ADBI Working Paper Series

FOREIGN DIRECT INVESTMENT SPILLOVERS AND PHARMACEUTICAL INNOVATION: THE ROLE OF INTELLECTUAL PROPERTY RIGHTS

Chun-Yu Ho, Xin Li,
and Weimin Zhou

No. 775
August 2017

Asian Development Bank Institute

Chun-Yu Ho is assistant professor of economics at University at Albany, State University of New York (SUNY), on leave from Antai College of Economics & Management, Shanghai Jiao Tong University. Xin Li and Weimin Zhou are assistant professors, also from Antai College of Economics & Management, Shanghai Jiao Tong University.

Suggested citation:

Ho, C-Y., X. Li, and W. Zhou. 2017. Foreign Direct Investment Spillovers and Pharmaceutical Innovation: The Role of Intellectual Property Rights. ADBI Working Paper 775. Tokyo: Asian Development Bank Institute. Available: https://www.adb.org/publications/foreign-direct-investment-spillovers-pharmaceutical-innovation-role-ipr

Please contact the authors for information about this paper.

Email: cho@albany.edu, chunyu.ho@sjtu.edu.cn

The authors thank Jim Brander, Lee Branstetter, and conference and seminar participants of the 5th IEFS China Annual Conference for comments and suggestions. Weimin Zhou would like to acknowledge financial support from the National Science Foundation of China (Project Number: 71203142).

Asian Development Bank Institute
Kasumigaseki Building, 8th Floor
3-2-5 Kasumigaseki, Chiyoda-ku
Tokyo 100-6008, Japan

Tel: +81-3-3593-5500
Fax: +81-3-3593-5571
URL: www.adbi.org
E-mail: info@adbi.org

Abstract

This paper examines the effect of foreign direct investment (FDI) on domestic innovation based on a data set covering the pharmaceutical industries across 29 provinces in the People's Republic of China (PRC) over the period 1998–2007. We show that there is a negative horizontal spillover effect of FDI on domestic innovation when the intellectual property rights (IPR) regime is weak. This spillover effect became more positive when the IPR regime |strengthened after the PRC's accession to the World Trade Organization) (WTO) in 2001. We also show that there is a positive upstream spillover effect of FDI on domestic suppliers of pharmaceutical intermediates. Taken together, our findings provide important policy implications on why developing countries should encourage FDI and strengthen the IPR regime together to enhance domestic innovation for promoting productivity and economic growth.

Keywords: innovation, patents, knowledge spillover, intellectual property rights, multinational enterprises, People's Republic of China

JEL Classification: D22, F23, L65, O31, O34, O38

Contents

1. INTRODUCTION 1

2. INDUSTRY BACKGROUND 2

2.1 The Relevance of Pharmaceutical Patent Data 4

3. EMPIRICAL MODEL AND DATA 4

3.1 Empirical Model 4
3.2 Data 6
3.3 Descriptive Statistics 7

4. EMPIRICAL RESULTS 8

4.1 Horizontal Spillover 8
4.2 Upstream Spillover 11
4.3 Robustness Checks 14

5. CONCLUSIONS 15

REFERENCES 17

1. INTRODUCTION

Foreign direct investment (FDI) has been widely introduced into developing countries in the expectation that foreign-invested enterprises (FIEs) can facilitate knowledge spillover to the host countries, yet FIEs' impact on domestic innovation remains ambiguous. With a global trend of increasingly strengthening intellectual property rights (IPR), how knowledge spillover performs in this context becomes even more complex. Some scholars argue that a stronger IPR regime would encourage FIEs to conduct research and development, which is beneficial to developing countries (Diwan and Rodrik 1991). This is because those FIEs would enable domestic firms to build up their innovation capacity through the "market for technology" (Chen and Puttitanun 2005), training of local staff in subsidiaries and joint ventures, turnover of skilled labor from foreign to domestic firms (Fosfuri, Motta and Rønde 2001; Gorg and Strobl 2005), and learning within the supply chain from FIEs (Rodriguez-Clare 1996; Javorcik 2004). Therefore, a stronger IPR would promote knowledge spillover of FDI.

Though there are many empirical works examining the impacts of IPR or FDI on innovation in developing countries, there are few studies investigating how IPR protection affects the knowledge spillover of FDI in developing countries. This paper examines how IPR protection affects the effect of FDI on domestic innovation based on a data set covering the pharmaceutical industries across 29 provinces in the People's Republic of China (PRC) over the period 1998–2007. One year before joining the WTO in 2001, the PRC amended its IPR laws and regulations to comply with the WTO Agreement on Trade-Related Aspects of Intellectual Property Rights (TRIPS). The TRIPS agreement is particularly significant, as it specifies strong minimum standards for the protection and enforcement of various types of IPR, including copyrights, patents, and trade secrets. The resulting IPR regime in the PRC became stronger in order to be more aligned with the IPR regimes in other WTO member countries. We show that there was a negative horizontal spillover effect of FDI on domestic innovation when the IPR regime was weak before the PRC's accession to the WTO. This spillover effect became more positive when the IPR regime strengthened after the PRC's accession to the WTO. We also show that there is a positive upstream spillover effect of FDI on domestic suppliers of pharmaceutical intermediates. Taken together, our findings provide important policy implications on why developing countries should encourage FDI and strengthen the IPR regime together to enhance domestic innovation for promoting productivity and economic growth.

Our paper contributes to three strands of literature. First, it extends the literature on the role of the IPR regime in promoting innovation in developing countries. Qian (2007) examines 26 countries that established pharmaceutical patent laws during the period 1978–2002, and concludes that such laws only stimulate domestic pharmaceutical innovation for countries with higher levels of economic development, educational attainment, and economic freedom. Kyle and McGahan (2012) find that the introduction of patent protection due to the TRIPS agreement in developing countries has not been followed by greater R&D investment by domestic firms. Our study extends the literature in showing that stronger IPR can promote domestic innovation by facilitating knowledge spillover from FIEs to domestic firms.

Our paper also adds to the growing literature on investigating the spillover effect of FDI along the supply chain. Javorcik (2004) and Liu, Wang and Wei (2009) show that FDI increases the productivity of domestic suppliers in the upstream industry for Lithuania and the PRC, respectively. Our work differs from the existing works in two aspects. First, we focus on the spillover effect of FDI on innovation. Second, we examine both

horizontal and vertical linkages within an industry instead of relying on aggregate input-output tables to examine those linkages across industries. Specifically, we show that pharmaceutical FDI fosters not only domestic pharmaceutical innovation, but also the innovation of domestic pharmaceutical upstream suppliers.

Finally, our paper adds to the literature on the spillover effect of FDI on domestic patenting activities at provincial level in the PRC. Cheung and Lin (2004) and Yang and Lin (2012) report that FDI promotes patent application across provinces in the PRC, but Fu (2008) and Yueh (2009) report mixed results for patents granted. However, their data include the patent applications submitted by foreign applicants and are aggregated across industries in a province. An exception is Huang and Wu (2012) who use the patent data provided by the State Intellectual Property Office (SIPO) of the PRC, which distinguishes domestic applicants from foreign applicants, to explore the effect of FDI on domestic innovation in nanotechnology. They show that there is a negative effect of horizontal FDI on nanotechnology patent applications across provinces in the PRC. However, they do not examine FDI spillover along the supply chain.

The rest of the paper is organized as follows. Section 2 provides background on the pharmaceutical industry in the PRC. Section 3 presents the model and data. Section 4 reports the empirical results. The last section concludes and provides policy implications.

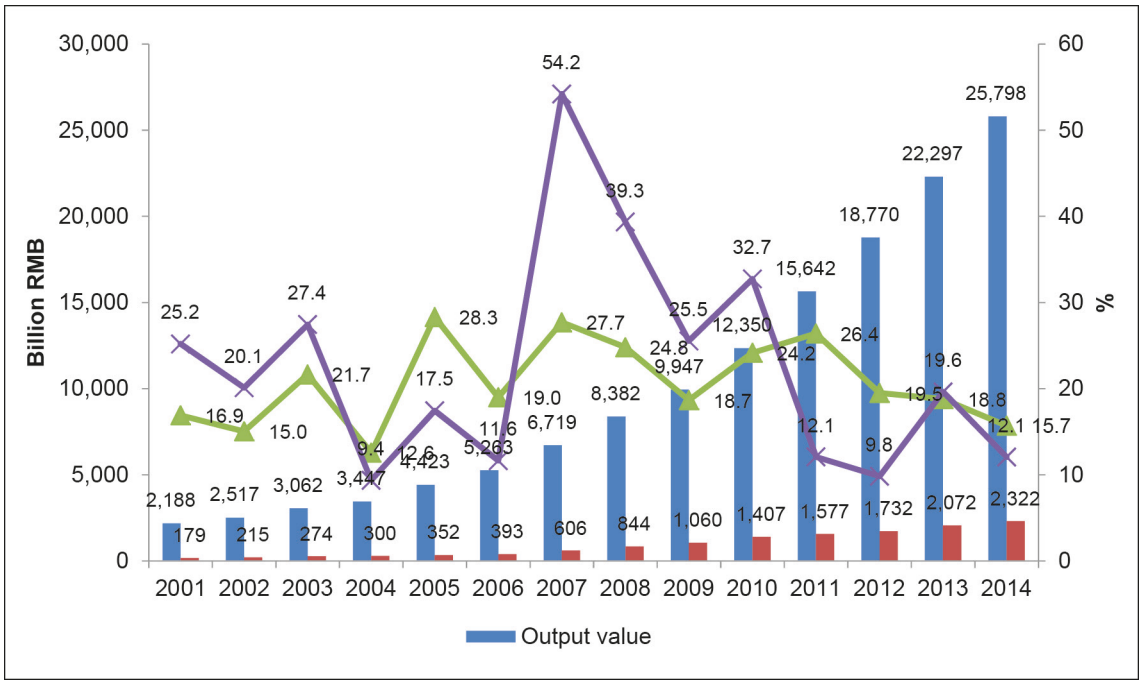
2. INDUSTRY BACKGROUND

Despite the recent global financial crisis, the PRC's economic growth is still surpassing expectations as the world's fastest-growing economy. As of 2014, the PRC is the second largest economy (in purchasing power parity) in the world with a GDP of an estimated international $17.6 trillion, which is growing at a rate of 8.9% (IMF 2015). Driven by the strong economic growth, increasing urbanization, and the health demands of an aging population, the country's pharmaceutical industry has also experienced a surge over the last few decades.

Figure 1 illustrates the PRC's gross pharmaceutical industry output value and profit from 2001 to 2014. The PRC's pharmaceutical industry output value increased from RMB 2,188 billion in 2001 to RMB 25,798 billion in 2014, and its profit increased from RMB 179 billion to RMB 2,322 billion during the same period. In addition, the compound annual growth rates (CAGR) of the PRC's pharmaceutical sector output value and profit between 2008 and 2013 were 21.9% and 21.0%, respectively. The PRC pharmaceutical market is currently the second-largest pharmaceutical market globally, after the US, and in 2014 was worth $105 billion. It is forecasted to increase dramatically to $200 billion by 2020 and increase its dominance as a leading player in Asia.[1]

[1] *Pharmaceutical Industry in China to 2020: An In Depth Analysis of Multinational and Chinese Biopharma Companies, Industry Trends, Environment, Regulation, Market Drivers, Restraints, Opportunities & Challenges*, Kelly Scientific Publications, 2015.

Figure 1: Output Value and Profit of the People's Republic of China's Pharmaceutical Industry, 2001–2014



Source: China Statistical Yearbook on Medicine.

Despite the rapid development of the pharmaceutical sector, it has some unique characteristics that may hinder its sustainable development in the future. More specifically, PRC pharmaceutical firms remain extremely fragmented with low capacity utilization. The total number of pharmaceutical firms was more than 4,500 by 2009; most of them were small-scale, duplicative producers of generic drugs. The sales revenue of the top ten pharmaceutical enterprises accounts for only 10% of total pharmaceutical sales and the top 100 firms account for only 33% of total sales, compared to the top ten international pharmaceutical companies, which account for about 42% of global pharmaceutical sales revenue.

Moreover, compared with international pharmaceutical giants, PRC pharmaceutical firms are not only small but also weak in terms of technology. On average, research and development (R&D) spending accounts for only 2.7% of sales revenue (Kermani and Zhou 2007), which is far lower than the 17.4% of their US counterparts (phRMA 2009). From 2000 to 2008, PRC firms independently developed only two new chemical entities (NCEs), whereas the US had 193 NCEs during the same period (Liang, Ding and Xue 2011). Having realized and tried to solve these problems, the PRC government has implemented a series of policies to encourage innovation in the pharmaceutical industry. Specifically, the National Development and Reform Commission (NDRC) specified that the focus of the Eleventh Five-Year Plan (2006–2010) is to improve the PRC's fundamental capacity for independent innovation. Companies are expected to invest at least 5% of their revenue in R&D and develop a total of 20 to 30 patented drugs and vaccines for diseases relevant to the PRC population. In addition, in December 2007, the State Council approved the Key New Drug Creation and Development Program. Under this initiative, the government will invest RMB 4 billion in the first five years and RMB 10 billion in the following ten years on pharmaceutical R&D, with a specific focus on selected major diseases. Overall, the PRC's domestic R&D activities are expected to gradually catch up with other countries.

2.1 The Relevance of Pharmaceutical Patent Data

This subsection discusses the features of pharmaceutical industries that fit our objective in using patent data to examine the impact of IPR protection on knowledge spillover. The pharmaceutical industry is one of the few industries where patents can capture, to a large extent, innovation capacity. On the one hand, the invention of pharmaceuticals is extremely time-consuming and costly: It takes on average ten years and a substantial sunk cost to develop a new medicine successfully (Mansfield 1986; Levin, Klevorick, Nelson and Winter 1987). On the other hand, the cost of imitation is extremely low: For example, the critical part of a medicine—active ingredients defined by a molecular formula—is easy to identify by reverse-engineering. As a result, pharmaceutical firms are forced to consistently resort to patent rights to protect their innovations. Therefore, patents can mostly represent the innovation capacity of the pharmaceutical industry.

In contrast, the inventions of other industries, such as machinery, are hard to imitate due to the complexity of the technology and the intricacy of the manufacturing process, so patent protection is not so critical for these industries. In addition, some industries may resort to other forms of protection, such as trade secrets, to attain more secure protection. Therefore, the patent data of these industries may reflect only a fraction of their innovation capacity and the size of the missing portion differs given firms' varied situations and purposes. For these industries, patents are less reliable as a measure of innovation capacity. Our argument on these unique features of the pharmaceutical industry is supported by a series of papers. For example, Mansfield (1986) and Levin et al. (1987) document that the value of patent protection for pharmaceuticals is way above the average for all industries.

3. EMPIRICAL MODEL AND DATA

3.1 Empirical Model

Our approach of examining pharmaceutical innovation in different provinces is based on the knowledge production function used in endogenous growth theory (Romer 1990; Grossman and Helpman 1991; Aghion and Howitt 1992). In alignment with the theory, we specify a knowledge production function as follows:

$$\Delta A_{it} = \delta(FDI_{it})A_{it}^{\varphi}H_{it}^{\sigma} \quad (1)$$

The province and year are denoted by *i* and *t*, respectively. ΔA_{it} represents the flow of new innovations, A_{it} represents the stock of useful knowledge available to drive future knowledge production, and H_{it} represents the total resources devoted to knowledge production. The parameter φ characterizes the return-to-scale effect of the existing knowledge stock on producing new knowledge. The parameter σ is the duplication parameter and ranges from 0 if all innovations are duplicates to 1 if no innovation is duplicated. In addition, FDI_{it} refers to FDI in a province, and $\delta(FDI_{it})$ captures the FDI spillover effect on domestic innovation.

We specify the following empirical model to examine the horizontal spillover of FDI to domestic pharmaceutical innovation:

$$lnPG_{it} = \beta_1 FShare_{it} + \beta_2 FShare_{it} * WTO_t$$
$$+\beta_3 lnPS_{it-1} + \beta_4 \left(\frac{RD}{FA}\right)_{it} + \beta_5 lnTA_{it} + \delta_i + \delta_t + u_{it} \quad (2)$$

The dependent variable is *PG*, the number of patents granted per 1,000 employees in pharmaceuticals, to measure domestic pharmaceutical innovation. Patents have been widely used, not without controversy, as measures of innovation output (Griliches 1990). Although not all inventions are patented, those that are must meet minimal standards of novelty, originality, and potential use. Therefore, patents are an appropriate proxy for economically significant innovation.

The main explanatory variable of interest is *FShare*, the ratio of foreign pharmaceutical firms to all pharmaceutical firms in a province, to measure FDI intensity. The coefficient β_1 captures the horizontal spillover of FDI in pharmaceutical industries on domestic pharmaceutical innovation. The variable *WTO* takes the value one in and after the year 2001, and zero otherwise. The choice of the year 2001 is based on the PRC's accession to the WTO in November 2001. We use the interaction term between *FShare* and *WTO* to capture how strengthening the IPR regime affects the horizontal spillover effect of FDI on domestic pharmaceutical innovation.

Moreover, we include a set of control variables in Equation (2). To incorporate the effect of existing knowledge stock on new innovation, we include the variable *PS*, which is the number of patent stocks per 1,000 employees in pharmaceuticals. To incorporate the effect of the resources devoted to innovation, we include the ratio of RD to fixed assets (*RD/FA*) and total assets (*TA*) of the pharmaceutical industry.

Equation (2) also includes a full set of province dummies, δ_i, which capture any time-invariant provincial factors that affect the equilibrium levels of innovation. For example, these dummies eliminate the effect of constant, potentially institutional factors. Additionally, a full set of year dummies, δ_t, are included to capture common shocks to pharmaceutical innovation in all provinces. This includes the potential common effect of strengthening the IPR regime on domestic pharmaceutical innovation in all provinces. The error term u_{it} captures all of the other omitted provincial factors, where $E[u_{it}] = 0$ for all *i* and *t*.

To examine the FDI spillover effect on an upstream industry, i.e. pharmaceutical intermediates, we specify the following empirical model:

$$lnPG - PI_{it} = \beta_1 FShare_{it} + \beta_2 FShare_{it} * WTO_t$$
$$+\beta_3 lnPS - PI_{it-1} + \beta_4 \left(\frac{RD}{FA}\right)_{it} + \beta_5 lnTA - PI_{it} + \delta_i + \delta_t + u_{it} \quad (3)$$

The dependent variable is *PG-PI*, which is the number of patents granted per 1,000 employees in pharmaceutical intermediates. Since pharmaceutical intermediates are input for drug manufacturing, the coefficient β_1 captures the upstream spillover of FDI in pharmaceutical industries on domestic innovation in pharmaceutical intermediates. The coefficient on *FShare*WTO* indicates how the strengthening of IPR protection affects that upstream spillover effect of FDI. The control variables include patent stock (*PS-PI*), ratio of RD to fixed assets (*RD/FA*), and total assets in pharmaceutical intermediates (*TA-PI*).

3.2 Data

We compile a novel panel data set at provincial level from various sources to conduct our empirical analysis. The sample period of the annual data is 1998–2007.[2] All variables have variations at province-year level. First, we collect the patent information from a unique database – the Chinese Pharmaceutical Patent (CPP) Database, developed by the SIPO of the PRC. Our analysis focuses on invention patents only because they represent higher quality and innovation capacity than other types of intellectual property.[3] To the best of our knowledge, there has not been any unified concordance approach that can be used to categorize patents into different industries. The challenge for defining such an approach lies in the complexity of the technology knowledge required (such as sections and search terms of patents) for the categorization. The CPP database provides a reliable source based on professional judgment to obtain pharmaceutical patents from among various overlapping International Patent Classification (IPC) classes.

The CPP database contains nearly 110,000 patent application entries for chemical medicine submitted by domestic and foreign applicants to the SIPO since 1985.[4] The information for each entry includes patent application and publication number, application and publication date, patent number, title, IPC code, abstract, claims, legal status, therapeutic effect, and so on. Furthermore, this database identifies whether patents applied for and granted belong to the category of drugs (including preparation methods) or pharmaceutical intermediates. Thus, we can aggregate patent applications and patent grants for drugs (*PA* and *PG*) and those for pharmaceutical intermediates (*PA-PI* and *PG-PI*) that have been submitted by domestic applicants at provincial level in each year.

Second, we use the firm-level data set from the Annual Surveys of Industrial Firms (ASIF) collected by the National Bureau of Statistics (NBS) of the PRC. We use the sample from Sector 272 (Chemical Medicine Preparation Pharmaceutical Industry) to compute the foreign firm penetration in pharmaceutical industries across PRC provinces. To identify foreign firms, we exploit the ownership information of our firm-level panel data set to define foreign firms with the following criteria. First, we define foreign firms as firms with at least 25% of shares owned by foreign investors. Based on this definition, we compute *FShare25*, the ratio of foreign firms to all firms in pharmaceutical industries at province-year level, to measure the foreign firm penetration. We also compute *FShare50* and *FShare100* in analogous ways as alternative measures for foreign firm penetration. Further, we compute the variables *TA* and *TA-PI* with the total assets across firms in Sector 272 and Sector 271 (Raw Chemical Medicine Pharmaceutical Industry) at provincial level in each year, respectively.

Third, we compute the ratio of R&D expenses to fixed assets to measure *RD/FA*. The provincial-level data on R&D expenses and fixed assets are collected from the Statistical Yearbook of High-Technology Industry published by the NBS of the PRC. We employ this data set because the ASIF does not provide information on R&D expenses over the sample period. The drawback of using this data set is that it reports data at a two-digit level for the pharmaceutical industry, which aggregates the

[2] The sample period of our panel data is limited by the availability of firm-level data.

[3] There are three types of patents that can be granted, namely invention, utility model, and design. Invention patents must meet the requirements of "novelty, inventiveness, and practical applicability," which is more innovative than the requirements of the other two patent types.

[4] We exclude about 70,000 patent application entries for traditional Chinese medicine.

information over Sectors 271–277. We use *RD/FA* as an imperfect proxy of R&D intensity for pharmaceutical and pharmaceutical intermediates in Equations (2) and (3), respectively.

3.3 Descriptive Statistics

We report the variable definitions and summary statistics in Table 1. On average, there are 1.1 patents granted per 1,000 employees for drugs and 0.2 patents granted per 1,000 employees for pharmaceutical intermediates. The patent stock per 1,000 employees for drugs is 13.6 and that for pharmaceutical intermediates is 0.7. The average ratio of R&D expenses to fixed assets is about 0.02. On average, about 8.5% of total pharmaceutical firms enjoy no less than 25% foreign ownership; about 5.9%, no less than 50% foreign ownership; and about 2.6% with 100% foreign ownership.

Table 1: Variable Definitions and Summary Statistics

	Mean	SD	Min	P25	Median	P75	Max
Dependent variables							
PG	1.13	1.53	0	0.31	0.60	1.31	11.9
PG-PI	0.15	0.25	0	0	0.05	0.18	1.80
PA	3.12	5.52	0	0.77	1.48	3.33	67.1
PA-PI	0.28	0.49	0	0.02	0.09	0.33	3.98
Control variables							
PS	13.6	15.2	1.84	5.09	8.31	13.8	90.4
PS-PI	0.68	1.08	0	0.15	0.30	0.71	7.22
RD/FA	0.018	0.014	0	0.007	0.016	0.025	0.078
TA	3,752	3,912	38.1	1,146	2,397	4,874	22,279
TA-PI	3,952	5,646	6.28	632.2	1,892	4,455	30,051
FDI variables							
FShare25	0.085	0.086	0	0	0.069	0.122	0.458
FShare50	0.059	0.071	0	0	0.034	0.091	0.333
FShare100	0.026	0.037	0	0	0	0.044	0.167
MNC	0.979	2.314	0	0	0	1	14

Note: Number of observations = 290 (29 provinces for 10 years). Each observation represents a province in a year.

PG = number of domestic patents of drugs granted per 1,000 employees; PG-PI = number of domestic patents of pharmaceutical intermediates granted per 1,000 employees; PA = number of domestic patent applications of drugs per 1,000 employees; PA-PI = number of domestic patent applications of pharmaceutical intermediates per 1,000 employees; PS = stock of domestic patents of drugs granted per 1,000 employees; PS-PI = stock of domestic patents of pharmaceutical intermediates granted per 1,000 employees; RD/FA = ratio of the expenses for research and development to fixed assets; TA and TA-PI = total assets (in RMB1,000,000) for drug and pharmaceutical intermediate industries, respectively; FShare25 = share of foreign firms in all firms, where we define foreign firms as firms with at least 25% of shares owned by foreign investors; FShare50 and FShare100 are defined in analogous ways; MNC = number of subsidiaries of MNCs.

Data source for PG, PG-PI, PA, PA-PI, PS, PS-PI: State Intellectual Property Office (SIPO). Data source for FShare25, FShare05, FShare100, TA, and TA-PI: a firm-level data set on Sectors 271 (Raw Chemical Medicine Pharmaceutical Industry) and 272 (Chemical Medicine Preparation Pharmaceutical Industry) from the Annual Surveys of Industrial Firms (ASIF). Data source for MNC: 18 company websites for Fortune 500 pharmaceutical firms and various transnational corporation reports (2001–2012) in the PRC edited by Zhile Wang and published by China Economic Publishing House. Data source for RD and FA: China Statistics Yearbook on High-Technology Industry, published by the National Bureau of Statistics (NBS) of the PRC.

Table 2 reports the correlation matrix of the key variables, which shows that patents granted in drugs positively correlate with patent stock, R&D intensity, total assets, and foreign firm penetration. Nonetheless, the correlations among most explanatory variables are statistically significant, thus we need to employ multivariate regression to establish the relationships between innovation and each explanatory variable.

Table 2: Correlation Matrix for Key Variables

	lnPS	lnPS-PI	RD/FA	lnTA	lnTA-PI	FShare25	FShare50	FShare100	MNC
lnPG	0.459***	0.740***	0.336***	0.434***	–0.019	0.492***	0.486***	0.329***	0.565***
lnPG-PI	0.326***	0.869***	0.430***	0.382***	0.147**	0.443***	0.480***	0.366***	0.631***
lnPA	0.479***	0.804***	0.427***	0.466***	0.014	0.495***	0.504***	0.399***	0.593***
lnPA-PI	0.359***	0.943***	0.486***	0.405***	0.158***	0.456***	0.496***	0.427***	0.645***
lnPS	1.000	0.366***	–0.029	–0.288***	–0.492***	0.041	0.090	0.126**	0.172***
lnPS-PI		1.000	0.481***	0.419***	0.129**	0.489***	0.507***	0.410***	0.645***
RD/FA			1.000	0.494***	0.374***	0.416***	0.447***	0.417***	0.402***
lnTA				1.000	0.492***	0.570***	0.549***	0.457***	0.356***
lnTA-PI					1.000	0.238***	0.232***	0.113***	0.458***
FShare25						1.000	0.926***	0.635***	0.171***
FShare50							1.000	0.707***	0.496***
FShare100								1.000	0.543***
MNC									1.000

Note: Number of observations = 290. Each observation represents a province in a year. *** p<0.01, ** p<0.05, * p<0.1.

4. EMPIRICAL RESULTS

In this section, we first discuss the empirical results of Equations (2) and (3) that are obtained from the fixed-effect model.[5] Then, we discuss two robustness checks.

4.1 Horizontal Spillover

Table 3 reports the results for Equation (2). The variables of interest in Column 1 are *FShare25* and *FShare25*WTO*. The coefficient of *FShare25* is negative and significant at the 1% level, and the coefficient of *FShare25*WTO* is positive and significant at the 1% level. Facing competition from foreign firms, domestic pharmaceutical firms reduce their innovation when the IPR regime is weak, but they increase their innovation when the IPR regime becomes stronger. These results suggest that domestic pharmaceutical firms increase their innovation in order to compete with foreign firms when the domestic firms have a stronger IPR protection. These results are in contrast to the study of Branstetter, Fisman and Foley (2006) in which they find that a stronger IPR increases the knowledge transfer from US-based parent companies to their affiliates in patent-reforming countries, yet they fail to find any impact on domestic innovation in terms of local resident patent filings with the stronger IPR.

[5] We reject the unit root null hypothesis for all variables used in Equations (2) and (3) with the panel unit test proposed by Levin, Klevorick and Nelson (2002), and conclude that all variables are stationary. We employ the Hausman specification test to compare the estimates from the fixed-effect models with those from the random effect models (Hausman, 1978), and we reject the null hypothesis that the provincial effects are uncorrelated with the other regressors in the empirical model. We conclude that the random effect model produces biased estimators, and therefore the fixed-effect model is preferred.

Table 3: Horizontal Spillover

Variables	(1) lnPG	(2) lnPG	(3) lnPG	(4) lnPG	(5) lnPG
FShare25	–1.260***				
	[0.469]				
FShare25*WTO	1.433***				
	[0.389]				
FShare50		–1.912***			
		[0.596]			
FShare50*WTO		1.746***			
		[0.484]			
FShare100			–3.243**	–2.631*	
			[1.301]	[1.351]	
FShare100*WTO			2.837**	2.040	
			[1.240]	[1.291]	
FShare5099				–1.441**	
				[0.686]	
FShare5099*WTO				1.650***	
				[0.599]	
FShare2549				–0.240	
				[0.870]	
FShare2549*WTO				1.032	
				[0.904]	
MNC					–0.168***
					[0.0398]
MNC*WTO					0.0499***
					[0.0155]
lnPS(t-1)	0.125**	0.123**	0.204***	0.133**	0.186***
	[0.0593]	[0.0595]	[0.0574]	[0.0614]	[0.0633]
RD/CAP	0.650	0.513	0.572	0.325	1.323
	[1.424]	[1.428]	[1.455]	[1.437]	[1.415]
lnTA	0.0910***	0.0991***	0.0977***	0.0935***	0.0935***
	[0.0339]	[0.0335]	[0.0342]	[0.0343]	[0.0330]
Province FE	Yes	Yes	Yes	Yes	Yes
Year FE	Yes	Yes	Yes	Yes	Yes
Observations	260	260	260	260	260
R-squared	0.598	0.598	0.584	0.605	0.606
No. of provinces	29	29	29	29	29

continued on next page

Table 3 *continued*

Variables	(6) lnPA	(7) lnPA	(8) lnPA	(9) lnPA	(10) lnPA
FShare25	–2.032***				
	[0.683]				
FShare25*WTO	1.942***				
	[0.566]				
FShare50		–2.749***			
		[0.869]			
FShare50*WTO		2.249***			
		[0.706]			
FShare100			–6.620***	–6.264***	
			[1.857]	[1.953]	
FShare100*WTO			6.612***	6.034***	
			[1.770]	[1.866]	
FShare5099				–1.691*	
				[0.992]	
FShare5099*WTO				0.924	
				[0.866]	
FShare2549				–0.725	
				[1.258]	
FShare2549*WTO				1.664	
				[1.307]	
MNC					–0.104*
					[0.0586]
MNC*WTO					–0.0325
					[0.0228]
lnPS(t-1)	0.190**	0.194**	0.285***	0.221**	0.444***
	[0.0864]	[0.0868]	[0.0819]	[0.0887]	[0.0931]
RD/CAP	2.150	1.968	1.784	1.657	3.478*
	[2.075]	[2.083]	[2.078]	[2.077]	[2.080]
lnTA	0.0794	0.0873*	0.0752	0.0688	0.0680
	[0.0493]	[0.0489]	[0.0488]	[0.0496]	[0.0485]
Province FE	Yes	Yes	Yes	Yes	Yes
Year FE	Yes	Yes	Yes	Yes	Yes
Observations	260	260	260	260	260
R-squared	0.628	0.626	0.631	0.640	0.628
No. of provinces	29	29	29	29	29

Note: *** p<0.01, ** p<0.05, * p<0.1. Dependent variable: patents granted per 1,000 employees for drugs for Columns 1–5 and patent applications per 1,000 employees for drugs for Columns 6–10.

Column 1 of Table 3 also shows that the coefficients of ln*PS* and ln*TA* are positive and significant at the 1% and 5% level, respectively. However, the coefficient of *RD/FA* is positive but statistically insignificant. Provinces have a higher number of patents granted for drugs in the current year when they have a larger knowledge stock in innovating drugs and have a larger scale of operation. Our results suggest that there is a decreasing return to scale for knowledge production and not all new knowledge duplicates existing knowledge. Further, the results reported in Column 1 of Table 3 are confirmed by the results reported in Columns 2 and 3, in which we define foreign firms as firms with at least 50% and 100% of shares owned by foreign investors, respectively.

Although the results from Columns 1–3 in Table 3 show that all three types of foreign firms (*FShare25*, *FShare50*, and *FShare100*) affect domestic pharmaceutical innovation, this specification does not allow us to examine which particular type of foreign firm penetration has the strongest impact on domestic pharmaceutical innovation. In order to achieve this goal, we investigate this issue by defining three types of foreign firms, namely firms with 25–49 % of shares owned by foreign investors, firms with 50–99 % of shares owned by foreign investors, and firms with 100% of shares owned by foreign investors, with the following specification:

$$lnPG_{it} = \beta_1 FShare100_{it} + \beta_2 FShare100_{it} * Policy_t + \beta_1 FShare5099_{it}$$
$$+\beta_2 FShare5099_{it} * Policy_t + \beta_1 FShare2549_{it} + \beta_2 FShare2549_{it} * Policy_t$$
$$+\beta_3 lnPS_{it-1} + \beta_4 \left(\frac{RD}{FA}\right)_{it} + \beta_5 lnTA_{it} + \delta_i + \delta_t + u_{it} \quad (4)$$

Column 4 in Table 3 reports the results. The coefficient on *FShare5099*WTO* is positive and significant at the 5% level and that on *FShare100*WTO* is positive and significant at about the 15% level. Our results suggest that horizontal spillover of FDI on domestic innovation is stronger for joint ventures with majority foreign ownership than that for wholly foreign-owned enterprises. However, joint ventures with minority foreign ownership have no spillover effect no matter whether the IPR regime is strengthened or not.

4.2 Upstream Spillover

Table 4 reports the results for Equation (3). The coefficients on *FShare25*, *FShare50*, and *FShare100* in Columns 1–3 are negative but insignificant. The coefficients on *FShare25*WTO* and *FShare50*WTO* in Columns 1–2 are positive and significant at the 1% level. Our results indicate that domestic innovation in pharmaceutical intermediates increases for provinces with a higher foreign firm penetration in pharmaceutical industries after strengthening the IPR regime. Column 4 reports that the coefficient of *FShare5099*WTO* is positive and significant at the 1% level. This indicates that a higher penetration of firms with majority foreign ownership in pharmaceutical industries is key to inducing domestic innovation of pharmaceutical intermediates after strengthening the IPR regime.

Table 4: Upstream Spillover

Variables	(1) lnPG-PI	(2) lnPG-PI	(3) lnPG-PI	(4) lnPG-PI	(5) lnPG-PI
FShare25	–0.187				
	[0.227]				
FShare25*WTO	0.538***				
	[0.187]				
FShare50		–0.295			
		[0.289]			
FShare50*WTO		0.707***			
		[0.234]			
FShare100			–0.254	0.0679	
			[0.639]	[0.661]	
FShare100*WTO			0.645	0.273	
			[0.610]	[0.632]	
FShare5099				–0.338	
				[0.333]	
FShare5099*WTO				0.824***	
				[0.292]	
FShare2549				–0.000499	
				[0.426]	
FShare2549*WTO				0.115	
				[0.443]	
MNC					–0.0211
					[0.0195]
MNC*WTO					0.0358***
					[0.00727]
lnPS-PI(t-1)	0.218***	0.206***	0.236***	0.205***	0.121**
	[0.0441]	[0.0447]	[0.0439]	[0.0458]	[0.0510]
RD/FA	0.480	0.545	0.628	0.546	0.644
	[0.783]	[0.781]	[0.801]	[0.793]	[0.753]
lnTA-PI	0.00343	0.00338	0.00277	0.00317	0.00850
	[0.0116]	[0.0115]	[0.0118]	[0.0117]	[0.0113]
Province FE	Yes	Yes	Yes	Yes	Yes
Year FE	Yes	Yes	Yes	Yes	Yes
Observations	247	247	247	247	248
R-squared	0.522	0.525	0.502	0.527	0.555
No. of provinces	28	28	28	28	28

continued on next page

Table 4 *continued*

Variables	(6) lnPA-PI	(7) lnPA-PI	(8) lnPA-PI	(9) lnPA-PI	(10) lnPA-PI
FShare25	–0.132				
	[0.249]				
FShare25*WTO	0.626***				
	[0.205]				
FShare50		–0.130			
		[0.318]			
FShare50*WTO		0.721***			
		[0.258]			
FShare100			–0.217	0.207	
			[0.700]	[0.727]	
FShare100*WTO			0.920	0.485	
			[0.668]	[0.695]	
FShare5099				–0.152	
				[0.366]	
FShare5099*WTO				0.671**	
				[0.321]	
FShare2549				–0.256	
				[0.469]	
FShare2549*WTO				0.508	
				[0.486]	
MNC					0.0489**
					[0.0207]
MNC*WTO					0.0327***
					[0.00773]
lnPS-PI(t-1)	0.574***	0.566***	0.589***	0.567***	0.386***
	[0.0483]	[0.0493]	[0.0481]	[0.0503]	[0.0542]
RD/FA	0.730	0.848	0.926	0.827	0.954
	[0.859]	[0.860]	[0.877]	[0.871]	[0.800]
lnTA-PI	-0.0175	-0.0178	-0.0176	-0.0172	-0.00739
	[0.0127]	[0.0127]	[0.0130]	[0.0128]	[0.0120]
Province FE	Yes	Yes	Yes	Yes	Yes
Year FE	Yes	Yes	Yes	Yes	Yes
Observations	247	247	247	247	248
R-squared	0.768	0.767	0.759	0.769	0.797
No. of provinces	28	28	28	28	28

Note: *** p<0.01, ** p<0.05, * p<0.1. Dependent variable: patents granted per 1,000 employees for pharmaceutical intermediates for Columns 1–5 and patent applications per 1,000 employees for pharmaceutical intermediates for Columns 6–10.

There are two potential reasons for these results to occur. First, foreign firms do not outsource their input to domestic suppliers when the IPR regime is weak. After strengthening the IPR regime, foreign firms outsource to domestic suppliers, which raises the innovation capacity of domestic suppliers. Second, after strengthening the IPR regime, domestic firms compete with foreign firms by producing higher-quality drugs. Consequently, domestic firms demand high-quality inputs from local suppliers.

Furthermore, our findings suggest that there is an upstream spillover effect of FDI on boosting domestic innovation. Liu, Wang and Wei (2009) show that FDI increases the productivity of domestic suppliers in upstream industry for the PRC. Our results show that FDI raises not only the productivity of domestic firms in upstream industry but also the innovation of domestic firms in upstream industry. Finally, Columns 1–4 in Table 4 report that domestic innovation in pharmaceutical intermediates depends positively on patent stocks.

4.3 Robustness Checks

In this subsection, we discuss two robustness checks. First, we employ an alternative measure of foreign firm penetration as an explanatory variable. We look into the Fortune 500 pharmaceutical corporations over the period 2001–2010. We collect the information on the location of their subsidiaries and starting operation year in the PRC from their company websites. We cross-check the location information with various transnational corporation reports in the PRC, which report information about local subsidiaries (including starting operation year, location, and ownership) for Fortune 500 corporations.

Figure 2: Location of Fortune 500 Pharmaceutical Firms in the People's Republic of China, 2001–2010

We compute a variable *MNC*, the number of subsidiaries of Fortune 500 pharmaceutical corporations in each province, to measure foreign firm penetration. Figure 2 illustrates the geographical distribution of MNCs across provinces. We re-estimate Equations (2) and (3) by replacing the variable *FShare* with *MNC*, and report the results in Column 5 of Tables 3 and 4, respectively. The results of Column 5 in Table 3 are consistent with those of Columns 1–3 in Table 3, in which the coefficient on *MNC* is negative and significant at the 1% level and the coefficient on *MNC*WTO* is positive and significant at the 1% level. Furthermore, the results of Column 5 in Table 4 are consistent with those of Columns 1–3 in Table 4, in which the coefficient on *MNC* is negative and insignificant and the coefficient on *MNC*WTO* is positive and significant at the 1% level.

The second robustness check employs patent applications as our measure of innovation. Compared with patent grants, patent applications have the advantage of timeliness: It usually takes two to three years for a patent application to be granted if successful. Thus, the measure of patent applications is better at reflecting the current innovation capacity. However, it also has a disadvantage – lack of quality control. Not all patents applied are qualified for granting, so a higher number of patent application rate does not necessarily mean higher innovative capacity.

Table 1 reports that, on average, there are 3.1 patent applications per 1,000 employees for pharmaceuticals and 0.3 patent applications per 1,000 employees for pharmaceutical intermediates. Table 2 reports the correlation matrix of the key variables, which shows that patent applications in drugs and pharmaceutical intermediates positively correlate with patent stock, R&D intensity, total assets, and foreign firm penetration. Moreover, Columns 6–10 in Tables 3 and 4 report the results of Equations (2) and (3) with patent application in drug and pharmaceutical intermediates as the dependent variable, respectively. The results are consistent with those reported in Columns 1–5 of Tables 3 and 4.

5. CONCLUSIONS

This paper employs provincial panel data on the pharmaceutical industry to examine the impact of FDI spillover on domestic innovation. Using a fixed-effect panel data model, we show that FDI promotes domestic innovation only after strengthening the IPR regime. Under a stronger IPR regime, FDI in pharmaceutical industries not only induces more innovation from domestic pharmaceutical firms, which compete with foreign firms in the same market, but also induces more innovation from domestic suppliers in upstream industry, i.e. pharmaceutical intermediates. These relationships are robust to the use of alternative measures for foreign firm penetration and innovation, and the inclusion of knowledge stock, R&D expenses, total assets, provincial fixed effects, and year fixed effects as control variables. In line with the literature, we show that innovation depends on the existing knowledge stock and the resources devoted to knowledge production.

Our empirical findings shed light on the policy debate regarding IPR protection in the pharmaceutical sector in developing countries. Our results suggest that developing countries can learn pharmaceutical innovation from FIEs more effectively under a stronger IPR protection. Although there is a potential cost in that developing countries are adversely affected by high-price patented medicines, our results suggest that developing countries may trade off these benefits and costs to design their IPR protection in pharmaceuticals.

Finally, our empirical findings provide implications for innovation policy in general, which should be of interest to policy makers aiming to sustain economic growth. Policy makers need to take the strength of the IPR regime into consideration when they try to attract FDI as FDI is more efficient in boosting domestic innovation under a stronger IPR regime. Besides a strengthened IPR regime, policy makers also need to take the composition of FDI into account: FDI in the form of joint ventures with foreign majority shareholding seems more effective in improving domestic innovation. Also, when policy makers assess the benefits of FDI for domestic innovation, they need to examine its effect throughout the supply chain.

REFERENCES

Aghion, P., and Howitt, P. (1992). A model of growth through creative destruction. *Econometrica*, 60, 323–51.

Branstetter, L., Fisman, R., and Foley, C. F. (2006). Do stronger intellectual property rights increase international technology transfer? Empirical evidence from US firm-level data. *Quarterly Journal of Economics*, 121, 321–349.

Chen, Y., and Puttitanum, T. (2005) Intellectual property rights and innovation in developing countries. *Journal of Development Economics*, 78(2), 474–493.

Cheung K. Y., and Lin, P. (2004). Spillover effects of FDI on innovation in China: evidence from the provincial data. *China Economic Review*, 15(1), 25–44.

Diwan, I., and Rodrik, D. (1991). Patents, appropriate technology, and North-South trade. *Journal of International Economics*, 30(1–2), 27–47.

Fosfuri, A., Motta, and M., Rønde, T. (2001). Foreign direct investment and spillovers through workers' mobility. *Journal of International Economics*, 53, 205–222.

Fu, X. (2008). Foreign direct investment, absorptive capacity and regional innovation capabilities: evidence from China. *Oxford Development Studies*, 36(1), 89–110.

Gorg, H., and Strobl, E. (2005). Spillovers from foreign firms through worker mobility: An empirical investigation. *Scandinavian Journal of Economics*, 107(4), 693–709.

Griliches, Z. (1990). Patent statistics as economic indicators: A survey. *Journal of Economic Literature*, 28(4), 1661–1707.

Grossman, G. M., and Helpman, E. (1991). *Innovation and Growth in the Global Economy*. Cambridge, MA: MIT Press.

Hausman, J. A. (1978). Specification tests in econometrics. *Econometrica*, 46, 1251–1271.

Huang, C., and Wu, Y. (2012). State-led technological development: A case of China's nanotechnology development. *World Development*, 40(5), 970–982.

International Monetary Fund (2015). *World Economic Outlook: Adjusting to Lower Commodity Prices.* Washington.

Javorcik, B. S. (2004). Does foreign direct investment increase the productivity of domestic firms? In search of spillovers through backward linkages. *American Economic Review*, 94, 605–27.

Kermani, F., and Zhou, Y. (2007). China commits itself to biotech in healthcare. *Drug Discovery Today*, 12, 501–503.

Kyle, M., and McGahan, M. (2012). Investments in pharmaceuticals before and after TRIPS. *Review of Economics and Statistics*, 94(4), 1157–1172.

Liang, H., Ding, J., and Xue, Y. (2011). China's drug innovation and policy environment. *Drug Discovery Today*, 16, 1–3.

Liu, X., Wang, C., and Wei, Y. (2009). Do local manufacturing firms benefit from transactional linkages with multinational enterprises in China? *Journal of International Business Studies*, 40, 1113–1130.

Levin, A., Lin, C. F., and Chu, C. S. J. (2002). Unit root tests in panel data: asymptotic and finite-sample properties. *Journal of Econometrics*, 108(1), 1–24.

Levin, R. C., Klevorick, A. K., Nelson, R. R., and Winter, S. G. (1987). Appropriating the returns from industrial R&D. *Brookings Papers on Economic Activity*, 18(3), 783–820.

Mansfield, E. (1986). Patents and innovation: an empirical study. *Management Science*, 32, 173–181.

phRMA. (2009). *Pharmaceutical industry profile 2009. Washington D.C.,* Pharmaceutical Research and Manufacturers of America.

Qian, Y. (2007). Do national patent laws stimulate domestic innovation in a global patenting environment? A coss-country analysis of pharmaceutical patent protection, 1978–2002. *Review of Economics and Statistics*, 89(3), 436–453.

Rodriguez-Clare, A. (1996). Multinationals, linkages, and economic development. *American Economic Review*, 86(4), 852–73.

Romer, P. M. (1990). Endogenous technological change. *Journal of Political Economy*, 98(5), S71–102.

Yang, C-H, and Lin, H-L. (2012). Openness, absorptive capacity, and regional innovation in China. *Environment and Planning A*, 44, 333–355.

Yueh, L. (2009). Patent laws and innovation in China. *International Review of Law and Economics*, 29(4), 304–313.