
NBER Working Paper No. 31021
March 2023, revised August 2023
JEL No. K11,O30,O32,O38

ABSTRACT

This paper contributes to the literature on innovation policies on conditions for effective institutional changes. The "three rights" reform of 26 universities and the mixed ownership reform of Southwest Jiaotong University are important explorations made by China in recent years to promote the commercialization of patents in universities. The two reforms have adopted different models in the allocation of university patent ownership. The former completely allocated the patent ownership to universities, while the latter allocated 70% of the patent ownership to the inventors. Based on Chinese patent data and university statistical data, we empirically test the effects of these two university-patent ownership allocation models on the commercialization of patents. We find that the institutional environment caused unexpected effects in both reform models. The "three rights" reform has a significant impact on patent-licensing in 26 universities. The mixed ownership reform has significantly increased the number of patent transfers and patent applications of Southwest Jiaotong University, yet has tilted research and development (R&D) toward experimental research with relatively low creativity. The findings yield broader implications for the organization and commercialization of innovations.

Jun Wang
Intellectual Property Research Institute
Xiamen University
Siming District, Xiamen City
Fujian Province
P.R.China
junwang@xmu.edu.cn

Yi Qian
Sauder School of Business
University of British Columbia
2053 Main Mall
Vancouver, BC V6T 1Z2
and NBER
yi.qian@sauder.ubc.ca

1 Introduction

Two broad issues of importance are not yet well-understood: Whether institutional changes should be consistent with other aspects of the institutional environment to have the intended impact (Scott 2014; Eesley et al., 2016)? How institutional changes that are inconsistent with the institutional environment affect organizations? A clear understanding is especially called for in the organization and innovation context (Prabhu et al. 2005). Previous studies emphasized that institutional changes will affect market reward and sanction mechanisms as well as the organizations' strategic behaviors (Hirsch 1975, Tolbert et al. 2011), yet ignored other institutional environmental conditions that would become important constraints for the expected effects of institutional changes. We attempt to shed lights into bridging this gap by examining a specific institutional change. We study how changes in two opposite university patent ownership institutions affect patent commercialization and what factors moderate the desired effects of patent commercialization. Among them, the fact that Chinese universities have always managed patents as state-owned assets is an important moderator.

As well documented in the literature, radical innovation is an important driver of the growth and wealth of firms and nations (Tellis et al. 2009; Aghion and Howitt 2008). Universities play an important role in national innovation systems. Many inventions that have an important impact on human development also originated from universities.[i] However, universities' research findings suffer from two problems in achieving commercial application: First, innovative findings are mainly presented in the form of academic publications (Mowery et al., 2001). The lag between academic publishing and their industrial application is about 20 years (Adams, 1990). Second, even if the innovations are presented in the form of patents, their commercialization is extremely low. For example, in 1980, less than 5% of the 28,000 patents in American universities were licensed (United States General Accounting Office [GAO], 1998). There are inherent difficulties in commercializing university patents, including the fact that university patents are far from mature (Thursby et al., 2001; Thursby & Thursby, 2002), and have greater uncertainty in value (Gambardella et al, 2007). Perhaps more importantly, universities lack incentives to commercialize their patents. University patents are often funded by government research projects, so that patents filed in the name of the university are de facto owned by the government. Governments often lack incentive and ability to commercialize patents. This results in a lack of implementers to specifically promote the commercialization of patents. To combat this, two models of inventor and university ownership of university patents have emerged, with Japan and most European countries assigning ownership of university patents to inventors (or "professors' privilege") (Organization for Co-operation and Development [OECD], 2003), the U.S. passed the Bayh–Dole Act in the early 1980s. This allowed universities to retain patent rights to the research findings arising from federal research grants (Hackett and Dilts, 2004).

Emerging markets like China have long faced the problem of low efficiency in its attempt to commercialize university patents. In particular, unlike the United States, where university invention patents account for only 2% of the total number of invention patents (Marcus, 2020), Chinese university invention patents account for about a quarter of the number of invention patents in the entire country.[ii] As a result, the low efficiency of university patent commercialization has become an important impediment to technological innovation in China. Influenced by the remarkable results achieved by the transfer of university patent ownership from the state to universities in the U.S.,[iii] China has almost copied the content of the Bayh-Dole Act since the year 2002. The law stipulates that, except in special circumstances, the intellectual property rights (IPR) arising from the research results of funded national scientific projects shall be granted to the project-executing unit. The unit may decide independently to implement, license, or transfer the IPR for commercial exploitation, with the State retaining the right to use them without compensation. The project owner is entitled to receive incentives for commercializing the research results. However, the transplantation of the Bayh-Dole Act to China has not had the desired effect (Luan et al., 2010). In reflection, policymakers concluded that the main reason for the failure was that Chinese universities do not acquire ownership rights in the sense of independent and autonomous disposal of patents, as American universities have since the Bayh-Dole Act.

In an era when China's influence on innovations and trade provoke heated debates in policy and academics (Aghion et al. 2023), it is of general interests and importance to understand the commercialization of Chinese university patents. Since 2011, China started a patent ownership reform, which granted central-level public institutions (including universities directly under the Ministry of Education) three rights for university-owned patents: usus (the right to use), disposal (the right to handle), and fructus (the right to the fruits of the property) (hereinafter: "Three Rights Reform [TRR]") in Beijing, Wuhan, Shanghai, and Hefei. This changes the status quo of universities with only nominal patent ownership. Subsequently, the three-rights reform was extended to cover the entire country through the amendment of the Law on Promoting the Transformation of Scientific and Technological Achievements at the end of 2015.

China is also exploring a reform similar to some European countries that would give professors ownership of university patents (Martínez and Sterzi, 2021). This reform firstly occurred at the Southwest Jiaotong University (SWJTU). SWJTU adopted a model in which patent rights are shared between the university and the inventor. SWJTU independently decided to transfer a substantial portion (70%) of patent ownership that was originally owned by universities to inventors, thus realizing a reform comprising mixed ownership of university patents. Therefore, the ex-post reward for inventors is transformed into an ex-ante property rights incentive, thereby also changing the attribute of state assets of university patents and theoretically helps to increase the incentive of inventors to participate in patent commercialization. Since then, Mixed Ownership Reform (MOR) has been gradually recognized by the central government, which issued a document in 2020 to launch more MOR pilot projects in forty Chinese universities and research institutes.

China's two pilot projects provide us with a unique quasi-natural experiment to analyze the impact of changes in university patent ownership. Existing research on the effects of adjusting the patent ownership model of universities in other countries usually do not use suitable control groups because the adjustment is carried out uniformly across the country, making it difficult to exclude the effects of other institutional environments (Henderson et al., 1998; Sampat et al., 2003; Mowery and Samptat, 2005; Geuna and Rossi, 2011). It is difficult for cross-country studies (Giuri et al., 2013) to make accurate causal inferences because of countries' heterogeneity. China's pilot projects provide useful regional variations within a country that overcome the challenge of suitable control groups. Based on Chinese patent data and university science and technology statistical data from 2008 to 2020, we study the impact of university patent ownerships on patent commercialization through effective identification strategies. In particular, we apply a combination of difference-in-difference panel analyses, propensity-score matching, and synthetic control methods to arrive at robust results.

We find that the TRR does affect the incentive level for universities to undertake commercialization, while the MOR has had significant incentive for inventors to commercialize and increase their patent applications. In particular, the TRR had significantly increased the number of licenses for pilot university patents, which is consistent with the commercialization model based on patent licensing in American universities (Thursby et al., 2001), while the effects of MOR were reflected in the significant increase in the number of patent transfers. Regarding the innovation outputs, the TRR has no significant impact on patent applications, while the MOR has significantly increased the number of patent applications of Southwest Jiaotong University. We consider impacts on the research orientation, namely the direction of research toward either basic research (with a high level of innovativeness that propose and solve fundamental problems) or applied research (with a focus on improvement of existing technologies and techniques). We find that the TRR has no impact on the research orientation, and the MOR has led to a significant increase in the proportion of projects with relatively weak creativity, possibly because the uncertainty of MOR makes inventors place more emphasis on short-term benefits, shifting their research orientation to applied research.

The findings of this article enrich the understanding of the incentive effects of two different types of university patent ownership models on patent commercialization. They provide a reference for China (as well as other countries) to implement effective reforms in the university patent ownership. It should be noted that our sample includes Chinese universities directly under the jurisdiction of the Ministry of Education. Although these 64 universities are only 5.32% of the total number of Chinese universities, they account for 31.43% of the number of R&D personnel, 51.29% of the R&D funding allocation, 52.31% of the R&D expenditure, and 34.74% of the number of patents granted in Chinese universities.[iv] Thus, these universities represent the highest level of Chinese universities, making the findings here salient to better understand the operation of patent commercialization and the application of core innovations in the context of reform.

2 Conceptual Framework and Hypotheses

2.1 Literature Review

Promoting the commercialization of university patents from the perspective of changes in ownership began in the United States. In December 1980, the U.S. passed the Bayh-Dole Act, granting the ownership of intellectual property rights generated by government-funded research projects to the universities, small businesses, and non-profit organizations that completed the projects. This change seemingly achieved expected results. In 1965, only 96 patents were granted to 28 U.S. universities, yet about 1,500 patents were granted to 150 universities by 1992, reflecting a 15-fold increase, while total U.S. patents increased by less than 50% during the same period (Henderson et al., 1998). Inspired by this, in 2000, Denmark, Germany, Austria, Norway, Finland and other major European countries began to gradually move away from inventor ownership toward university ownership of patent rights.

Existing research on the impact of university patent ownership changes in the U.S., Europe, and other countries examined the quantity and quality, research orientation, and commercialization of university patents (Henderson et al., 1998; Mowery et al., 2001; Mowery and Sampat, 2004; Sampat, 2006; Mowery et al., 2002; Mowery and Ziedonis, 2002). However, previous studies reported inconsistent results for the same university patent ownership. Mowery and Sampat (2005) constructed a trends chart reflecting the number of university patent applications, proportion of university patents to total patents, and the number of university patents per capita of R&D investment in the U.S. from the 1960s to the 1990s. They found that implementing the Bayh-Dole Act did not have a structural impact on the above indicators. Between the late 1960s and the 1990s, the number of patents stayed on a relatively stable growth trajectory. Geuna and Rossi (2011) divided European countries into five groups based on their university patent ownership policies and compared the impact of different patent ownership policies on the number of university patents and licenses. They found that the U.S. Bayh-Dole Act model had only a short-term impact on patent growth, and that European countries were far weaker in university patent licensing than the United States. Crespi et al. (2010) compared patents owned by universities with patents for inventions not owned by universities in six European countries and found no significant differences in commercialization rates. Hvide and Jones (2018) found that the number of patent applications and the number of enterprises established by university inventors decreased after Norwegian universities' patent ownership shifted from scientific inventors to universities. Luan et al. (2010) compared changes in the quantity and quality of university patents before and after the implementation of the Chinese version of the Bayh-Dole Act. They found that, although the number of university patent applications significantly increased, there was no significant change in patent quality or commercialization.

These differences in patent commercialization performance may be due to differences in the institutional environment outside of patent ownership adjustments. Several factors may have affected university patenting and licensing before and after the policy changes. For example, several U.S. policies may have shaped university patent production and commercialization: the Bayh-Dole Act enforcement, the 1980 Federal Supreme Court decision in Diamond v. Chakrabarty that allowed patent grants for some biotechnology, the 1982 Federal Circuit Court of Appeals decision on patents (Mowery et al., 2001), and the 1984 passage of Public Act 98-620 that further expanded the scope of university patents (Henderson et al., 1998). As early as the late 1960s, U.S. universities began to establish technology transfer offices and hire professional technology transfer personnel (Mowery & Sampat, 2005). The lack of unified and centralized management in the U.S. university system led to fierce competition among universities for resources, reputation, and students, which encouraged universities to attach importance to patent commercialization (Geiger, 1993).

There is generally a lack of clear identification of whether these differences were driven by the institutional environment of corresponding development trends, legislation and policies related to patent creation and protection, or changes in university patent ownership. Two pilot projects in Chinese universities provide an effective comparison of the impacts of university-owned and inventor-owned patent ownership on patent commercialization.

2.2 The Institutional Context of Patent Rights Changes in Chinese Universities

Unlike in the U.S., Chinese universities consist almost entirely of public universities. Public universities in China are generally under the jurisdiction of national ministries or local governments.[v]

For a long time, patents produced by researchers in Chinese universities originally belonged to the State. There is no specific subject to realize the commercialization of the patent. To promote patent commercialization in universities, in the Chinese version of the Bayh-Dole Act (Certain Provisions on the Management of Intellectual Property Rights of Research Results of National Research Program Projects, promulgated in 2002, then confirmed by Science and Technology Progress Law in 2007), patent ownership derived from government-funded research findings was formally granted to universities. Yet Chinese universities have only obtained nominal patent ownership, the nature of university patents as state assets has not changed. Using university patents requires the same procedures needed to use other state-owned assets.[vi] The complicated procedures and prolonged approval process hinder university patent commercialization (He and Chen, 2013; Zhu, 2016). In addition, universities cannot directly obtain the income from patent commercialization.[vii] Such provisions also reduce universities' enthusiasm to commercialize patents.

To resolve the difficulties associated with university patent commercialization, with the approval of the State Council, the Ministry of Finance launched in May 2011 a pilot reform in the management of the disposal and revenue rights of scientific and technological achievements of central-level institutions in Zhongguancun Innovation Pilot Zone in Beijing. This reform covers the universities under the jurisdiction of the Ministry of Education in Beijing. In September 2013, the reform pilot was further expanded to universities under the jurisdiction of the Ministry of Education located in Wuhan, Shanghai, and Hefei Independent Innovation Pilot Zone,[viii] where pilot units may independently decide to carry out patent commercialization by means of transfer, licensing, and share investments under certain criteria. Therefore, pilot units' patent commercialization did not require filing with or approval from the competent authority when the value of the patent is less than 8 million yuan, and the pilot units could determine the patents' transaction price through agreement pricing, technology market listing transactions, and auctions, etc. The income from patent commercialization was partially retained by the pilot unit and did not need to be turned over to the treasury. This pilot reform program was initiated at 26 qualifying universities, granting them real patent ownership comprising three elements of property rights: usus (the right to use), disposal (the right to handle), and fructus (the right to the fruits of the property). In October 2015, the TRR was able to be expanded from pilot universities to universities nationwide through the newly revised law on Promoting the Transformation of Scientific and Technological Achievements. All universities in China are granted patent ownership, including the aforementioned rights.

However, Southwest Jiaotong University (SWJTU) 's continued inability to incentivize inventors to substantially participate in subsequent stages of patented technology development led it to believe that granting patent ownership to the university alone, while ignoring inventors closely related to the university patents, cannot effectively promote the commercialization of patents. There is also a theoretical basis for such concerns. On the one hand, since the inventors have no ownership of the invention, they lack legitimate rights and reasons to participate in the commercialization of their patents, rendering inventors as mere bystanders most times in the patent commercialization process. Inventor involvement plays an important role in the commercialization of immature university patents. The university patent is often in the early experimental stage of the technology, far from commercial application. Thus, the tacit knowledge in patent implementation makes it difficult to achieve commercial application without the active participation of inventors. On the other hand, although the TRR requires universities to reward inventors with a certain percentage of their income after the commercialization of patents,[ix] some universities have not adopted formal royalty-sharing arrangements with academic inventors. Even if institutional arrangements for *ex post* rewards exist, the uncertainty in the field of R&D leads to incompleteness of contracts, which can prevent the inventor from getting the *ex post* return required to compensate for his *ex-ante* investment (Grossman and Hart, 1986). The extremely low rate of commercialization of university patents leaves inventors with no incentive to participate in the commercialization process.

Therefore, with the difficulty of effectively incentivizing inventors to participate in the commercialization of patents, SWJTU explored the implementation of another reform on university patent ownership within the university. In January 2016, SWJTU issued the "Regulations on Patent Management of Southwest Jiaotong University," where the *ex post* inventor cash and equity awards were changed to *ex ante* patent rights incentives, thereby changing university patent from purely owned by the university to mixed ownership by the university and inventor. The university and the inventor have 30% and 70% ownerships of the patent, respectively, and the inventor acquires the decision-making power to commercialize the patent. This provides an incentive for the inventor to participate in the commercialization of the university patent with property rights.

The MOR implemented by SWJTU was initiated and implemented on the basis of the Law on the Transformation of Scientific and Technological Achievements, which grants the right to dispose of scientific and technological achievements of universities. There are some controversies about the legality and the risk of accountability for the loss of state assets by granting inventors partial ownership of inventions resulting from the implementation of scientific research projects. Therefore, the MOR has even been called the "Xiaogang Village experiment" of China's science and technology system reform.[x] Coincidentally, Sichuan Province, where Southwest Jiaotong University is located, was listed as an innovation reform demonstration zone, and the local government supported SWJTU's MOR for early and pilot implementation. The positive results achieved led to the MOR gradually being recognized by the central government.[xi]

SWJTU's experimental effect has important theoretical and practical significance. The model of shared patent rights between inventors and universities is an original institutional arrangement with the theoretical advantages of both university and inventor ownership. Can both universities and inventors be incentivized to participate in patent commercialization? Are there likely to be unintended effects? These require further research on the effects of MOR to inform improvements in the larger MOR pilot currently underway. While SWJTU is the only university to have done so within the sampling period, this experimentation conveniently provides a standard application of the synthetic control method to identify the effect. Related literature reports on other organizations provide representative cases with fruitful insights (e.g., Scherer and *Weisburst* [1995] examine Italy's patent reform, Levitt and Venkatesh [2000] investigate one drug-selling street gang, etc.).

Implementing the TRR at the 26 universities expanded university patent rights, allowing universities to acquire real patent ownership. SWJTU's patent MOR extended patent ownership from universities to inventors, making the inventor the main implementer of the commercialization of university patents. What effects do these different ownership structure have in practice? We hypothesize and analyze the effects of different patent ownership models on university patent commercialization and production based on two pilot projects.

2.3 Theoretical Mechanism and Research Hypotheses

The essence of the TRR and MOR involves the redistribution of intellectual property rights that emerge from university research. Reconfiguring ownership affects all parties' costs and benefits regarding the innovation process, thereby changing the incentives of all parties involved in innovation (Aghion and Tirole, 1994). Those affected by the incentive effects of TRR and MOR are mainly universities and inventors. The difference is that TRR is an *ex post* incentive for inventors in the patent commercialization, while MOR is an *ex ante* incentive for inventors in the patent commercialization. Therefore, TRR directly incentivizes universities, while MOR directly incentivizes inventors. Whether and how the policies realized intended goals are empirical questions to evaluate. We assess the potential impact of TRR and MOR in the following three areas: the commercialization of university patents, the innovation outputs, and the research orientation, accounting for the different incentives of recipients and the institutional environment in which the pilot was implemented.

First and foremost, we focused on patent commercialization. Both the TRR and MOR provide incentives for patent commercialization, and the difference lies in the target of the incentives. Implementing the TRR has given universities an incentive to reap the benefits of patent commercialization. The right to independently dispose of and gain benefits from patent commercialization allows universities to promote patent commercialization, and they have the resources and potential capacity to do so. In contrast, the MOR mainly encourages inventors to actively participate in the patent commercialization process. Since they gain ownership of 70% of the patent prior to commercialization, they gain the decision-making power to commercialize the patent. Because inventors are most familiar with the patent technology, they have tacit knowledge that would facilitate commercialization. Their participation in commercialization facilitated connecting with an enterprise's technical staff, thereby shortening the patented technology cycle from theory to practical application and increasing the probability of successful patent commercialization.

However, a number of limiting factors, particularly the institutional environment associated with the pilot reforms, can affect the achievement of TRR and MOR in incentivizing patent commercialization goals and the corresponding strategies of implementing entities. There are some negative impediments to incentivizing the commercialization of patents. On the one hand, the bureaucratization of universities and the complexity of commercialization may constrain the realization of the TRR incentive effect (Kenney and Patton, 2011). On the other hand, inventors often lack the human and financial resources needed for patent commercialization, which may also limit the realization of the MOR incentive effect.

In terms of overall impact, we expect the incentive effects of TRR and MOR on universities and inventors to commercialize their patents to outweigh the effects of negative restrictive factors, and thus both policies should have a positive impact on patent commercialization.

Commercializing patents involves patent selling and patent licensing, where selling is a one-shot ownership transfer, and licensing grants either exclusive or non-exclusive patent use rights, which can generate sustainable benefits. How should universities and inventors choose their patent commercialization strategy? Selling or licensing? Essentially, selling and licensing are two ways of allocating the risk of uncertainty between the parties to a transaction. For patents with a high degree of technical uncertainty, the patentee may prefer to sell the patent, while for patents with a lower risk of technical uncertainty and higher quality, the patentee may prefer to license (Jeong et al., 2013).

However, the institutional environment associated with different enforcement agents may affect patent commercialization strategies that are supposed to be determined by the uncertainty of the patented technology. For the TRR, the main factor affecting the decision of the university as a patent owner is the risk of losing state assets. Despite the fact that Chinese public universities have acquired real patent ownership, university patents are still state-owned assets in terms of their legal nature, and university administrators are still liable for the loss of state-owned assets if the value of the patents depreciates during commercialization. Since patent licensing involves only the transaction of patent usage rights, it does not lead to the loss of state assets, thus becoming the only viable form of patent commercialization under TRR. As for the MOR, although the vast majority of the patent rights were granted to the inventor prior to commercialization, the stability of rights can affect the inventor's decision to commercialize the patent. Since the MOR was implemented at the discretion of SWJTU and the legality of the controversy exists, there is a high degree of uncertainty regarding the patent rights obtained by the inventor. The risk of uncertainty, coupled with the inventor's lack of ability to manage the commercialization of the patent, could add to the inventor's preference to obtain immediate income in the form of a one-shot patent transfer rather than the long-term stable benefits of patent licensing. We thus develop the following hypothesis.

Hypothesis 1: The TRR and MOR can incentivize universities and inventors to implement patent commercialization, respectively, thus may increase the probability of patent commercialization. However, under the influence of the institutional environment related to the pilot reform, the two differ in the manifestations of patent commercialization, with the TRR favoring the promotion of patent licensing and the MOR favoring the promotion of patent transfer.

The premise of commercialization is that there may be as many patents as possibly available for commercialization. Therefore, we further discuss the impact of the changes in university patent ownership on patent applications. The increase in the number of patents depends on whether the incentive to patent can be assured.

TRR directly incentivizes university patent applications. To increase the number of patents, universities can work on two fronts: they could improve the external environment that allows researchers to create inventions, and they could promote patent applications for existing or near-completed technical inventions. For the former aspect, improving the external environment is a gradual process that may take years to yield significant results. For the latter, the information asymmetry between universities and inventors needs to be addressed, where the inventor has information about the research progress but the university does not. Therefore, if universities want to increase the number of patent applications, they must encourage inventors to disclose patentable research results to universities. However, university researchers can only obtain *ex post* rewards after the commercialization of patents. Therefore, motivating inventors to actively engage in R&D or to disclose patentable technology information to universities relies on altering the incentives of inventors.

In fact, inventors at Chinese universities are extremely low in expectation of obtaining rewards from patents. According to relevant survey data, the ratio of patent licensing in universities is only 3.4%, and the commercialization rate is 4.1% (SIPO, 2018). Therefore, if the reward mechanism (post-reward) for inventors remains unchanged, the TRR may not increase patent filings when it only incentivizes universities.

The MOR could incentivize both universities and researchers to file patents. SWJTU has shared the reform dividend, giving the university an incentive to promote patent production. However, by granting 70% ownership to the inventor after the patent is granted rather than as a reward after the patent is commercialized, the indeterminate debt of the inventor is converted into a definitive property right. This gives the inventor an incentive to disclose patent information to universities and to convert existing and near-completed technical inventions into patents, thereby promoting the inventor's patent applications. In light of this, we propose

Hypothesis 2: The increase in the number of university patent applications is primarily due to increased innovation and the increased willingness of inventors to disclose patentable technical information to universities. Thus, increasing the number of patent applications depends heavily on incentives for inventors. The TRR only motivates universities to promote patent applications; it does not affect the incentive level for inventors to apply for patents. However, the MOR can simultaneously motivate the university and inventors to apply for patents and may have a better stimulating effect on patent filing as compared to TRR.

Next, we asked, do changes in university patent ownership affect the orientation of university research? China's TRR and the Bayh-Dole Act both transfer university patent ownership from the state to universities. Previous studies examined the impact on universities' research orientation of implementing the Bayh-Dole Act, and found that applied research significantly increased after the Act was implemented (Morgan et al., 1997). The logic is that the Act shifted ownership of state-funded research projects from the state to universities, which have an incentive to promote patent commercialization and increase universities' revenues. Inventors can then share the commercialization benefits. University researchers are more inclined to invest their energy in applied research that is likely to yield benefits (Thursby et al., 2007).

Unlike universities in the U.S., Chinese universities are established and funded almost entirely by the government. They are evaluated primarily on the basis of papers that emphasize basic research. There is little incentive for universities to gain short-term benefits from scientific and technological achievements. In contrast, universities are influenced by TRR to conduct high-level research that both can yield gains from the disposal of scientific and technological results and is compatible with the university's evaluation system. Therefore, it is also difficult for TRR to change the setting of research orientations in Chinese universities without changing the institutional and evaluation systems of Chinese universities. From the perspective of university researchers, Chinese universities have a very low rate of patent commercialization. Based on previous experiences, university researchers do not expect to gain benefits from patent commercialization, so the TRR may not change their inherent preferences for basic or applied research.

The MOR changes the incentives of inventors who make decisions about the research orientation. When inventors choose research orientation, applied research has a shorter period and lower risk than basic research. Given the uncertainty of the pilot reform itself, inventors may have an incentive to devote more energy to applied research that will facilitate patentable results, thereby obtaining patent commercialization benefits faster. We thus formulate the following hypothesis:

Hypothesis 3: Both in terms of the institutional environment of Chinese universities and the impact on incentive recipients, the TRR may not change the research orientation of Chinese universities, and the MOR stimulates inventors’ enthusiasm to promote patent commercialization. However, policy uncertainty encourages inventors to shift their research orientation to research that requires a lower level of innovation and is more likely to yield research findings.

3 Data Sources and Empirical Strategy

3.1 Data Sources

We empirically test these research hypotheses with a unique dataset we assembled from various sources. The research data included patent and university data. The patent data were published by the State Intellectual Property Office from 2008 to 2020 (He et al. 2018), and contained information about the applicant, application date, grant date, and the legal status changes, such as the transfer and license for each patent. Because this study focused on the commercialization of patents with higher innovation value, we studied invention patents for which universities independently applied. The university data came from the "Compilation of Scientific and Technological Statistics of Colleges and Universities (2009-2018),"[xii] which included relevant statistical data on research projects, R&D expenditures, number of R&D personnel, and various universities’ research orientation.

For the two pilot reforms of university patent ownership, the TRR selected 26 universities under the jurisdiction of the Ministry of Education located in Beijing, Shanghai, Wuhan and Hefei. The MOR was only adopted by SWJTU until 2020. These universities were used as the treatment group for this study. Correspondingly, other universities under jurisdiction of the Ministry of Education served as the control group. There are 76 such universities, including arts, languages, finance, and others. Some of such universities indicated almost no scientific achievements. To ensure that the universities in the control group were as comparable as possible to the treatment group, we excluded the 16 art, language, and financial institutions, all of which filed fewer than 600 patents from 2012 to 2019, and limited the total sample size to 60 universities.

Regarding the implementation time of the two reform pilots, the TRR was first implemented in 2011 at 12 universities under the jurisdiction of the Ministry of Education in Beijing, and then extended to 14 universities under the same jurisdiction in Wuhan, Shanghai and Hefei in 2013. By October 2015, through the amendment of the Law on Promoting the Transformation of Scientific and Technological Achievements, the relevant policies of the reform began to be implemented nationwide, thereby ending the pilot program. The MOR started in January 2016. In October 2020, the Ministry of Science and Technology issued a notice that significantly expanded the scope of the pilot to implement MOR.[xiii] In summary, we define two observational periods: 2008-2015 for the TRR, and 2008-2020 for the MOR. Table 1 shows the key timing and policy for the two university-patent-ownership reform pilots. For TRR, we uniformly use the second year after the promulgation of the policy as the policy implementation year due to the time lag between the superior notification and the implementation by the universities. For MOR, SWJTU promulgated the policy in January 2016 and implemented it immediately, so we use the year of the policy's promulgation as the policy implementation year.

Table 1. Timetable and specific policies for implementing TRR and MOR

TRR			MOR		
Year	Implementation target	Specific policies	Year	Implementation target	Specific policies
2011.2	Central-level institutions in Beijing	Notice on the Pilot Reform of the Right to Dispose of Scientific and Technological Achievements of Central-level Institutions in Zhongguancun National Independent Innovation Demonstration Zone	2016.1	Southwest Jiaotong University	Patent Management Regulations of Southwest Jiaotong University
2013.11	Central-level institutions in Wuhan, Shanghai and Hefei	Notice on expanding the scope of the pilot reform of the management of disposal rights of scientific and technological achievements of central-level institutions and extending the pilot period	2020.10	Forty universities and research institutions	Pilot Implementation Plan for Granting Researchers Ownership or Long-term Use of Scientific and Technological Achievements on Duty

2015.8	Nationwide	Promote the transformation of scientific and technological achievements law

3.2 Empirical Strategy

3.2.1 Difference-in-Difference

Early domestic and foreign policy changes in university patent ownership were one-size-fits-all. Therefore, we could only use the "single difference method" to compare before and after policy changes. However, the “single difference method” cannot identify the policy’s causal effects, because it cannot determine whether the before and after policy were driven by corresponding time trends or other factors not included in the model. An important advantage of the reform examined in this study is that the TRR started in only a set of universities. This provides us with a “treatment group” affected by the policy change and a “control group” that was not affected, allowing us to apply the “difference-in-difference” (DID) method to estimate the impact of university patent ownership changes on patent commercialization and production. The DID method uses forward and backward changes in the control group to estimate the impact of the trend change, eliminating this type of effect in the estimation results. Therefore, if the treatment and control group samples are sufficiently similar and meet the parallel-trend assumption, the DID method can detect net effects of the policy change. Both the treatment and control universities were under the jurisdiction of the Ministry of Education,[xiv] representing the highest caliber of Chinese universities; this ensured that the treatment and control samples were as similar as possible.

In the DID model, we controlled the variables related to human and physical capitals. In addition, to ameliorate missing variable bias caused by unobservable variables, we added fixed effects at the university and time levels to control for the influence of factors that do not change by university or over time.[xv] The two-way fixed-effect panel model based on the DID:

$$\mathrm{Y}_{i,t} = \beta\, policy_{i,t} + \gamma' X_{i,t-1} + \eta_i + \mu_t + \varepsilon_{i,t} \qquad (1)$$

where $Policy_{i,t}$ represents 26 universities' TRR, and its value is equivalent to the interaction term used to capture the net effects of policy in the DID model. That is, when the university belonged to the treatment group and pilot reform had been launched, the $Policy_{i,t}$ was 1, otherwise 0. β gives the effect of reforms on the outcome variable. University-fixed effects η_i and time-fixed effects μ_t were included to address other unobserved university and time variations, while $\varepsilon_{i,t}$ is the random error.

$Y_{i,t}$ was measurement of patent commercialization, patenting, and research orientation, where patent commercialization was proxied by patent selling and patent licensing frequency, patent production was measured by the number of patent applications, and research orientation was proxied by the share of low-level applied projects in university R&D. Specifically, it was measured by the number of experimental development (ED) projects in the total number of projects. The internationally accepted criteria for classifying R&D activities include: basic research, applied research, and experimental development (OECD, 2015). The Chinese Bureau of Statistics applied the same criteria as OECD, but differs slightly in the definitions of different categories of R&D activities.[xvi] According to the criteria for classifying R&D activities, both basic and applied research involve a high level of creativity, while experimental development involves improvement, without strong creativity. In a question-and-answer session with the head of the Chinese Statistics Bureau, it was also pointed out that basic and applied research are theoretically forward-looking and usually take place in universities and research institutes with strong capabilities, while experimental development is more likely to take place in enterprises.[xvii] This shows that experimental development is categorized as a less creative type of R&D activity. Therefore, we chose the proportion of experimental development projects as the dependent variables, to test the impact of pilot reform on universities' research orientation.

The selection of universities participating in the TRR pilot may be non-random. The selection is likely to be influenced by the university characteristics, thus making the model estimation results biased by whether the university enters the pilot variable $Policy_{i,t}$ associated with the random error term $\varepsilon_{i,t}$. In order to obtain unbiased estimates of the coefficients β in model (1), a vector of university characteristics variables $X_{i,t-1}$ are included to mitigate the possible bias in estimates due to the endogeneity of the TRR pilot selection.

Since there is no relevant document specifying the selection criteria for universities to enter the TRR pilot. We conjecture that the R&D personnel, the number of graduate students, and investment in sci-tech funds may be the determinants of whether a university is included in the TRR pilot. In order to verify whether the above university characteristics are the main influencing factors, referring to Lu et al. (2013), logit models were constructed to estimate the probability of universities being included in the 2011 and 2013 TRR pilots, respectively. The aforementioned university characteristics prior to the implementation of the TRR as explanatory variables, and whether the universities would be selected for the TRR pilot was the dependent variable. The results from Appendix Table 2 reveal that the selection of TRR pilot universities is influenced by the R&D personnel, the number of graduate students, and investment in sci-tech funds. Therefore, a first-order lagged term of the above university characteristic variables should be included in the regression model to control for possible endogeneity in the selection of universities participating in the TRR.

3.2.2 Synthetic Difference-in-Difference

Although the SWJTU's MOR was a spontaneous experiment, it may have its own particularities. Since only SWJTU implemented MOR, we could not identify a university in the control group that had characteristics similar to all aspects of SWJTU. Therefore, the DID may not be applicable to the assessment of MOR effects, while the synthetic control method (SCM) is exactly suitable for assessing the impact of individual cases.

SCM was first applied to the study of terrorist activities in the Basque region of Spain. A combination of two Spanish regions was used to synthesize a Basque region similar to that before the Basque region was affected by terrorist activities, allowing investigators to study the impact of terrorist activities on economic growth (Abadie and Gardeazabal, 2003). Since then, the SCM has been widely used in case studies, with representative applications, such as the impact of the California Tobacco Control Act on tobacco consumption, the impact of German unification on the per capita GDP of West Germany, etc. (Abadie et al., 2010; Abadie et al., 2015). Powell (2022) further extends the SC estimation beyond case studies.

The synthetic control method can produce a "synthetic SWJTU" with similar characteristics to all aspects of SWJTU by linearly combining other universities in the control group, and comparing the two to obtain the real effect of the SWJTU MOR. The SCM has transparency and the choice of weights is determined by data, which reduces subjective judgment. Therefore, we can apply SCM to assess the impact of MOR on SWJTU's patent commercialization and production. However, since the SCM does not have an analytical solution, it is not possible to estimate standard errors and thus it is difficult to assess the policy effects of MOR.

The Synthetic Difference-in-Difference (SDID) (Arkhangelsky et. al. 2021) is not only able to estimate the policy impact of MOR, but also has the advantages of both DID and SCM. SDID can apply the placebo method to estimate standard errors, allowing the policy effects of MOR to be assessed and compared with the policy effects of TRR.

SDID combines the advantages of both DID and SCM. On the one hand, the SDID matches the pre-treatment trends of individuals in the control group with those in the treatment group by introducing individual weights and time weights, and balances the pretreatment and post-treatment periods, which takes advantage of the SCM and weakening the reliance on the parallel trend assumption. On the other hand, the SDID also incorporates the advantages of the DID method by introducing individual- and time-fixed effects, and allows for valid large panel inference. Therefore, compared with DID and SCM, using the SDID method may arrive at more robust estimates.

Therefore, we use the SDID to evaluate the effects of MOR on patent commercialization and production in SWJTU. We also use the SCM to test the robustness of the MOR's effects.

4 Empirical Findings

4.1 Impact on University Patent Commercialization

The direct purpose of the TRR and MOR was to promote universities' patent commercialization. Table 2 shows the effects of the two types of pilot reforms on patent selling and patent licensing. We found that both TRR and MOR had a significant and positive impact on patent commercialization, but there are differences in the manifestations of patent commercialization.

Table 2. *The Effects of Pilot Reform on Patent Commercialization in Universities*

Variables	TRR(DID)		MOR(SDID)	
	Ln(Patent transfers)	Ln(Patent licenses)	Ln(Patent transfers)	Ln(Patent licenses)
Policy	-0.167 (0.214)	0.328** (0.129)	1.421** (0.659)	0.610 (0.538)
University Characters	Yes	Yes	Yes	Yes
Year FE	Yes	Yes	Yes	Yes
University FE	Yes	Yes	Yes	Yes
Obs.	420	420	720	540
Adjusted R^2	0.601	0.658		

Note. Standard errors are clustered by university in parentheses. In applying the SDID, we use the "placebo method" standard error estimator. ***Significant at 1%, **at 5%, *at 10%.

The TRR had a significant positive impact on the number of patent licenses at the 5% level, but no significant impact on the number of patent transfers; while the MOR had a significant positive impact on the number of patent transfers at the 1% level, but no significant impact on the number of patent licenses. These findings supported Hypothesis 1. The significant positive impacts of TRR and MOR on patent commercialization demonstrate the effectiveness of both pilots in providing incentives for rights holders to commercialize their patents by granting ownership to universities and inventors, respectively.

However, the TRR and MOR have produced different strategies for commercializing their patents. The impact of TRR on patent commercialization is only on patent licensing, while the impact of MOR is only on patent transfer. The above differences can only be reasonably explained in terms of the institutional environment. For TRR, although it has had a similar effect on patent commercialization as the implementation of the Bayh-Dole Act in the United States, the motivation behind it is different. The possible reason for the license-based commercialization of Chinese university patents is that under the state asset management system, the university administrators are concerned about the risk of losing state assets due to the transfer of patents. The reason that patent commercialization in the U.S. is dominated by licensing is that universities generally seek to generate sustainable and stable income from licensing. For MOR, the risk of policy uncertainty also makes inventors more willing to obtain immediate benefits in the form of patent transfer. thereby increasing the probability of successful patent commercialization.

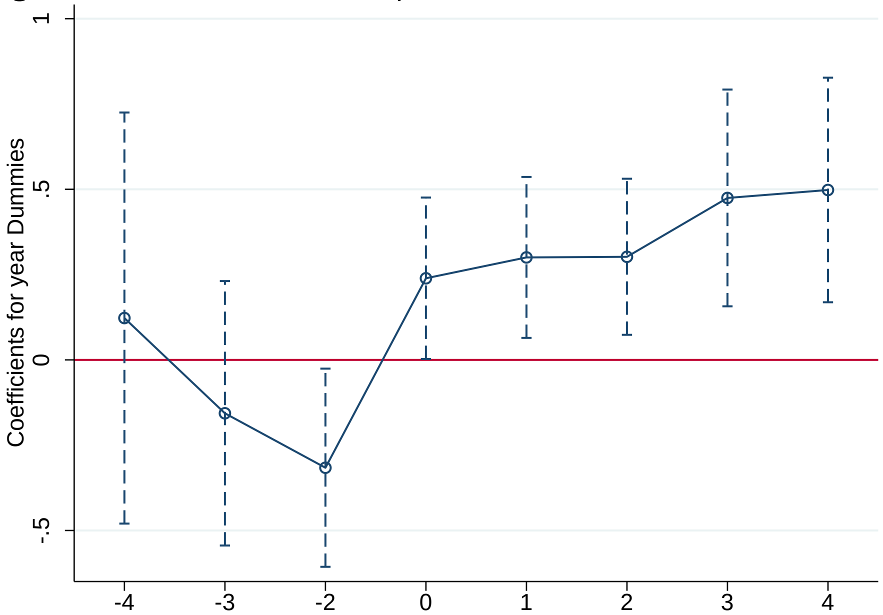
A potential challenge to the DID regression estimations is that the treatment and control groups must be comparable before the TRR implementation. To investigate this, we compared the coefficients before and after the implementation to test the parallel time trends before reform implementation and the impact after the reform. We used the model:

$$Licenses_{it} = \sum_{j=-4, j\neq -1}^{4} \theta_j T_{it}^{j} + \lambda X_{i,t-1} + \eta_i + \mu_t + \varepsilon_{it} \qquad (2)$$

where T_{it}^{j} is a series of dummy variables, T_{it}^{j}=1 when j>0 if university i is a university participating in the TRR and is in the jth year after being listed, and T_{it}^{j}=1 when j<0 if university i is a university that will participate in the TRR and is in the jth year before being listed. We use the year prior to the university's participation in the TRR as the base year, so $j \neq -1$. The coefficient θ_j indicates whether there is a significant difference in the trend of the number of patent licenses between the treated and control groups in the year j after (or the year before) the university's participation in TRR. Other variables are the same as in Model 1.

Based on Model 2, we constructed a parallel-trends test chart of whether there was a between-group difference in the logarithm of the number of patent licenses, where the control group is the period before the policy was implemented. The results are shown in Figure 1, which illustrates that the estimate of θ_j is not significantly different from 0 when $j<0$, with the exception that the patent licenses of the TRR universities were significantly lower than the control group universities when $j= -2$, there was no significant difference in the number of patent licenses between TRR universities and other universities in the control group. After reform implementation, we found that the number of patent licenses was significantly higher for TRR universities than for the control group universities, and the policy effects of TRR on patent licensing gradually increased over time.

Figure 1. *Parallel-Trends Test of Patent Licenses: TRR vs. Universities in the Control Group*



Note: Period -1 is the control group, and the results for each of the other times are relative to period -1.

4.2 Impact on Universities' Patent Application and Research Orientation

An increase in the number of university patents was also the desired effect of reform implementation. We further explored the empirical implications of the two pilot programs by examining patent applications after the policy, including the two dimensions of patent applications and research orientations. which we measured using the logarithm of the number of patent applications and the proportion of experimental development (ED) projects, respectively. The results are shown in Table 3.

Table 3. *The Effects of Pilot Reform on the Number of Patent Applications and Research Orientation*

Variables	TRR(DID)		MOR(SDID)	
	Ln(number of patent applications)	Proportion of ED projects	Ln(number of patent applications)	Proportion of ED projects
Policy	-0.096 (0.082)	-0.001 (0.020)	0.549*** (0.203)	0.268*** (0.056)
University Characteristics	controlled	controlled	controlled	controlled
Year FE	Yes	Yes	Yes	Yes
University FE	Yes	Yes	Yes	Yes
Obs.	420	420	660	540
Adjusted R^2	0.936	0.743		

Comparing the TRR and MOR effects on the number of patent applications, we found that the TRR did not have a significant impact on universities' patent applications. However, the MOR had a significantly positive impact at the 1% level, with patent applications increasing by about 55%. This corroborated Hypothesis 2. Because the TRR did not change the status of inventors who can only passively wait for patents to be commercialized for rewards, in the absence of an expectation that the inventor will receive an *ex post* reward for commercialization, inventors cannot be incentivized to disclose patentable information to universities. Incentivizing patent applications from the perspective of the external environment for universities to improve innovation is a relatively slow process, so TRR cannot have the effect of promoting patent applications. The MOR provided inventors 70% ownership of their own patents, thereby enhancing their motivation to patent existing results. This in turn stimulated patent filings.

As for the impact of the pilot reform on universities' research orientation, we found that the TRR had no significant impact on the proportion of ED projects, while the MOR significantly increased the proportion of ED projects. This suggests that the proportion of basic and applied research requiring higher creativity decreased. This confirmed Hypothesis 3. Just as the TRR has failed to motivate Chinese university researchers to boost patent applications in the absence of reward expectations, the TRR has also failed to change the research orientation preferences of university researchers. However, under the MOR, universities sharing patent ownership with inventors facilitated inventors taking the initiative to promote commercialization. The uncertainty of MOR encouraged inventors to shift their research orientation to research with lower levels of innovation with short-term cycles and faster payoffs.

5 Robustness Test

5.1 The Effects of TRR on Patent Licensing in Universities

To verify the impact of TRR on university patent licensing, we perform robustness tests through three aspects as follows: First, although the treatment and control groups were universities under the Ministry of Education's jurisdiction, the 26 pilot universities involved in TRR may differ tremendously from other universities, we use propensity score matching with difference-in-difference to further verify the TRR's impact on university patent licensing. Since we had a panel of universities observed over time, matching universities was implemented year-by-year using lagged covariates. After estimating the propensity score with the Kernel method, treatment universities were matched with control universities based on the propensity scores. After the matching procedure, the pre-existing observed differences between treatment and control groups were expected to be substantially ameliorated. Before continuing, the balancing property of the propensity score was tested in the annual sub-samples, and the results showed that the balance characteristics were satisfied.[xviii] Then we applied the DID model to further verify the real TRR effect. The DID model is shown in Equation (1). The results are shown in Column 1 of Table 4. We found that the TRR have had a significant impact on universities' patent licensing and the magnitude of the effect was similar to the results for DID.

Second, we restrict our sample to Chinese universities selected for Project 985, which are the top comprehensive or science and technology universities and are the main force engaged in high-level R&D in China, making the samples of the treatment and control groups more comparable. Among the universities studied in this paper, 32 of them belong to the Project 985 universities. The results from Column 2 of Table 4 show that the results based on DID still support the conclusion that TRR has a significant and positive impact on the number of patent licenses.

Third, based on the sample of 985 universities, we further add the patent-related policies autonomously adopted by universities during the sample observation period as control variables, thus examining the impact of TRR on patent commercialization while controlling for the impact of relevant patent policies implemented by universities on inventors. We divide the university's patent policies into five categories. Equity share denotes the share of equity between the university and the inventor after the patent has been funded as equity. Royalty share denotes the share of revenue from patent transfer and licensing between the university and the inventor. Patent subsidy represents whether the university subsidizes the patent application fee. Tenure denotes that patent authorization and commercialization are the basis for the appointment and assessment of professors. Bonus denotes the reward of the university to the inventor after the patent is granted. We construct the above five policy variables at the "university-annual" level. When the above variables are 0, it means that the university does not adopt such policies. When equity share and royalty share are greater than 0 and less than 1, it means the share that the inventor can obtain. When the other three policy variables are 1, it means that the university has adopted the policy. From Column 3 of Table 4, it can be found that the TRR still has a significant and positive impact on patent licensing after controlling the policy variables at the university level.

Table 4. *The Effects of TRR on Patent Licensing in Universities*

Variables	PSM-DID	985 Universities	985 Universities (including university-level patent policies)
Policy	0.300** (0.133)	0.545*** (0.195)	0.517*** (0.165)
Equity share			-0.258 (0.318)
Royalty share			-0.034 (0.398)
Patent subsidy			0.135 (0.279)
Tenure			-0.256 (0.370)
Bonus			0.088 (0.295)
University Characters	Yes	Yes	Yes
Year FE	Yes	Yes	Yes
University FE	Yes	Yes	Yes
Obs.	376	210	210
Adjusted R^2	0.654	0.759	0.756

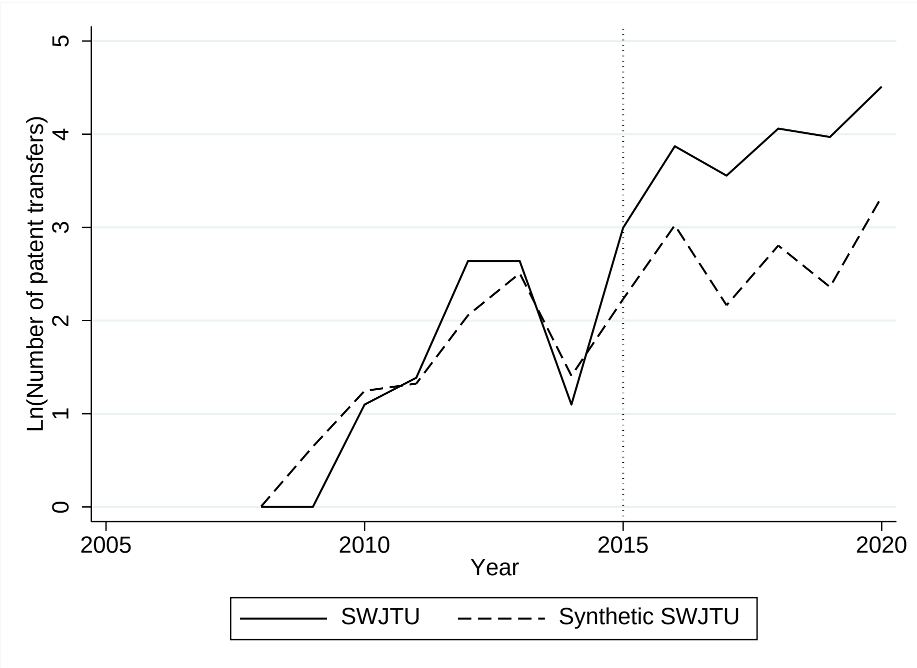
Note: The five categories of university patent-related policy information in column 3 were obtained from (Yi and Long, 2021).

5.2 The Effects of MOR on SWJTU

We use the synthetic control method (SCM) to test the robustness of the MOR effects. The predictive control variables include the number of R&D personnel in universities, the number of graduate students, and the total investment in science and technology. The advantage of SCM is that it provides an intuitive way to show the effects of MOR.

First, we examined the impact of MOR on the number of patent transfers. Applying the SCM method, we found that the synthetic SWJTU was composed of four universities: Huazhong Agricultural University, Xidian University, Wuhan University of Technology and Sichuan University (with weights 0.584, 0.215, 0.198 and 0.003, respectively). Trends in the number of patent transfers between SWJTU and synthetic SWJTU are shown in Figure 2. We found that before the MOR implementation, the number of patents transferred by SWJTU and synthetic SWJTU almost converged. However, after the MOR implementation, the number of patent transfers at SWJTU increased significantly compared to the synthetic SWJTU, beginning with the year 2015.

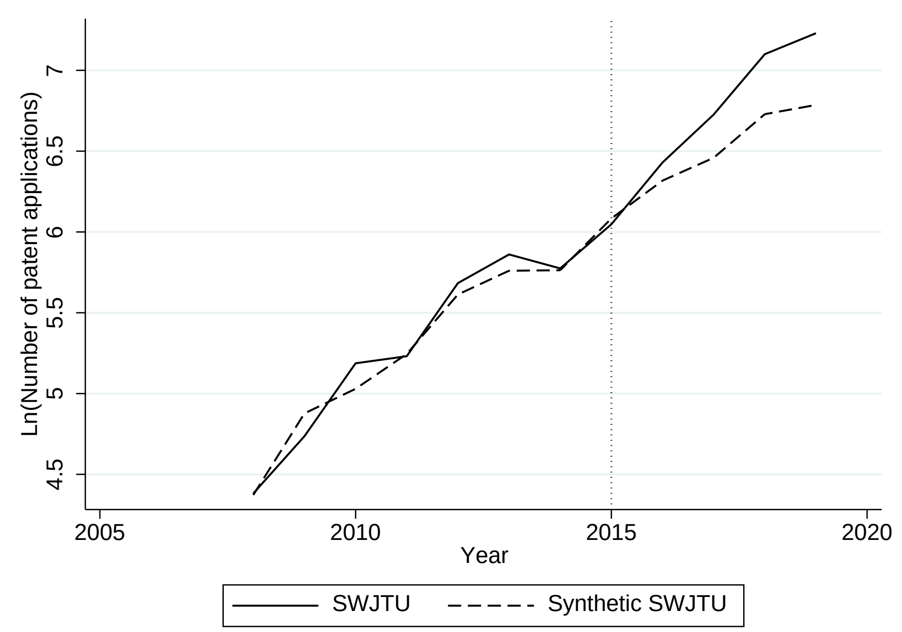
Figure 2. *Patent Transfer Trends: SWJTU and Synthetic SWJTU*



Then we constructed a comparison chart of the logarithm of the number of patent applications between SWJTU and synthetic SWJTU, we found that the synthetic SWJTU was composed of six universities: Sichuan University, Chang'an University, China University of Geosciences (Beijing), China University of Geosciences (Wuhan), Southwest University and China University of Petroleum (East China) (with weights 0.427, 0.225, 0.161, 0.093, 0.071 and 0.021, respectively). Trends in the number of patent applications between SWJTU and synthetic SWJTU are shown in Figure 3. We found that in 2015, before the MOR implementation, patent application trends were almost the same between the synthetic SWJTU and the real SWJTU, indicating that the SCM was a good fit for the

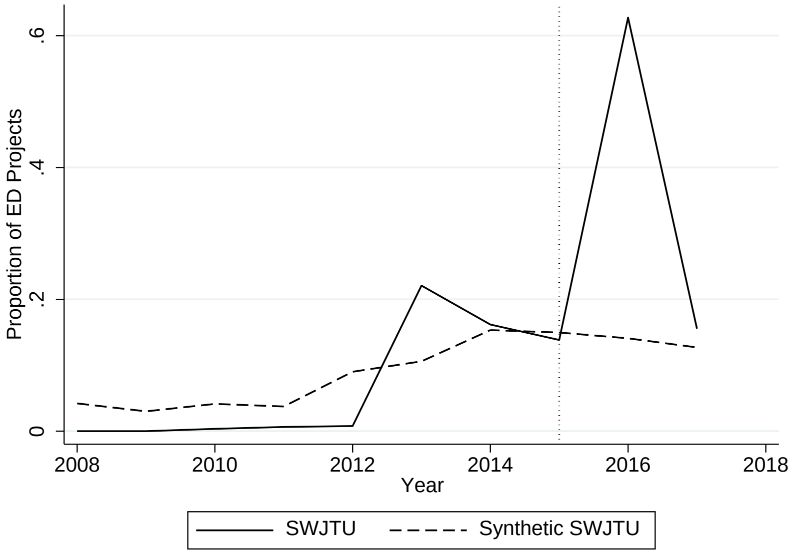
SWJTU patent applications change path before MOR implementation. After MOR implementation, the real SWJTU patent applications were significantly higher than those for the synthetic SWJTU. These results are consistent with our previous findings, indicating that the finding that MOR had a significant positive effect on the number of patent applications was robust.

Figure 3. *Patent Application Trends: SWJTU and Synthetic SWJTU*



Finally, we examined MOR's impact on the proportion of ED projects. Applying the SCM method, we found that the synthetic SWJTU comprised East China University of Science and Technology, Southwest University and Fudan University (with weights 0.488, 0.309 and 0.203, respectively). Figure 4 shows that before the MOR, SWJTU had mostly similar proportions of ED projects to synthetic SWJTU. However, after the MOR, SWJTU's proportion of ED projects sharply increased and the gap between SWJTU and synthetic SWJTU significantly increased in 2016. However, in 2017, the proportion began to decline and is no longer significantly different from synthetic SWJTU. The possible reason is that the uncertainty of MOR is waning as it is not repealed by the government after one year of implementation. Therefore, university inventors no longer deliberately adjust the research orientation to applied research with short cycles and low returns.

Figure 4. *Trends of Proportion of ED Projects: SWJTU and Synthetic SWJTU*



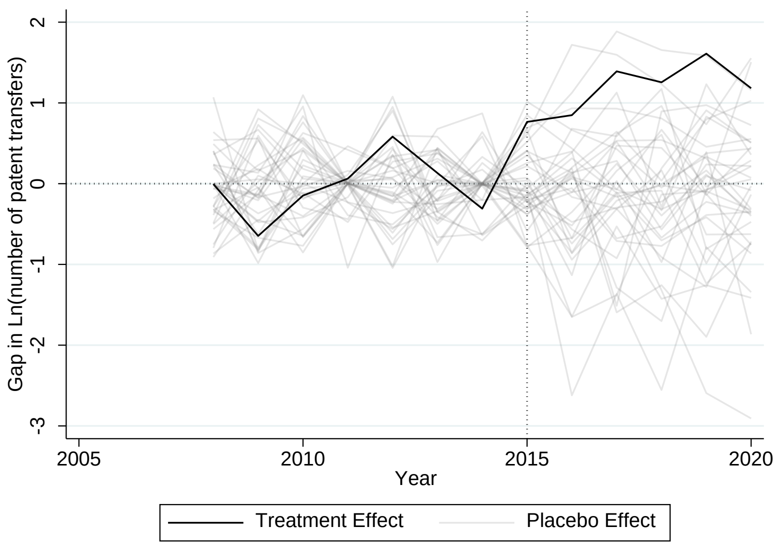
However, could the above results have occurred by chance? How often would we obtain these results if we had chosen a university at random instead of using SWJTU? To verify the robustness of the results, we use placebo tests. Based on methods used by Abadie and Gardeazabal (2003) and Abadie et al. (2010), we ran placebo studies by applying the SCM to a university that did not implement MOR during our study's sample period. That is, the treatment status was assigned to one control university as if it had implemented MOR in the intervention year. This procedure was then repeated for all control universities in the original donor pool. Placebo effects were calculated as gaps between the outcome values of a placebo university and its synthetic objects. If the placebo studies showed that the gap estimated for SWJTU was unusually large relative to the gaps for the universities that did not implement MOR, this would further support the credibility of our results.

In addition, the placebo test has an applicable premise; the SCM requires that each university's synthetic object have a good fit before MOR implementation. If a university had a poor fit before MOR implementation, that is, the pre-intervention mean-squared prediction error (MSPE) was quite different from that of SWJTU, then even a large difference in predictors obtained after MOR implementation could not reflect the true effects. Therefore, we conducted the placebo tests suggested by Abadie et al. (2010), excluding universities that had a pre-MOR of more than two times SWJTU's MSPE, allowing us to focus exclusively on those universities that fit almost as well as SWJTU in the period prior to MOR.

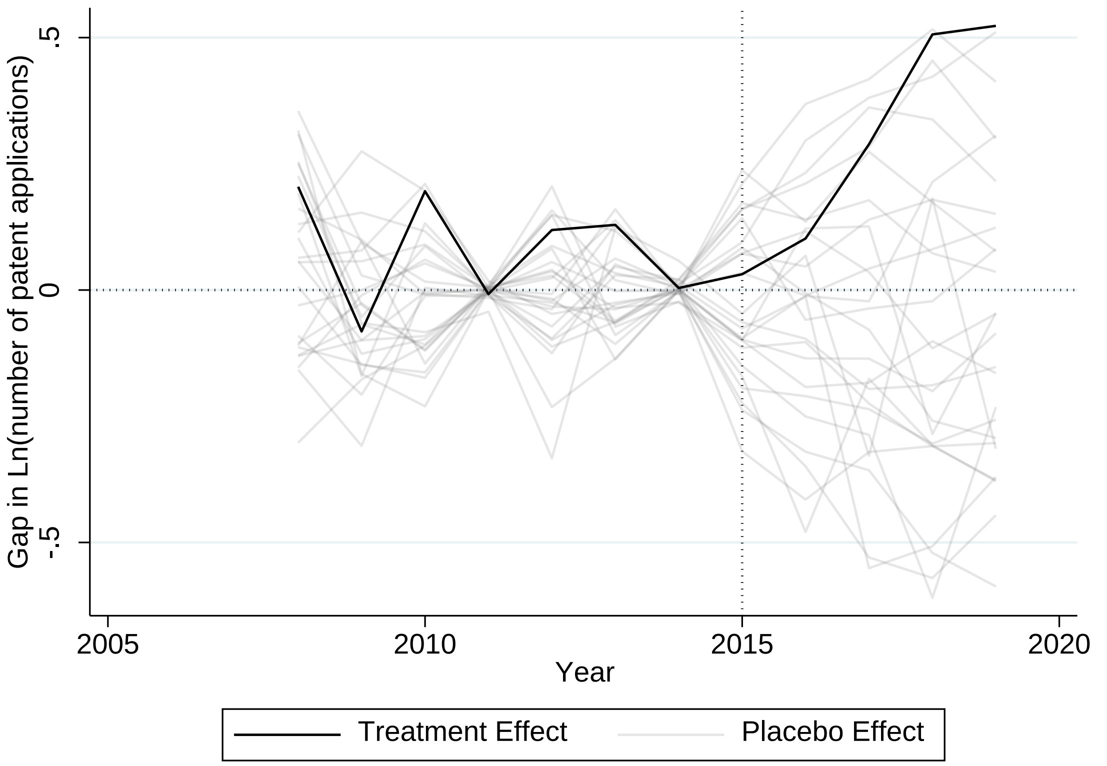
After obtaining all placebo estimates, the time trends of estimated treatment effects and placebo effects were compared graphically. If the treatment effects for SWJTU were larger than most placebo effects, the treatment effects may be considered plausible. Figures 5a-c display the placebo test results. The dashed lines represent the MOR effect on patent commercialization, patent applications, and research orientation for each university in the control group, while the solid line denotes the effect for SWJTU. As shown in Figures 5a-c, in general, the effect line for SWJTU is large relative to the distribution of the control universities' lines after the MOR implementation, which demonstrated the significant positive impact of MOR on patent transfers, the patent applications, and the shift of R&D direction to applied research. The placebo test results were consistent with the previous findings.

Figure 5

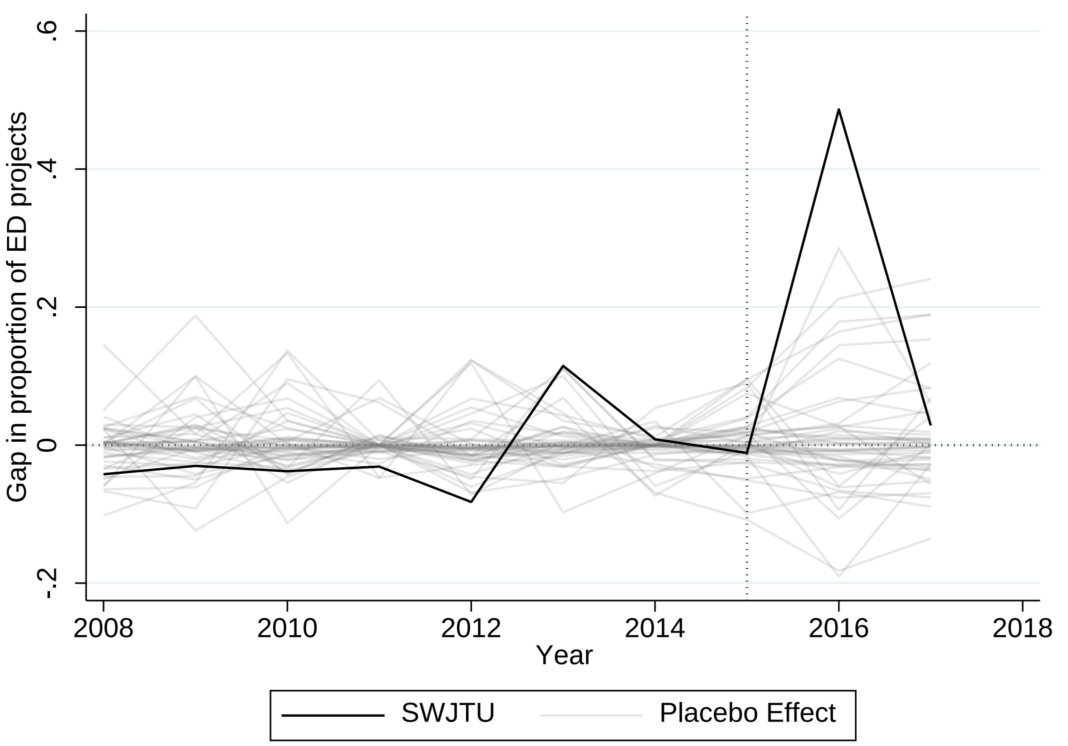
a. *Logarithm of Patent Transfers Gaps in SWJTU and Placebo Gaps in Control Universities (Excludes Universities with Pre-MOR MSPE Two Times Higher Than SWJTU's)*



b. Logarithm of Patent Applications Gaps in SWJTU and Placebo Gaps in Control Universities (Excludes Universities with Pre-MOR MSPE Two Times Higher Than SWJTU's)



c. Proportion of ED Projects Gaps in SWJTU and Placebo Gaps in Control Universities (Excludes Universities with Pre-MOR MSPE Two Times Higher Than SWJTU's)



6 Discussion and Conclusion

As reviewed and proposed in the research agenda for innovations, the impacts of macro-environmental factors such as government policies on innovations have been listed as one of the key challenges in organizations and innovations (Hauser, et al. 2006). The 26 universities' TRR and SWJTU's MOR are important explorations made by a typical emerging market, China, in recent years to promote patent commercialization in universities. Which patent ownership allocation model better promotes application and commercialization of university patents? How do different policies shape the research orientations and innovation directions? These questions are of general interests to policy makers, academic researchers, and industry practitioners.

Based on Chinese patent data and university science and technology statistical data, our study tests the effects of two university patent ownership allocation models on university patent commercialization. Our results revealed that the two opposite models for the allocation of university patent ownership produce different patent commercialization outcomes, with TRR favoring an increase in the number of patent licenses and MOR favoring an increase in the number of patent transfers. As the two main types of patent commercialization models, the choice between patent licensing or patent transfer should have been made by the implementing entity based on the quality and other characteristics of the patent. However, the different impact of TRR and MOR on patent commercialization is actually due to the special institutional environment and policy uncertainty risk in China. Under the management system of university patents as state-owned assets, in order to avoid the risk of losing state-owned assets, Chinese universities can only commercialize their patents through patent licensing, which may be the reason why TRR can only significantly increase the number of patent licenses. Since MOR is a policy implemented by SWJTU on its own initiative, the uncertainty makes inventors more willing to obtain short-term income through patent transfer. Thus, the impact of MOR is only reflected in increasing the number of patent transfers.

Furthermore, in terms of the impact of TRR and MOR on university patent application, the "anti-commons tragedy" of patents caused by the state-owned asset management system has led to the extremely low commercialization level of Chinese universities for a long time. In this situation, the TRR, which does not directly affect the incentive level of researchers to improve their willingness to accelerate technology development and disclose patentable technology information to universities, cannot change researchers' patent applications and research orientations. The MOR, on the other hand, has changed the status of university patents as state-owned assets by giving inventors the majority of ownership of patent commercialization, effectively motivating researchers to accelerate patent applications. Yet the uncertainty of MOR and the pursuit of personal gain also makes researchers more focused on short-term gains, and thus tend to shift their R&D projects to low-level applied research.

Therefore, in terms of the impacts of the two different patent rights allocation models in China, it is difficult to make a judgment call on which model is more conducive to promoting patent commercialization. For the TRR, it can promote the increase of patent licenses with sustainable benefits, so it is conducive to the formation of a virtuous circle of patent commercialization. However, it cannot effectively stimulate the increase of patent application as the basis of patent commercialization. From the perspective of increasing the number of patent transfers and applications, the MOR achieved remarkable results. Nonetheless, we need to be aware of two potential problems: first, in terms of its impact on research orientation, the MOR may guide universities' R&D investment to research with a lower level of innovativeness. This deviates from the original intention of promoting patent commercialization in China's universities and does not facilitate the realization of China's innovative national strategic goals in the long run. Second, the type of university patent commercialization driven by the MOR was patent transfer, not patent licensing. Patent transfer cannot bring sustainable and stable benefits to universities.

Problem solving needs to start with the root of the problem. For the TRR, the state asset management system is a key constraint on patent transfer, and although it objectively leads universities to adopt a patent licensing model that is more conducive to generating sustainable income, it does not mean that all patents can only be licensed. Instead, it should respect the laws of the market and give implementing entities the option to adopt appropriate commercialization models depending on the circumstances of different patents. This can also increase the income from the commercialization of university patents, stimulating the production of a larger number of patents by raising the expectation that researchers will receive *ex post* rewards.

For the MOR, the main problem lies in the instability of the MOR and the lack of commercialization of the inventors. Although MOR has been supported by local and central governments, it has not been formally recognized by law. Therefore, researchers are not sure whether the ownership allocated to inventors by MOR still exists when more resources have been invested in more innovative research, so they invest more energy into short-term research. Therefore, we must clarify the legal issues related to MOR as soon as possible to ensure the stability of ownership, so that university patent inventors can form long-term stable expectations. Article 6 of the Patent Law, revised in October 2020, provides that entities can dispose of their service invention patent application rights and patent rights in accordance with the law, providing an opportunity to legalize mixed ownership reform. In addition, university researchers are often poor at patent commercial operation and management, and often sell patents to save time and effort. Therefore, while giving the vast majority of ownership rights to inventors, universities should also take an active role. If universities can establish professional technology transfer teams, who manage patents after application and connect patent commercialization channels to continuously improve patent maturity (Choudhury et al., 2020), enterprises would be more willing to cooperate with universities to facilitate patent licensing. Patent licensing could then become a stable source for nurturing universities' R&D.[xix]

In summary, institutional change does not operate in isolation. In order to achieve the desired effect of institutional changes, it is necessary to analyze whether the institutional changes are consistent with the relevant regulative, normative, and cognitive-cultural institutional environment. In cases of inconsistency, our research suggests ways to adjust and adapt in order to achieve the expected effect of the institutional changes. As long as the relevant institutional obstacles and uncertain expectations are effectively addressed, it is believed that both the TRR and MOR can achieve effective incentives for patent commercialization and promote a virtuous cycle of university innovation and patent commercialization.

Data Availability Statement:

The data that support the findings of this study are available from SIPO. Restrictions apply to the availability of these data, which were used under license for this study. Data are available from China National Intellectual Property Administration (http://english.cnipa.gov.cn) with the permission of SIPO.

References

Abadie, A., & Gardeazabal, J. (2003). The economic costs of conflict: A case study of the Basque Country. *American Economic Review*, 93(1), 113-132.

Abadie, A., Diamond, A., & Hainmueller, J. (2010). Synthetic control methods for comparative case studies: Estimating the effect of California's tobacco control program. *Journal of the American statistical Association*, 105(490), 493-505.

Abadie, A., Diamond, A., & Hainmueller, J. (2015). Comparative politics and the synthetic control method. *American Journal of Political Science*, 59(2), 495-510.

Adams, J. D. (1990). Fundamental stocks of knowledge and productivity growth. *Journal of Political Economy*, 98(4), 673-702.

Aghion, P., & Tirole, J. (1994). The management of innovation. *The Quarterly Journal of Economics*, 109(4), 1185-1209.

Aghion, P., Antonin, C., Paluskiewicz, L., Strömberg, D., Sun, X., Wargon, R., & Westin, K. (2023). Does Chinese

Research Hinge on US Coauthors? Evidence from the China Initiative. NBER SI f183830.pdf (nber.org), with Prof. Lee Branstetter's Discussions.

Association of University Technology Managers. (1996). *AUTM Licensing Survey: Survey Summary*. Association of University Technology Managers, Norwalk, CT.

Association of University Technology Managers. (1998). *AUTM Licensing Survey: Survey Summary*. Association of University Technology Managers Norwalk, CT.

Arkhangelsky, D., Athey, S., Hirshberg, D. A., Imbens, G. W., & Wager, S. (2021). Synthetic difference-in-differences. *American Economic Review*, 111(12), 4088-4118.

Choudhury, P., Khanna, T., & Makridis, C. A. (2020). Do managers matter? A natural experiment from 42 R&D labs in India. *The Journal of Law, Economics, and Organization*, 36(1), 47-83.

Cohen, W. M., Nelson, R. R., & Walsh, J. P. (2002). Links and impacts: the influence of public research on industrial R&D. *Management Science*, 48(1), 1-23.

Cowan, R., & Zinovyeva, N. (2013). University effects on regional innovation. *Research Policy*, 42(3), 788-800.

Crespi, G. A., Geuna, A., Nomaler, Ö., & Verspagen, B. (2010). University IPRs and knowledge transfer: is university ownership more efficient? *Economics of Innovation and New Technology*, 19(7), 627-648.

Department of Science and Technology, Ministry of Education. (2015). *Compilation of Science and Technology Statistics of Higher Education Institutions in 2015*. Higher Education Press.

Eesley, C., Li, J. B., & Yang, D. (2016). Does institutional change in universities influence high-tech entrepreneurship? Evidence from China's Project 985. *Organization Science*, 27(2), 446-461.

Gambardella, A., Giuri, P., & Luzzi, A. (2007). The market for patents in Europe. *Research policy*, 36(8), 1163-83.

Geiger, R.L. (1993). *Research and Relevant Knowledge: American Research Universities Since World War II*, Oxford University Press.

Geuna, A., & Rossi, F. (2011). Changes to university IPR regulations in Europe and the impact on academic patenting. *Research Policy*, 40(8), 1068-1076.

Giuri, P., Munari, F., & Pasquini, M. (2013). What determines university patent commercialization? Empirical evidence on the role of IPR ownership. *Industry and Innovation*, 20(5), 488-502.

Grossman, S. J., & Hart, O. D. (1986). The costs and benefits of ownership: A theory of vertical and lateral integration. *Journal of Political Economy*, 94(4), 691-719.

Guo, H. (2007). IP management at Chinese universities. Intellectual property management in *health and agricultural innovation: a handbook of best practices*, Oxford Press, 1673-82.

Hackett, S. M., & Dilts, D. M. (2004). A systematic review of business incubation research. *The Journal of Technology Transfer*, 29(1), 55-82.

Hauser, J., Tellis, G. J., & Griffin, A. (2006). Research on innovation: A review and agenda for marketing science. *Marketing Science*, 25(6), 687-717.

He, L., Chen J. (2013). Failure of China's 'Bayh-Dole Act' and the Way Out for the Transformation of University Intellectual Property, *Intellectual Property*, 3,84-88. (in Chinese)

He, Z. L., Tong, T. W., Zhang, Y., & He, W. (2018). Constructing a Chinese patent database of listed firms in China: Descriptions, lessons, and insights. *Journal of Economics & Management Strategy*, *27*(3), 579-606.

Henderson, R., Jaffe, A. B., & Trajtenberg, M. (1998). Universities as a source of commercial technology: a detailed analysis of university patenting, 1965–1988. *Review of Economics and statistics*, 80(1), 119-127.

Hirsch, P. M. (1975). Organizational effectiveness and the institutional environment. *Administrative science quarterly*, 327-344.

Hvide, H. K., & Jones, B. F. (2018). University innovation and the professor's privilege. *American Economic Review*, 108(7), 1860-1898.

Jeong, S., Lee, S., & Kim, Y. (2013). Licensing versus selling in transactions for exploiting patented technological

knowledge assets in the markets for technology. *The Journal of Technology Transfer*, 38, 251-272.
Kang, K. N., Liu, A. L., Yan, B. (2018). The Basic Logic of Mixed Ownership of Scientific and Technological Achievements of Jobs, *Science and Technology of Chinese Universities*, 11, 47-50 (in Chinese).
Kenney, M., & Patton, D. (2011). Does inventor ownership encourage university research-derived entrepreneurship? A six university comparison. *Research Policy*, 40(8), 1100-12.
Lee, K., & Jung, H. J. (2021). Does TTO capability matter in commercializing university technology? Evidence from longitudinal data in South Korea. *Research Policy*, 50(1), 104-133.
Levitt, S. D., & Venkatesh, S. A. (2000). An economic analysis of a drug-selling gang's finances. *The Quarterly Journal of Economics*, 115(3), 755-789.
Luan, C., Zhou, C., & Liu, A. (2010). Patent strategy in Chinese universities: a comparative perspective. *Scientometrics*, 84(1), 53-63.
Marcus, J. (2020). Think universities are making lots of money from inventions? Think again. *The Hechinger Report*, 17.
Martínez, C., & Sterzi, V. (2021). The impact of the abolishment of the professor's privilege on European university-owned patents. *Industry and Innovation*, 28(3), 247-282.
Morgan, R. P., Kannankutty, N., & Strickland, D. E. (1997). Future directions for university-based research. *ASEE Prism*, 6(7), 30-36.
Mowery, D. C., Nelson, R. R., Sampat, B. N., & Ziedonis, A. A. (2001). The growth of patenting and licensing by US universities: an assessment of the effects of the Bayh–Dole act of 1980. *Research Policy*, 30(1), 99-119.
Mowery, D. C., & Sampat, B. N. (2004). The Bayh-Dole Act of 1980 and university–industry technology transfer: a model for other OECD governments? *The Journal of Technology Transfer*, 30, 115-127.
Mowery, D. C., Sampat, B. N., & Ziedonis, A. A. (2002). Learning to patent: Institutional experience, learning, and the characteristics of US university patents after the Bayh-Dole Act, 1981-1992. *Management Science*, 48(1), 73-89.
Mowery, D. C., & Ziedonis, A. A. (2002). Academic patent quality and quantity before and after the Bayh–Dole act in the United States. *Research Policy*, 31(3), 399-418.
Powell, D. (2022). Synthetic Control Estimation Beyond Comparative Case Studies: Does the Minimum Wage Reduce Employment? *Journal of Business & Economic Statistics*, 40:3, 1302-1314, DOI: 10.1080/07350015.2021.1927743
Prabhu, J. C., Chandy, R. K., & Ellis, M. E. (2005). The impact of acquisitions on innovation: poison pill, placebo, or tonic? *Journal of Marketing*, 69(1), 114-130.
Sampat, B. N. (2006). Patenting and US academic research in the 20th century: The world before and after Bayh-Dole. *Research Policy*, 35(6), 772-789.
Sampat, B. N., Mowery, D. C., & Ziedonis, A. A. (2003). Changes in university patent quality after the Bayh–Dole act: a re-examination. *International Journal of Industrial Organization*, 21(9), 1371-1390.
Scherer, F. M., & Weisburst, S. (1995). Economic Effects of Strengthening Pharmaceutical Patent Protection in Italy, *International Review of Industrial Property and Copyright Law*, 26(6), 1009-1024.
Scott WWR. (2014). *Institutions and Organizations: Ideas, Interests, and Identities*, Sage Publications, Thousand Oaks, CA.
Thursby, J. G., & Thursby, M. C. (2011). Has the Bayh-Dole act compromised basic research? *Research Policy*, 40(8), 1077-1083.
Thursby, J. G., Jensen, R., & Thursby, M. C. (2001). Objectives, characteristics and outcomes of university licensing: A survey of major US universities. *The Journal of Technology Transfer*, 26, 59-72.
Thursby, J. G., & Thursby, M. C. (2002). Who is selling the ivory tower? Sources of growth in university licensing. *Management Science*, 48(1), 90-104.

Thursby, M., Thursby, J., & Gupta-Mukherjee, S. (2007). Are there real effects of licensing on academic research? A life cycle view. *Journal of Economic Behavior & Organization*, 63(4), 577-598.

Tolbert, P. S., David, R. J., & Sine, W. D. (2011). Studying choice and change: The intersection of institutional theory and entrepreneurship research. *Organization Science*, 22(5), 1332-1344.

United States General Accounting Office. (1998). *Technology Transfer: Administration of the Bay-Dole Act by Research Universities*.

Yi, W., & Long, C. X. (2021). Does the Chinese version of Bayh-Dole Act promote university innovation? *China Economic Quarterly International*, 1(3), 244-257.

Zhu, Y. (2016). Review and reconstruction of the legal system for the transformation of scientific and technological achievements in universities, *Law Science*, (4), 81-92. (in Chinese)

Appendix

Table A1. Comparison of R&D levels of Chinese Universities by Affiliation (2014)

	Central ministry-affiliated institutions	**Universities directly under the Ministry of Education**	**Local government-owned universities**	**Total**
Quantity	27	64	1058	1146
Number of R&D personnel	19072	116138	234300	369510
Average number of R&D personnel	706.37	1903.9	221.46	
R&D funds allocated	11495754	42315738	28693908	82505400
Average R&D funds allocated	425768.67	693700.62	27120.9	
R&D expenditure	8719224	35043779	23231515	66994518
Average R&D expenditure	322934.22	574488.18	21957.95	
Number of patents granted	5233	28614	48522	82369
Average number of patents granted	193.81	469.08	45.86	

Note: The summary statistics were based on the 2015 compilation of science and technology statistics of Chinese higher education institutions (Department of Science and Technology, Ministry of Education, P. R. China, 2015). The units of the R&D funds and expenditure variables are in thousands of RMB, and the numbers of universities and patents are in numbers as listed. The units of R&D Personnel are in persons.

Table A2. Prerequisites for TRR Pilot University Selection

	(1) Universities in the TRR (2011)	(2) Universities in the TRR (2013)
Ln(R&D personnel)	-2.438*** (0.693)	-0.860** (0.384)
Ln(graduate students)	1.578*** (0.565)	-0.169 (0.293)

Ln(sci-tech funds)	0.192 (0.539)	0.748** (0.324)
N	120	192
Pseudo R^2	0.193	0.035

Note: The model controls for year fixed effects. All explanatory variables are first-order lagged terms.

Table A3. Balance Test

		2009		2011		2013		2015	
Covariate		%bias	t	%bias	t	%bias	t	%bias	t
Ln(R&D personnel)	Un-matched	-58.1	-2.21	-45.4	-1.72	-31.4	-1.17	-44.6	-1.68
	Matched	-0.8	-0.03	-12.3	-0.41	2.6	0.11	0.2	0.01
Ln(graduate students)	Un-matched	12.2	0.45	-1.8	-0.07	-13.7	-0.52	-15.0	-0.57
	Matched	4.0	0.12	-0.4	-0.01	-7.0	-0.25	10.5	0.36
Ln(sci-tech funds)	Un-matched	-3.3	-0.12	-2.3	-0.09	-9.5	-0.36	-25.3	-0.96
	Matched	-1.0	-0.04	-18.4	-0.65	5.1	0.18	-9.6	-0.36

[i] For example, during the current COVID-19 pandemic, the Pfizer and Moderna vaccines were all based on the mRNA research from the university.

[ii] According to China's 2018 Annual Report on Patent Statistics, from December 1985 to December 2018, the cumulative number of invention patents granted to universities accounted for 25.2% of the total number of invention patents, second only to the 64.6% share of enterprises.

[iii] The report of the Association of University Technology Managers shows that the number of universities with technology transfer offices increased from 25 in 1980 to 200 in 1990, and the patent licensing income of the association's universities increased from $222 million in 1991 to $6.98 billion in 1997 (Association of University Technology Managers, 1996, 1998).

[iv] The above data are from the 2015 Compendium of Science and Technology Statistics for Higher Education Institutions, reflecting the data of Chinese universities in 2014. See Appendix Table 1 for detailed comparative information.

[v] Private universities supplement China's higher education system, with a relatively small number and a low level of education. According to the 2016 National Education Development Statistics Bulletin of the Ministry of Education, there are 2,596 colleges and universities in China, including 742 private colleges. China's colleges and universities have enrolled 671,700 graduate students, of which privately-run colleges only admit 715 graduate students, and no private colleges have qualifications for doctoral admissions.

[vi] According to the provisions of Article 9 of the "Interim Measures for the Management of the Disposal of State-owned Assets of Central-level Public Institutions," issued by the Ministry of Finance in 2009, university intellectual property, a kind of intangible property, is correspondingly included in the scope of state-owned assets

management.
[vii] Income from patent commercialization is subject to “two lines of revenue and expenditure” management.
[viii] Referring to the Zhongguancun National Innovation Pilot Zone Yearbook 2013, most of the universities in the cities where each pilot zone is located enjoy the policy benefits of the pilot zone in the form of setting up university science and technology parks in the pilot zone, and a search reveals that the pilot zone covers all universities directly under the Ministry of Education in Beijing, Shanghai, Wuhan and Hefei.
[ix] Although the patent-in-stock method can motivate inventors to participate in patent commercialization, the complicated approval procedures and many restrictions for university patents as state assets make it difficult to implement the patent-in-stock method for university patent commercialization in practice (Kang et al., 2018).
[x] Xiaogang Village is the birthplace of China's rural reform. In order to stimulate farmers' enthusiasm for production, farmers in Xiaogang Village, Anhui Province, risked great political risks in 1978 when they began to contract out land to households and resume family agricultural production in the era of planned economy.
[xi] In 2018, the central government's work report proposed to "explore the granting of ownership and long-term use rights of scientific and technological achievements to scientific researchers". In May 2020, the Ministry of Science and Technology and nine other departments issued the "Pilot Implementation Plan for Granting Researchers Ownership or Long-term Use of Scientific and Technological Achievements on Duty", and selected 40 university research institutions nationwide to conduct MOR pilot projects. The Patent Law revised in October 2020 also further emphasizes that units have the right to dispose of the patent rights of inventions on duty, so MOR has largely cleared the legal hurdle.
[xii] The compilation provides college-level data from 2008 to 2017. From 2018, the compilation no longer provides university-level data.
[xiii] See the notice issued by China's Ministry of Science and Technology: " To give researchers the right to ownership of scientific and technological achievements or long-term use of the pilot unit list ".
[xiv] There are 75 universities under the jurisdiction of the Ministry of Education. This paper excluded 15 universities with fewer than 600 patents.
[xv] We have searched for all patent-related information including the "Patent Management Regulations of Southwest Jiaotong University", which marked the beginning of the implementation of MOR. We have not found any other institutional support or other smaller initiatives/actions that could have implemented together with the reform of the ownership of scientific and technological achievements in the intervention period.
[xvi] According to the definition of the Chinese Bureau of Statistics, basic research refers to experimental or theoretical research to obtain new knowledge about the basic principles of phenomena and observable facts. It does not aim at any specific application or use. Applied research refers to creative research carried out to identify possible uses of basic research results, or to explore new methods or approaches to achieving predetermined goals. Experimental development (ED) is the use of existing knowledge obtained from basic research, applied research, and practical experiences to create new products, materials, and devices; establish new processes, systems, and services; and produce and establish substantial improvement and systematic work. See the National Statistical Bureau's National Statistical Bulletin on Scientific and Technological Funds.
[xvii] See the official website of the National Bureau of Statistics of China, Wan Donghua, the main person in charge of the Department of Social Science and Culture of the National Bureau of Statistics, answers reporters' questions on the release of the Specification for Research and Experimental Development (R&D) Input Statistics (for Trial Implementation), http://www.stats.gov.cn/tjsj/sjjd/201905/t20190507_1663329.html
[xviii] The results of the balance test are shown in Appendix Table 3.
[xix] In April 2018, the Department of Science and Technology of the Ministry of Education and the Zhongguancun Management Committee issued the Implementation Plan on Promoting the Transformation of Scientific and Technological Achievements in Universities in Beijing. Establishing the first batch of 12 university technology transfer offices provides a useful exploration of technology transfer office models in Chinese universities.