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Does the Chinese version of Bayh-Dole Act promote university innovation?

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ABSTRACT

The Chinese version of Bayh-Dole Act (BD for short) refers to the ownership reform policy for patents arising from government funding research grants. We collected the policies of 31 "985 project" universities from 1998 to 2015 to explore the impact of the Chinese BD. Empirical evidence suggested that patent applications, patent approvals, patent durations, patent citations, and profits from technology transfer of the universities adopting the BD policy had increased significantly. The BD policy encouraged more researchers to disclose and commercialize their inventions and to pursue global patent filing strategies. Compared with the BD policy, the incentive effect of subsidies, tenure promotion and cash bonuses were relatively limited.

1. Introduction

The scientific achievements within Chinese universities have long been featured by a low rate of patenting and low technology transfer. A large number of new technologies and inventions fail to transfer into values, but end with the closure of relevant projects or the publication of relevant papers, which is a huge waste of resources. Existing studies demonstrated that making good use of the scientific achievements of universities could not only increase the R&D investment of local enterprises (Jaffe, 1989; Cardamone et al., 2015), boost the number of patents and product output of high-tech industries (Wei et al., 2013), but also could drive employment and wage growth (Hausman, 2013). Therefore, it is extremely important to figure out how to improve the transformation of scientific achievements within universities and turn universities into a "booster" of China's economic development.

Amid fierce international competition, developed countries have long been exploring measures to promote university innovation. The US federal government passed the Bayh-Dole Act (hereinafter abbreviated as BD) in 1980, permitting universities to pursue ownership of an invention arising from federal government-funded research to license and transfer patents, and requiring universities to share the profits from an invention with its inventor. After BD took effect, the number of patent applications of US universities rose by 238% during 1991–2000, and the number of and the amount from patent transfer contracts went up by 161% and 520% respectively.[1]The increasing transformation and patenting of scientific achievements of universities have significantly enhanced the university-industry integration, giving new vitality into the scientific and technological innovation as well as industrial development of the US, and addressing the declining comparative edge of the US over Japan in manufacturing (Siegel et al., 2003; Lach and Schankerman, 2004, 2008; Sampat, 2006; Belenzon and Schankerman, 2009; Bu et al., 2014). BD is acclaimed as "the most inspired piece of legislation to be enacted in America over the past half century," and sets an example for countries around the world.

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[1] Source: Thursby and Thursby (2003).

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In reference to the US BD, the Chinese government rolled out a series of policies designed to stimulate universities to transform scientific achievements in succession during 2000–2016. To be specific, the government permits universities to pursue ownership of a patent arising from government-funded research, gives them independent decision-making power over a patent and requires them to share the profits from a patent with researchers. Despite its similarity with BD in content, this reform is subject to the influence of China's progressive reform model. Or to be specific, on one hand, various universities may adopt different policies in different years, and on the other hand, the disposal of state-owned property also imposes restrictions on this reform. Hence, whether the Chinese version of BD is efficient in promoting university innovation still deserves further studies.

In recent years, there are studies paying attention to the efficiency of permitting universities to pursue ownership of government-funded scientific achievements and requiring universities to share profits from an invention with its inventor in China. Based on a descriptive statistical analysis, Tang et al. (2014) investigated the influence of the implementation of the Chinese version of BD by two Chinese universities (Tsinghua University and Chongqing University) in 2002 on their patent application and profits from patent license, discovering that this act had increased the numbers of patents and patent licenses of universities. Fong et al. (2018) and Chang et al. (2016) conducted empirical studies to probe into the impacts of the distribution policies of patent transfer profits of the top 35 universities in terms of the number of patents during 2002–2012, finding that the profit distribution policy stimulates university faculty to publish their research results in the form of patents, and significantly improve the transformation of scientific achievements. However, samples in current studies are not representative, in that these studies focus on either several top universities or those owning a large number of patents. In terms of empirical design, these studies either take the year 2002 as the implementation time of the policy, failing to take into account the different implementation times of various universities, or substitute the variable of profit distribution into the regression equation in a fixed proportion, ignoring the time-varying feature of profit distribution of various universities.

In contrast to current studies, this paper has made the following contributions: (1) It has expanded the current research scope. Most existing studies focus on developed countries such as the US and those in the Europe, while few of them pay attention to developing countries. Will the unique progressive reform model and restrictions of state-owned property management of China which is the largest developing country affect the efficiency of the Chinese version of BD? Exploring answers to this question can undoubtedly generate relevant empirical evidence. (2) It has enriched existing research conclusions. We find that the BD policies adopted by universities have boosted the number, quality and transfer of patents, because these policies motivate more researchers (including original inventors and new inventors) to publish their research results in the form of patents, and help to maintain a steady proportion of new inventors. Compared with policies like BD, patent subsidy policies are mainly effective in raising the numbers of patent applications and licenses, and incentive policies for job promotion have improved the duration of patent and citation. These findings have provided different conclusions than previous studies in understanding the advantages and limitations of the innovation policies of Chinese universities, inspiring other developing countries in formulating similar policies. (3) We have collected information about the policies and relevant revisions of "985 project" universities designed to promote the transformation and patenting of scientific achievements during 1998–2015 via information disclosure statement and web queries, sorted out the time of implementing relevant policies and detailed proportions of profits distribution of these universities, and figured out the changes of profits distribution proportion with "university-year", thus providing solid empirical support for future studies.

The following analysis is arranged as the following. The second part is devoted to illustrating the institutional background and describing variables; the third part introduces the data source and descriptive statistics; the fourth part presents econometric models and baseline regression results; the fifth part describes the mechanism analysis and the policy comparison; and the sixth part presents conclusions and policy implications of this paper.

2. Institutional background and variable description

Since 2000, the government has issued a series of policies aimed at promoting the transformation of scientific achievements within universities, to encourage the application and spread of scientific achievements of universities. Following the introduction of these national policies, various universities have laid down more specific regulations and supporting measures in succession, and we have classified these policies into BD policies and non-BD policies by nature. In this section, we will first introduce the adoption and evolution of national policies, and then interpret content and key terms of both categories of university policies.

2.1. Adoption and evolution of the Chinese version of BD

The R&D investment of Chinese universities in 1999 was CNY 6.35 billion, accounting for 9.3% in the total R&D expenditure of the government, whereas scientific achievements of universities were characterized by a low patenting rate and a low transfer rate. To be specific, the number of patents of universities took up only 1.3% in the total number of patents across China, among the 13,000 licensed patents of universities, only 2% were transferred and the amount from patent transfers accounted for only 1.7% in R&D expenditure.[2] Reasons are as following: (1) Universities do not have a reasonable evaluation system and need to raise the awareness of intellectual property rights protection. Papers and projects have always been the major objects of evaluation on university faculty, and most offices of research affairs of universities usually evaluate and accept projects according to the quantity and quality of papers published, leading to the rejection of patent applications of many new technologies due to a loss of novelty (Guo et al., 2007). Some universities evaluating

[2] Data are collected from *China Statistical Yearbook on Science and Technology*, *Compilation of Scientific and Technical Statistics of Chinese Higher Education* and patent data of China National Intellectual Property Administration.

patents merely count the number of patents but pay no attention to the commercial value or the transfer of patents. (2) Universities give insufficient rewards to service inventors. Back then, most universities pursued the policy of "one bonus and two rewards" as stipulated in *Detailed Rules for the Implementation of the Patent Law of the People's Republic of China* issued in 1992, which greatly discouraged service inventors by giving them insufficient rewards. (3) Patents of universities. Patents of universities as a kind of state-owned property have been subject to the stringent regulation of universities as well as government departments. As most of the research projects of Chinese universities are government-funded, their scientific achievements are state-owned intangible assets and belong to the government. On one hand, the inventors will lose most of their rights to a technology after turning it into a service invention by disclosing it to the university, and can gain only meager earnings. On the other hand, enterprises will be cautious about seeking cooperation with universities because of the nature of patents as a kind of state-owned property. Concern over the loss of state-owned property imposes danger to inventors, universities and enterprises. Therefore, researchers of universities are not motivated to apply for or transfer patents.

Since 2000, the government has issued a series of policies regarding patent ownership and profit distribution of universities (see Table 1) in succession. The Opinions on Strengthening the Protection and Management of Technology-Related Intellectual Property Rights issued in 2000 permit universities to pursue ownership of patents but endow researchers with only moral rights. Since most Chinese universities are government-affiliated public institutions, patents arising from government-funded research projects, as intangible assets, are under the restraint of regulations on management of state-owned assets, and the patent transfer requires approval of administrative units at all levels. Patent ownership delegation is merely an empty promise without entrusting universities with the right to dispose patents. Therefore, the State Council promulgated Rules for the Management of Intellectual Property Rights of Research Achievements of National Scientific Research Projects in 2002, further expanding the discretionary power of universities over patents and making it explicit to give researchers bonuses and rewards. It was this policy that got the core of BD and was regarded as the Chinese version of BD (Guo et al., 2007; Tang et al., 2014). To dispel universities' misgivings over the possible loss of state-owned property, the State Council enacted Rules for the Implementation of Law of the People's Republic of China on Promoting the Transformation of Scientific and Technological Achievements in 2016 to exempt university leadership from decision-making responsibility and strengthen universities' independent decision-making power.

Source: Official websites of the Ministry of Education of the People's Republic of China and the Ministry of Science and Technology of the People's Republic of China.

2.2. Policies of universities promoting the transformation and patenting of scientific achievements

To strengthen intellectual property rights management of universities and encourage the faculty to involve in R&D innovation and industrialization of scientific and technological achievements, Chinese universities have formulated corresponding policies of mainly two categories: the BD policies, including equity share distribution and royalty share distribution; the non-BD policies, including patent application subsidy, tenure promotion and cash bonus policies.

2.2.1. BD policies

BD policies refer to policies concerning the distribution of profits from technology transfers, which stipulates those profits from technology transfers shall be distributed among universities, colleges, and inventors by a certain percentage, demonstrating the core spirit of the Chinese version of BD. According to the different transformation forms of patents, the profits distribution policies can be

Table 1
Evolution of the Chinese version of BD.

Policy	Policy content	Policy description
Opinions on Strengthening the Protection and Management of Technology-related Intellectual Property Rights in 2000	The intellectual property rights of the scientific and technological achievements of government-funded research projects may be owned by responsible units; and the inventors are entitled to such moral rights as the rights to an invention, a discovery, and other scientific and technological achievements	Permitting universities to pursue ownership of patents
Management of Intellectual Property Rights of Research Achievements of National Scientific Research Projects in 2002	The government grants responsible units with the intellectual property rights of scientific achievements of government-funded research projects. Responsible units may independently decide to implement, permit others to implement, transfer a patent or become a shareholder at a price, and obtain corresponding profits according to law; and responsible units shall provide bonuses and rewards to people completing the research projects and those contributing to the transformation of research achievements	Chinese version of BD: universities may decide to implement a patent and request bonuses and rewards for inventors
Implementation of Law of the People's Republic of China on Promoting the Transformation of Scientific and Technological Achievements in 2016	Establishing a collective decision-making system on major issues concerning the transformation of scientific and technological achievements; and exempting university leadership from decision-making responsibilities arising from value changes in the pricing of scientific and technological achievements	Universities' misgivings over the possible loss of state-owned property and strengthening universities' independent decision-making power

Table 2
Major terms of BD policies.

Explanatory variable	Relevant terms
Equity share	①For the transformation of scientific achievements in the form of technology investment, the inventor takes *% of the equity share, the university takes *% of the equity share and the college takes *% of the equity share ②For the equity obtained by contributing intellectual property rights as investment, the university may reward the person who accomplishes the achievements with 8% of the equity and the industrial group has the remaining equity on behalf of the university. The university and the college take *% of returns on the equity respectively
Royalty share	① Profits from technology transfer and license is distributed among the university, the college and the researcher by a certain percentage ② Classified reward system: profits smaller than CNY * ten thousand are distributed by *%; for profits larger than CNY *% ten thousand, CNY * ten thousand are distributed by 8% and the surplus are distributed by *%

Note: * stands for the percentage by which various kinds of profits are distributed or the amount of profits.
Source: replies to applications disclosed by university, official websites of the offices of science and technology administration/offices of research affairs as well as Baidu search results.

subdivided into equity share policies and royalty share policies, and specific terms are listed in Table 2. The two systems of profit distribution are different in that the equity share allows the inventors to enjoy the future benefits of their patented technologies, thus stimulating them to take part in technology transfer, technical test, product development and promotion, while the royalty share refers to the lump-sum profits given to the inventors after the completion of technology transfer or license, and the inventors have no access to the future benefits of patents. To avoid the moral hazards caused by information asymmetry, enterprises usually preferred the technology investment of university faculty to maintain long-term bilateral cooperation (Dechenaux et al., 2011; Chang et al., 2016). Comparatively speaking, the equity share policy is conducive to commercialization of patented technologies of universities.

To examine the effect of BD policies, we have constructed the following "university-year" variables: *Transform* is assigned 1 when universities adopting at least one category of profit distribution policies are in the year of the implementation of the policies or subsequent years, and otherwise, it is 0; *Equity dummy* is assigned 1 when universities adopting equity share are in the year of the implementation of the policy or subsequent years, and otherwise, it is 0; *Equity share* replaces the dummy variable with the inventor's proportion in the equity share, which is time-varying; *Royalty dummy* is assigned 1 when universities adopting the royalty share are in the year of the implementation of the policy or subsequent years, and otherwise, it is 0; *Royalty share* replaces the dummy variable with the inventor's proportion in the royalty share, which is also time-varying. These variables will be used to evaluate the effects of BD policies in following empirical research.

2.2.2. Non-BD policies

BD policies are designed to promote the patent transformation of universities. In the meanwhile, the enormous economic stimulus may indirectly increase the number of patents of universities, and in comparison, patent application subsidies can directly spur patenting of scientific achievements of universities. Some universities have set up patent funds to support the faculty in covering patent application and maintenance expenses, which has reduced patent application and maintenance costs, and is expected to stimulate the patent application of universities. Specific terms are presented in Table 3. However, the cost shift brought about by the subsidies might encourage investors to focus on the quantity rather than the quality of patents, paying no attention to the economic value of technologies (Long and Wang, 2015).

Besides, many universities try to involve their faculty in patent application by incorporating the number of patents and technology transfer performance into their evaluation system or offering a lump-sum cash bonus. Specific terms are listed in Table 3. To verify policy

Table 3
Major terms of non-BD policies.

Explanatory variable	Relevant terms
Subsidy	① For patents with the first applicant being **university, the university covers the application cost as well as expenses in the three years after approval ②Universities set up special funds for intellectual property rights to provide subsidies for patent application and maintenance as well as other expenses related to protection of intellectual property rights
Tenure	①Universities will reward units and individuals actively promoting the transformation of scientific and technological achievements, and link the transformation performance to verification of scientific research workload and professional-title evaluation ②Approved patents can be taken as the same scientific achievements as papers, and used as a performance indicator and condition for faculty employment and evaluation
Bonus	① Upon the approval of patents, universities shall offer their inventors or designers rewards, with the cash bonus for an invention patent being CNY * and that for a utility model patent or design patent being CNY * ② The cash bonus for an approved invention patent is CNY *, and that for an approved utility model patent is CNY *

Note: the sign * refers to the amount of cash bonus.
Source: replies to applications disclosed by university information, official websites of the offices of science and technology administration/offices of research affairs as well as Baidu search results.

Table 4
Descriptive statistics of variables.

Variable	Mean	Std.	Min.	Max.	Quantile		
					p25	p50	p75
Dependent variable :							
Appl_Pate(piece/person)	0.1047	0.1183	0.0000	0.7493	0.0189	0.0637	0.1421
Appr_Pate(piece/person)	0.0493	0.0593	0.0000	0.2959	0.0048	0.0268	0.0682
Duration (ratio)	0.2982	0.1664	0.0000	1.0000	0.2000	0.2874	0.3750
Citations (time/person)	0.1947	0.1951	0.0006	1.0524	0.0520	0.1224	0.2885
Income (CNY 1000/person)	1.5970	3.2851	0.0000	18.6206	0.0000	0.3558	1.4074
Foreign_Pate(piece/person)	0.0052	0.0112	0.0000	0.0801	0.0000	0.0016	0.0044
Independent variable :							
Transform	0.4785	0.5000	0.0000	1.0000	0.0000	0.0000	1.0000
Equity dummy	0.3548	0.4789	0.0000	1.0000	0.0000	0.0000	1.0000
Equity share (ratio)	0.1469	0.2369	0.0000	0.7000	0.0000	0.0000	0.3500
Royalty dummy	0.4194	0.4939	0.0000	1.0000	0.0000	0.0000	1.0000
Royalty share (ratio)	0.2024	0.2863	0.0000	0.9500	0.0000	0.0000	0.4000
Subsidy	0.5000	0.5004	0.0000	1.0000	0.0000	0.5000	1.0000
Tenure	0.3297	0.4705	0.0000	1.0000	0.0000	0.0000	1.0000
Bonus	0.3907	0.4883	0.0000	1.0000	0.0000	0.0000	1.0000
Control variable :							
RD	205.0451	167.0624	11.3308	922.1834	80.7286	157.5538	298.1176

Table 5
Influence of BD policies on per capita number of invention patent applications.

Dep. Var. : *Appl_Pate*	(1)	(2)	(3)	(4)	(5)	(6)
Transform	0.0290**			0.0287**		
	(0.013)			(0.013)		
Equity dummy		0.0378			0.0379	
		(0.025)			(0.025)	
Royalty dummy		−0.0152			−0.0155	
		(0.027)			(0.027)	
Equity share			0.0758*			0.0764*
			(0.044)			(0.044)
Royalty share			−0.0232			−0.0233
			(0.045)			(0.045)
Prov_policy				0.0035	0.0076	0.0085
				(0.011)	(0.011)	(0.012)
RD	0.0006***	0.0006***	0.0006***	0.0006***	0.0006***	0.0006***
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
Univ FE	Yes	Yes	Yes	Yes	Yes	Yes
Year FE	Yes	Yes	Yes	Yes	Yes	Yes
Obs.	354	354	354	354	354	354
R^2	0.7622	0.7639	0.7645	0.7622	0.7641	0.7648

Note: (1) figures in brackets are robust standard errors clustered at the university level; (2) signs ***, ** and * stand for the significance levels of 1%, 5% and 10% respectively.

efficiency, we have constructed the following three "university-year" variables: *Subsidy* is assigned 1 when universities offering subsidy are in the year of the implementation of the policy or subsequent years, and otherwise, it is 0; *Tenure* is assigned 1 when universities adopting job promotion are in the year of the implementation of the policy or subsequent years, and otherwise, it is 0; *Bonus* is assigned 1 when universities giving cash bonuses are in the year of the implementation of the policy or subsequent years, and otherwise, it is 0.

3. Data and descriptive statistics

To investigate the influence of universities' policies to promote the transformation and patenting of scientific achievements on their innovation output, we take into account two kinds of data: policy data which are collected from official websites of office of information disclosure, office of science and technology administration/office of research affairs as well as Baidu search results; numbers of patents and research fellow as well as R&D expenditure which are collected from the patent database of China National Intellectual Property Administration, *Compilation of Scientific and Technical Statistics of Chinese Higher Education* and WIPO international patent search engine. In this section, we will first introduce data sources and data processing, and then make corresponding descriptive statistical analyses.

To be specific, we have collected the patent incentive policies of various universities in the following three ways (in order of priority). First, according to Measures for the Information Disclosure of Institutions of Higher Learning, we submit information disclosure applications to 39 "985 project" universities through e-mail, applying for the disclosure of the original and revised documents of various policies promoting the transformation of scientific and technological achievements, as well as management of intellectual property

Table 6
Influence of BD policies on per capita number of invention patent approvals.

Dep. Var. : *Appr_Pate*	(1)	(2)	(3)	(4)	(5)	(6)
Transform	0.0145*			0.0148*		
	(0.007)			(0.007)		
Equity dummy		0.0175*			0.0175*	
		(0.009)			(0.009)	
Royalty dummy		−0.0025			−0.0025	
		(0.009)			(0.009)	
Equity share			0.0302			0.0301
			(0.019)			(0.019)
Royalty share			−0.0002			−0.0002
			(0.017)			(0.017)
Prov_policy				−0.0027	−0.0008	−0.0002
				(0.006)	(0.006)	(0.006)
RD	0.0003***	0.0003***	0.0003***	0.0003***	0.0003***	0.0003***
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
Univ FE	Yes	Yes	Yes	Yes	Yes	Yes
Year FE	Yes	Yes	Yes	Yes	Yes	Yes
Obs.	354	354	354	354	354	354
R^2	0.8043	0.8061	0.8060	0.8044	0.8062	0.8060

Note: (1) figures in brackets are robust standard errors clustered at the university level; (2) signs ***, ** and * stand for the significance levels of 1%, 5% and 10% respectively.

Table 7
Influence of BD policies on patent duration.

Dep. Var.: *Duration*	(1)	(2)	(3)	(4)	(5)	(6)
Transform	0.0449			0.0452		
	(0.029)			(0.031)		
Equity dummy		−0.0245			−0.0245	
		(0.029)			(0.029)	
Royalty dummy		0.0698***			0.0698***	
		(0.023)			(0.024)	
Equity share			−0.0475			−0.0474
			(0.059)			(0.059)
Royalty share			0.0871*			0.0870*
			(0.046)			(0.046)
Prov_policy				−0.0038	−0.0013	0.0016
				(0.045)	(0.045)	(0.044)
RD	−0.0001	−0.0001	−0.0001	−0.0001	−0.0001	−0.0001
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
Univ FE	Yes	Yes	Yes	Yes	Yes	Yes
Year FE	Yes	Yes	Yes	Yes	Yes	Yes
Obs.	354	354	354	354	354	354
R^2	0.5712	0.5747	0.5709	0.5712	0.5747	0.5709

Note: (1) figures in brackets are robust standard errors clustered at the university level; (2) signs ***, ** and * stand for the significance levels of 1%, 5% and 10% respectively.

rights. Then, we looked up relevant policy documents in "Policies and Regulations" on the official websites of office of science and technology administration/office of research affairs of these universities. Finally, we made queries on the Baidu search engine with such keywords as "university name" plus "management of intellectual property rights", "patent management", "transformation of scientific and technological achievements" and "patent rewards". With complementary information collected through the three channels, we have obtained the original and revised documents of the patent incentive policies of 31 "985 project" universities during 1998–2015, and relevant data of 17 universities were acquired from their information disclosure offices. By reading through these documents, we have sorted out the different time at which different universities issued various policies for following empirical research.[3] Most of these universities implemented BD policies (technologies invested as capital and royalty shares) during 2003–2009, indicating that only after the Chinese version of BD took effect in 2002 did various universities begin to formulate relevant policies in succession. Subsidies for patent application were pursued earlier than other policies, mostly before 2007. Compared with the other policies, promotion was the least adopted one. The cash bonus was implemented at similar times.

Apart from these policy variables, we have also collected the number of invention patents, the legal status of patents, the number of

[3] Due to space limitations, the policy implementation time of various universities are not presented in the paper, and they are available upon request.

Table 8
Influence of BD policies on per capita number of patent citations.

Dep. Var.: *Citations*	(1)	(2)	(3)	(4)	(5)	(6)
Transform	0.0684*			0.0655*		
	(0.036)			(0.036)		
Equity dummy		0.0154			0.0163	
		(0.052)			(0.051)	
Royalty dummy		0.0282			0.0266	
		(0.049)			(0.049)	
Equity share			0.0238			0.0267
			(0.081)			(0.080)
Royalty share			0.0483			0.0476
			(0.075)			(0.075)
Prov_policy				0.0352	0.0419*	0.0444*
				(0.021)	(0.021)	(0.022)
RD	0.0004**	0.0004**	0.0004**	0.0004**	0.0004**	0.0004**
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
Univ FE	Yes	Yes	Yes	Yes	Yes	Yes
Year FE	Yes	Yes	Yes	Yes	Yes	Yes
Obs.	354	354	354	354	354	354
R^2	0.5314	0.5206	0.5207	0.5344	0.5249	0.5255

Note: (1) figures in brackets are robust standard errors clustered at the university level; (2) signs ***, ** and * stand for the significance levels of 1%, 5% and 10% respectively.

Table 9
Influence of BD policies on technology transfer.

Dep. Var.: *Income*	(1)	(2)	(3)	(4)	(5)	(6)
Transform	1.1180**			1.0722**		
	(0.472)			(0.455)		
Equity dummy		1.0553*			1.0698**	
		(0.534)			(0.519)	
Royalty dummy		0.2289			0.2020	
		(0.444)			(0.427)	
Equity share			1.8882*			1.9366*
			(1.021)			(0.984)
Royalty share			−0.2743			−0.2864
			(0.910)			(0.898)
Prov_policy				0.5593	0.6780	0.7312
				(0.419)	(0.431)	(0.451)
RD	0.0057***	0.0058***	0.0055***	0.0059***	0.0059***	0.0056***
	(0.001)	(0.001)	(0.002)	(0.001)	(0.001)	(0.002)
Univ FE	Yes	Yes	Yes	Yes	Yes	Yes
Year FE	Yes	Yes	Yes	Yes	Yes	Yes
Obs.	354	354	354	354	354	354
R^2	0.1268	0.1305	0.1222	0.1295	0.1345	0.1268

Note: (1) figures in brackets are robust standard errors clustered at the university level; (2) signs ***, ** and * stand for the significance levels of 1%, 5% and 10% respectively.

patent citations, profits from technology transfer, the number of international patent applications and the data of various control variables from the patent database of China National Intellectual Property Administration, *Compilation of Scientific and Technical Statistics of Chinese Higher Education* and WIPO international patent search website. In reference to previous studies, we use the following two indicators as the proxy variables of patent quality: (1) The first is the duration of patent (Long and Wang, 2015). We have calculated *Duration* by first choosing approved patents with effective date of termination, and then obtaining the ratio of the number of patents with a duration larger than five years[4] to the total number of approved patents of a university in a certain year. The ratio represents the proportion of patents with a duration larger than five years in the total approved patents of a university in a certain year, and in general, *Duration* is in direct proportion to patent quality. (2) The second is patent citations (Trajtenberg, 1990; Henderson et al., 1998). We have calculated *Citations* by first determining the forward citations of each patent, and totaling up the forward citations of all patients at the "university-year" level, and generally speaking, *Citations* are in direct proportion to patent quality. Finally, we divide the number of researchers by all aggregate indicators to get per capita indicators. The descriptive statistics of various variables are presented in Table 4.

[4] Universities offering patent subsidies usually fund the maintenance costs of patents in the three years after approval, and we find that around 80% of the patents in our samples have stopped renewing the approval five years after their first approval. We deem a patent valid for over 5 years as high-quality, or in other words, the inventor chooses to maintain patent validity even without the university's support.

Table 10
Influence of BD policies on per capita number of international patent applications.

Dep. Var.: *Foreign_Pate*	(1)	(2)	(3)	(4)	(5)	(6)
Transform	0.0012			0.0011		
	(0.001)			(0.001)		
Equity dummy		0.0038**			0.0038**	
		(0.001)			(0.001)	
Royalty dummy		−0.0015			−0.0015	
		(0.002)			(0.002)	
Equity share			0.0067*			0.0067*
			(0.003)			(0.003)
Royalty share			−0.0035			−0.0035
			(0.003)			(0.003)
Prov_policy				0.0009	0.0011	0.0011
				(0.002)	(0.002)	(0.002)
RD	0.0000**	0.0000**	0.0000**	0.0000**	0.0000**	0.0000**
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
Univ FE	Yes	Yes	Yes	Yes	Yes	Yes
Year FE	Yes	Yes	Yes	Yes	Yes	Yes
Obs.	354	354	354	354	354	354
R^2	0.4242	0.4354	0.4317	0.4248	0.4363	0.4327

Note: (1) figures in brackets are robust standard errors clustered at the university level; (2) signs ***, ** and * stand for the significance levels of 1%, 5% and 10% respectively.

Table 11
Mechanism analysis of BD policies.

Dep. Var.:	Inventor			New Inventor			New Inventor (%)		
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
Transform	0.0512**			0.0293**			0.0021		
	(0.022)			(0.012)			(0.017)		
Equity dummy		0.0238			0.0123			0.0223	
		(0.040)			(0.024)			(0.020)	
Royalty dummy		0.0132			0.0073			−0.0224	
		(0.033)			(0.020)			(0.017)	
Equity share			0.0725			0.0384			0.0209
			(0.059)			(0.034)			(0.033)
Royalty share			−0.0041			−0.0024			−0.0015
			(0.050)			(0.031)			(0.033)
RD	0.0008***	0.0008***	0.0008***	0.0004***	0.0004***	0.0004***	−0.0000	−0.0000	−0.0000
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
Univ FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Year FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Obs.	354	354	354	354	354	354	354	354	354
R^2	0.7574	0.7540	0.7547	0.7166	0.7122	0.7130	0.5186	0.5215	0.5194

Note: (1) figures in brackets are robust standard errors clustered at the university level; (2) signs ***, ** and * stand for the significance levels of 1%, 5% and 10% respectively.

Table 4 demonstrates that the average value of patent applications *Appl_Pate* of "985 project" universities during 1998–2015 was 0.1047. In other words, each researcher applied for 0.1 patent each year, and the mean value of approved patents *Appr_Pate* was 0.05; the mean value of *Duration* illustrates that around 30% of the patents of universities had a duration of over five years; each patent was cited 2 times on average[5]; the mean value of *Income* was 1.5970, signifying that per capita profits from technology transfers was CNY 1597, and figures in the "75%" column show that patented technologies with large profits from technology transfers came from a small number of universities; as for the proportion of profits distribution, universities gave 15% of the equity shares and 20% of the royalty shares to the person transforming an achievement.

4. Econometric models and baseline regression results

To explore the influence of universities' policies which promote the transformation and patenting of research achievements on the quantity, quality and transformation gains of innovation output, we have first constructed econometric models, performed baseline regression tests with these models and interpreted the regression results of key variables in economic terms.

To be specific, we employ the following difference-in-difference (DID) model to evaluate policy effects:

[5] According to the mean values of *Citations* and *Appl_Pate*, 0.1947/0.1047 ≈ 2.

Table 12
Influence of other incentive policies on university innovation.

Dep. Var.:	*Appl_Pate*			*Appr_Pate*			*Duration*			*Citations*
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
Subsidyrowhead	0.0360**			0.0171**			−0.0078			0.0310
	(0.013)			(0.007)			(0.034)			(0.032)
Tenure		0.0256*			0.0103			0.0744***		
		(0.015)			(0.007)			(0.025)		
Bonus			−0.0116			−0.0013			0.0019	
			(0.019)			(0.009)			(0.030)	
Controls, Univ FE, and Year FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Obs.	354	354	354	354	354	354	354	354	354	354
R2	0.7633	0.7613	0.7574	0.8046	0.8018	0.7988	0.5673	0.5791	0.5672	0.5175

$$Y_{i,t} = \beta Policy_{i,t-1} + \gamma Z_{i,t-1} + \eta_i + \mu_t + \varepsilon_{i,t} \quad (1)$$

where i stands for the university, t stands for the year, and $Y_{i,t}$ stands for the outcome variable of university i in year t, including per capita number of patent applications $Appl\_Pate_{i,t}$, per capita number of patent approvals $Appr\_Pate_{i,t}$, $Duration_{i,t}$, per capita number of $citations_{i,t}$, per capita income from technology transfer $Income_{i,t}$, and per capita number of international patent applications $Foreign\_Pate_{i,t}$. As it takes time for a policy to work, we substitute all the policy variables and control variables that lag one period, namely, $Policy_{i,t-1}$ and $Z_{i,t-1}$, into the regression equation. Policy variables include the following: (1) BD policy $Transform_{i,\ t-1}$, which can be divided into equity share $Equity\ dummy/share_{i,t-1}$ and royalty share $Royalty\ dummy/share_{i,t-1}$; (2) patent application subsidy $Subsidy_{i,t-1}$; (3) incentive policy for promotion of professional titles $Tenure_{i,t-1}$; and (4) cash bonus for patent approval $Bonus_{i,t-1}$. Per capita R&D expenditure of universities is the control variable. The item η_i represents the fixed effect of university, μ_t represents the fixed effect of year, and $\varepsilon_{i,t}$ represents the stochastic error term. The coefficient β signifies the influence of various policies on the innovation output of universities, and a significantly positive β indicates that a policy is able to raise the innovation output of universities, and vice versa.

4.1. Influence of BD policies on the number of patents

As regards the influence of BD policies on the number of patent applications of universities, the regression results of Model (1) are demonstrated in Table 5. The regression results in Column (1) show that the coefficient of *Transform* is significantly positive at the level of 5%, suggesting that sharing profits from technology transfers is effective in increasing the number of patent applications. Column (2) presents the regression results of the two subdivided policy variables, *equity share* and *royalty share*, and we find that the coefficient of *Equity dummy* is positive, but it is not statistically significant. The regression results with the dummy variables being replaced by specific distribution proportions demonstrate that the coefficient of equity share in Column (3) is significantly positive at the level of 10%, indicating that the larger the equity share inventors can get, the larger the number of patent applications of universities will be. In contrast, the royalty share exerts no appreciable influence on the number of patent applications. However, biased estimations may occur due to the possible influence of the innovation policies of the place where a university is located on the innovation policies of the university. Therefore, we include the dummy variable of provincial-level innovation policies in the regression in columns (4)–(6),[6] and the regression results show that there is no noticeable difference between the coefficients of *Transform* and *Equity share* after allowing for the influence of provincial-level policies and those in columns (1)–(3), implying that the influence of BD policies of universities is robust and free from the impacts of local innovation policies. On this basis, we proceed to study the influence of patent incentive policies on the number of patent approvals of universities. The regression results in Table 6 reveal that the regression results about patent approvals are basically consistent with those about patent applications.

4.2. Influence of BD policies on patent quality

We use patent duration and the number of patent citations as the proxy variables of patent quality for the following reasons. On one hand, the stair-step renewal fees make it more and more costly for an inventor to maintain a patent, and hence, an inventor's evaluation of the benefit and cost of maintaining a patent will determine its duration. An inventor would give up on the thought of renewing a patent if he/she saw lower expected benefit than the maintenance cost, and therefore, patents with longer duration were usually deemed as patents of higher quality (Pakes, 1986; Schankerman and Pakes, 1986; Schankerman, 1998). On the other hand, a patent citation was any exiting technology information cited by a patent applicant or patent examiner during patent application (or review), to highlight a patent's relationship with and similarity to existing patents. The more frequently a patent was cited, the more important it would be in the process of technological development (Trajtenberg, 1990; Henderson et al., 1998). Therefore, we include *Duration* and *Citations* as

[6] Source: Dang and Motohashi (2015).

Citations			Income			*Foreign_Pate*	
(11)	(12)	(13)	(14)	(15)	(16)	(17)	(18)
		0.5062			0.0003		
		(0.544)			(0.002)		
0.0857**			0.3745			0.0025	
(0.032)			(0.406)			(0.002)	
	−0.0067			−0.0604			0.0011
	(0.032)			(0.551)			(0.001)
Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
354	354	354	354	354	354	354	354
0.5430	0.5150	0.1132	0.1127	0.1108	0.4227	0.4305	0.4240

explained variables in the regression equation, and the regression results are presented in Table 7 and Table 8 respectively. The regression results in Table 7 demonstrate that the royalty share as a part of BD policy has markedly improved the patent duration of universities. The regression results in Table 8 are basically consistent with those in Table 7. In conclusion, the BD policies of universities have enhanced patent quality.

Existing studies revealed that patent incentive policies would increase the number of patents of enterprises, but would undermine patent quality (Long and Wang, 2015). The varied policy effects can be ascribed to the difference between enterprises and universities in the system of value evaluation. Enterprises are faced with intense business competition and attempt to maximize profits, and the patent application, as a competition strategy, enables enterprises to acquire monopoly over a technology. Patent incentive policies may encourage enterprises to apply for a great deal of low-quality patents out of strategic needs, but this is not true for university faculty. Universities were scientific research-oriented, and their faculty mostly pursued academic achievements and reputation (Merton, 1988). Therefore, tenure promotion which can improve the reputation of university faculty is more effective. In the meanwhile, other policies do not necessarily play a negative role. In spite of the economic stimulus of royalty share, the university faculty is not unlikely to patent "shoddy technologies" so as to secure the rewards. On one hand, it is generally impossible to transform low-quality patents, and on the other hand, doing this will damage their academic reputation. In conclusion, to be prudent, we can at least come to the following conclusion: BD policies have raised the number of patent applications of universities without influencing patent quality.

4.3. Influence of BD policies on profits from technology transfer

This section is to investigate the influence of BD policies on technology transfers. Only a small number of patents of Chinese universities have been transformed. According to the legal status of the patents of our sample universities, we have selected 2896 patents whose legal status was identified as "Filing of Patent License Contract" and "Transfer of Patent Application Right and Patent Rights" during 2001–2011, accounting for 8% of total patent approvals of universities in the same period. Most of university patents (around 93.8%) were transferred to enterprises, 48.2% of which were enterprises in the local province, and technology transfers were concentrated in such fields as semiconductor, wastewater treatment, manufacturing of macromolecular compounds, alloy manufacturing, and material testing and analysis. University patents transferred to individuals took up only 0.73% of total patents transferred, and scientific research institutions or universities were another receiver of patents transferred.[7]

Since *Compilation of Scientific and Technical Statistics of Chinese Higher Education* lists only the profits from technology transfers of universities, we will study the influence of BD policies on profits from technology transfers. The regression results in Column (1) in Table 9 demonstrate that the coefficient of *Transform* is significantly positive at the level of 5%, and we can see from the regression results in Column (2) that only *Equity dummy* has positive influences on profits from technology transfers. The coefficient of *Equity share* in the regression results in Column (3) remains significant and is larger than the coefficient of *Equity dummy*, indicating that universities with inventors enjoying higher equity shares benefit more from technology transfers. These results remain true with the influence of local policies being controlled. To sum up, BD policies have revitalized the past innovation achievements of universities by sharing benefits with the inventors, bringing about enormous economic benefits to universities and inventors. Besides, the equity share is efficient in stimulating the university faculty to transform their scientific achievements.

4.4. Influence of BD policies on the international layout of patents

In the end, we try to explore whether BD policies will encourage researchers to apply patents in foreign countries. We have obtained the number of patent applications which our sample universities submitted to overseas patent offices by making queries on the WIPO website.[8] Data show that Chinese universities submitted 23 patent applications to overseas patent offices on average, accounting for only 4.8% of total patent applications of universities. We use per capita number of foreign patent applications as the dependent variable

[7] We have analyzed the heterogeneous impacts of the different receivers of university patents transferred, and found that the proportion of university patents transferred to enterprises and the proportion of university patents transferred to enterprises in the local province have no significant influence on the transformation performance.

[8] http://patentscope2.wipo.int/search/zh/search.jsf, accessed on February 20, 2019.

to perform the regression, and the regression results in Table 10 reveal that the coefficient of *Equity share* is significantly positive, implying that the equity incentive has stimulated university researchers to apply for patents overseas to a certain extent. One possible explanation is that because of the long-term incentive effect of equity share, researchers attach importance to the commercial value and strategic significance of new technologies, thus enhancing and expanding protection of intellectual property rights for these technologies worldwide. This has further demonstrated that BD policies have effectively involved university researchers in such commercial activities as patent application, transformation, and international filing.[9]

5. Mechanism analysis and policy comparison

The baseline regression results have provided evidence for the claim that BD policies play a positive role in improving the innovation output of universities and its economic effect. To clarify the mechanism by which BD policy's function, we will explore the following questions: which category of researchers is subject to more influences from BD policies? Is it more effective to stimulate previous inventors to apply for more patents, or to encourage "new entrants" to patent and then publish their research findings? In addition, apart from BD policies, will other patent incentive policies of universities affect various indicators? In this section, we will analyze the mechanism by which BD policy's function and make policy comparisons.

5.1. Mechanism analysis

We have obtained the annual number of inventors of various universities *Inventor* from patent inventors' data by first extracting the names of inventors applying for patents each year, deleting repetition and adding up all qualified inventors. Then, we have extracted the names of new inventors and calculated the number of new inventors of various universities *New Inventor*. The proportion of new inventors *New Inventor* (%) can be calculated through dividing the total number of inventors by the number of new inventors. The regression results in columns (1)–(6) in Table 11 reveal that BD policies have markedly raised the numbers of inventors and new inventors. This fact signifies that in addition to encouraging previous inventors to apply for more patents, the material incentive from the royalty share has also attracted more new entrants, who begin to patent their research findings before publishing them, and also attempt to commercialize new technologies. In this way, more advanced new technologies will be made public, and inventors are also motivated to extend the patent duration. The regression results in columns (Dang and Motohashi, 2015)–(9) show that the policies have no significant impact on the proportion of new inventors, which shows that the influences of the policies are relatively balanced.

5.2. Policy comparison

BD policies have enhanced the innovation efficiency of universities through property incentives, but do other incentive policies with the same purpose have the same effect? We will further study the influence of patent application subsidy, tenure promotion and cash bonus on the six innovation output indicators. The regression results in Column (1) in Table 12 show that the coefficient of patent application subsidy is significantly positive at the level of 5%, indicating that reducing the patent application cost for the university faculty by providing subsidies is effective in raising the number of university patents. As demonstrated in the regression results in Column (2), tenure promotion plays a positive role in boosting the number of patent applications of universities, signifying that to involve patents into the evaluation is able to stimulate the university faculty to apply for patents. The regression results in Column (3) demonstrate that the cash bonus has no remarkable influence on the number of patent applications, which can possibly be attributed to the situation that the bonus and patent value are unequal, or to be specific, the bonus of some universities for inventors is CNY 2000/piece, while it takes many years for a teacher and even a scientific team to acquire an invention patent. The regression results about the number of patent approvals reveal that subsidies still play a significantly positive role, but the tenure promotion has no significant influence on the number of patent approvals. The regression results in columns (Dang and Motohashi, 2015)–(12) show that the tenure promotion has significantly positive influences on patent quality, indicating a strong incentive effect of tenure promotion on researchers who are motivated to develop high-quality technologies to raise their academic reputation. As illustrated by the regression results in columns (Jaffe, 1989)–(18), neither subsidy, tenure promotion nor cash bonus has significant influence on profits from technology transfers or international patent application.

In conclusion, non-BD policies stimulate innovation in an unbalanced and biased way. To be specific, subsidies have boosted the number of patents; the tenure promotion has improved patent quality; and the cash bonus has no significant effect. Therefore, these policies cannot play a substantial role in commercializing the patented technologies of universities.

6. Conclusion and implication

In this paper, we have investigated the influence of the Chinese version of BD on university innovation through empirical research and have found that universities implementing BD policies have seen remarkable growth in the number of patent applications, the number of patent approvals, duration, citations, profits from technology transfers as well as the number of international patent

[9] To eliminate the possible endogenous effects of reverse causality and variable omission, we have tested our baseline regression results by means of dynamic regression and propensity score marching (PSM), and our conclusions remain robust and true. Due to space limitations, the test results are not presented in the analysis, and they are available upon request.

applications. Among the BD policies, the equity share has played a dominant role, or to be specific, universities with inventors enjoying higher equity shares have more patent applications, patent approvals, profits from technology transfers and international patent applications. The analysis on the function mechanism of these policies reveals that BD policies have significantly raised the number of additional patents applicants but exerted no influence on the proportion of new inventors. Compared with BD policies, patent application subsidies have raised the numbers of patent applications and approvals, but have no significant influence on patent duration, citations, or profits from technology transfers. The tenure promotion has increased patent duration and citations. The cash bonus does not have any policy effect.

The research conclusions indicate that the Chinese version of BD has accelerated the transformation of scientific and technological achievements in the short run by dividing the university royalty share, but it is imperative to ensure that scientists will eventually get the benefit and speed up the establishment of technology transfer offices (TTOs). With the increased transformation amount and value of patents, the interest dispute among enterprises, universities and inventors turns into an obstacle. On one hand, enterprises, after getting profits from a project, are motivated to breach the contract, not distributing the profits according to the agreement, and universities and inventors with insufficient legal and business knowledge and experience often fail to get what they deserve. On the other hand, some universities and their inventors also have disputes over the distribution of profits. Studies suggested that currently, the equity acquired by inventors through technology transfers was usually held by the asset management companies of universities, and inventors were not allowed to transfer or sell the equity (Chang, 2017). Moreover, TTOs of the US play an irreplaceable role in the transformation of scientific and technological achievements of universities. TTOs, as the research broker of universities, are responsible for the achievement evaluation, enterprise screening, contract making, business negotiation and dispute resolution among other affairs, and they have accelerated the transformation of scientific and technological achievements of the US universities. However, even though many Chinese universities have appointed professionals to take charge of the transformation of scientific and technological achievements, most of them are responsible for only the routine work for initiating horizontal scientific and technological achievements and fail to fulfill the responsibility of a research broker to assist the university faculty in transforming their scientific and technological achievements.

The heatedly debated Regulations on Patent Administration of Southwest Jiaotong University (abbreviated as Southwest University Regulations) which proposes to prepose cash, equity, and other gain-sharing forms as the rewards of intellectual property ownership is a reform in implementing the mixed ownership of job-related scientific and technological achievements of universities. Former President of Southwest Jiaotong University Xu Fei has pointed out that equity and patent ownership can be likened to “limited property rights” and “unlimited property rights” respectively, and the royalty share no longer has positive marginal effects at the moment, rendering it imperative to pursue incentives granting “unlimited property rights”.[10] However, are there any legal theories supporting the mixed ownership of job-related scientific and technological achievements? Can it be introduced across China? What are the risks along with the adoption of the policy? These issues deserve explorations in future studies.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Appendix

[10] Excerpted from the speech of the former President of Southwest Jiaotong University Xu Fei at the Sichuan Provincial Party Committee Symposium on Comprehensive Innovation Reform Pilot Zone Construction on October 8, 2015.

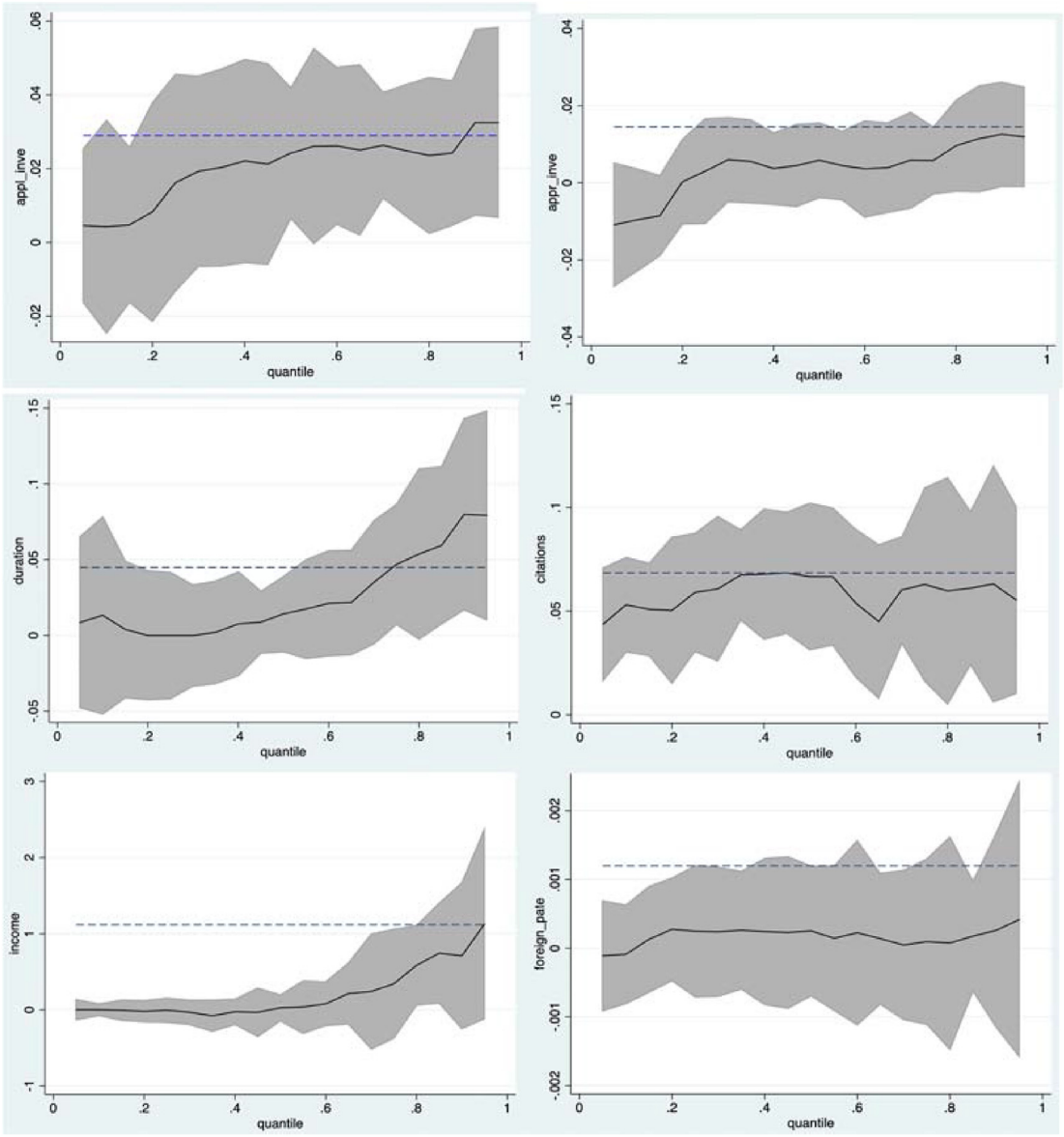

Figure 1. Quantile regression.

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