

The Impact of FDI on Domestic Firm Innovation

Evidence from Foreign Investment Deregulation in China

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WORLD BANK GROUP

Finance, Competitiveness and Innovation Global Practice

May 2021

Abstract

This paper studies the impact of foreign direct investment on domestic firms' innovation in China. It provides causal evidence by exploiting China's foreign direct investment deregulation in 2002 and employs a difference-in-difference estimation strategy. Using a matched firm-patent data set from 1998 to 2007, the results show that the quantity and quality of domestic firms' innovation benefit from foreign direct investment. Moreover, the paper emphasizes the importance of knowledge spillover from foreign direct investment in similar technology domains. The analysis examines the role of horizontal foreign direct

investment and foreign direct investment in technologically close industries—industries that share similar technology domains. The findings show that foreign direct investment in technologically close industries generates much bigger positive spillovers than horizontal foreign direct investment. The paper also shows that knowledge spillover from foreign direct investment in similar technology domains is not driven by input-out linkages. Moreover, the spillover effect is stronger in cities with higher human capital stock and firms with higher absorptive capacity.

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The Impact of FDI on Domestic Firm Innovation: Evidence from Foreign Investment Deregulation in China

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JEL classification: F2, O1, O3

Keywords: Foreign Direct Investment, innovation, spillover, technological closeness

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I. Introduction

Innovation is an essential driver of economic growth and policy makers make huge efforts to encourage innovation, such as human capital investment and support for research and development (R&D). But developing countries find it hard to close the technology gap with rich countries on their own. They often seek to open their markets and attract foreign direct investment (FDI) in the belief that FDI can spur domestic innovation and industry upgrading. However, we still have no clear evidence on whether FDI promotes domestic firms' innovation or not.

The relationship between FDI and domestic firms' innovation is not clear in theory. On the one hand, foreign firms can disseminate cutting-edge technology, hire and train local workers, generating positive effects on domestic firms' innovation. The presence of FDI in the same industry could lower the cost of domestic firms' innovation through multiple channels, including demonstration effect, supplier sharing and labor mobility (Javorcik and Spatareanu 2009; Alfaro and Rodriguez-Clare 2004; Alfaro-Ureña et al. 2019; Bai et al. 2020). Besides the traditional horizontal FDI spillover effect, researchers have recently realized the importance of spillover within similar technology domains, because knowledge can be transferred to firms that share similar industry know-how and talent input. Fons-Rosen et al. (2017) find that FDI can boost domestic firms' productivity and innovation if foreign firms enter sectors that are technologically close to domestic firms. FDI could also induce learning and upgrading in upstream and downstream firms through input-output linkages (Javorcik 2004, 2008). On the other hand, FDI could hurt domestic firms' performance through the competition effect, heightened competition can discourage domestic firms' innovation (Aghion et al. 2005). If the technology gap between home and host countries is too big or domestic firms lack sufficient absorptive capacity, they would not be able to assimilate the knowledge brought by FDI (Zhang et al. 2010). Ultimately, the impact of FDI on domestic firms' innovation remains an underexplored topic.

This paper provides causal evidence on whether domestic firms become more innovative after being exposed to FDI. We consider two main measures of FDI presence: the traditional horizontal FDI, measured by the share of FDI in the same industry; and technologically close FDI, measured by the FDI from industries that share similar technological domains.³ We explore China's FDI deregulation in 2002 upon joining the WTO, which exogenously increased the share of FDI in deregulated industries. The deregulation offers a great opportunity to examine the causal effects of FDI on domestic firms' innovation. China has been the largest FDI recipient among developing countries. FDI fueled China's sizzling economic growth

³ Two industries are technologically close if they have largely overlapping technological domains. Detailed methodologies for measuring technologically close FDI is explained in Section 2.2.

in the past three decades and dramatically transformed China's export portfolio. During the same period, Chinese firms also significantly improved their indigenous innovation capabilities, China's PCT patent application increased from 276 in 1999 to 58,990 in 2019, surpassing the United States to be the largest PCT patent applicant. What role did FDI play in stimulating China's innovation capability? How does the effect vary by patent type, local human capital, and domestic firms' absorptive capacity? Does FDI discourage domestic firms' innovation through the competition effect? These are the questions on which this paper seeks to shed light.

To test the impact of FDI deregulation on innovation, we combine three main data sets: a comprehensive data set of all medium and large manufacturing enterprises in China between 1998 and 2007, patent application data from the State Intellectual Property Office (SIPO), and patent citation data. We measure two dimensions of innovation activities: output quantity (number of patent application), and quality (type of patent applications, patent grants, and patent citations).

The deregulation in 2002 allows us to use a difference-in-difference estimation strategy to establish the causal impact of FDI. China liberalized 112 of its 425 four-digit manufacturing industries for FDI, and we show that these industries indeed received more foreign investment after 2002. To examine whether our DID design is valid, we first show graphical evidence that before 2001 patent applications in treatment and control groups follow similar patterns. Our event study confirms this point by showing that the estimated difference in patent application before 2001 is tiny in magnitude and not statistically significant. In the graphical evidence we demonstrate domestic firms in treatment group become more innovative right after the reform. Lastly, we provide IV-DID estimation to quantify the economic magnitude of such spillovers.

Our analysis yields several interesting findings. First, we find a strong and persistent spillover effect of both horizontal FDI and FDI from technologically close industries. Second, the increase of patent applications mainly comes from utility model and invention patent, liberalized industries see more invention patent grants and these patents get more citations, suggesting that the quality of domestic firms' innovation also improved. Third, the competition effect outweighs agglomeration effects in local markets, horizontal FDI in the same city negatively affects domestic firms' innovation while horizontal FDI from other cities generate positive effects. Finally, we show that local human capital stock and domestic firms' absorptive capacity can hugely magnify positive spillovers. This informs policy makers about the important factors to focus on to reap the benefits from FDI.

Specifically, we construct a technological closeness measure between industry pairs to explore a novel channel of FDI spillovers from technologically close industries. To the best of our knowledge, our paper is the first to establish causal relationship between technologically close FDI and domestic firms' innovation.

Our work builds on and contributes to two main strands of literature. First, this paper ties into a growing body of literature on FDI and innovation. Javorcik et al. (2018) examined the relationship between the presence of foreign affiliates and product upgrading by Turkish manufacturing firms. The paper found Turkish firms in sectors and regions more likely to supply foreign affiliates tend to introduce more complex products. Guadalupe et al. (2012) used a panel dataset of Spanish manufacturing firms to show that multinational firms acquire the most productive domestic firms, which, on acquisition, conduct more product and process innovation and adopt foreign technologies, leading to higher productivity. Iacovone et al. (2009) examined the impact of FDI on the industry structure, productivity, and the rate of innovation of domestic firms in Mexico. The paper studied the entry of Wal-Mart into Mexico following the 1994 North American Free Trade Agreement. Top Mexican manufacturers that supply to Wal-Mart increased their R&D spending as well as outlays on technology acquisitions as the number of Wal-Mart shops in their state went up. Cheung and Ping (2004) used provincial data from 1995 to 2000 to study the impact of FDI on domestic patent applications in China. They found positive spillovers from FDI on the number of domestic patent applications for all three types of patents. Girma et al. (2009) investigated the relationship between inward FDI and product innovation by Chinese state-owned enterprises (SOEs). Hu and Jefferson (2009) found the growth of FDI in China stimulated a surge in patent application. Fu (2008) studied the impact of FDI on regional innovation in China. The paper showed that FDI had a significant positive impact on the overall regional innovation capacity, and the strength of this positive effect depends on the absorptive capacity and innovation-complementary assets in the host region. Zhang (2017) explored FDI spillovers on domestic firms' research activities in China. FDI was found to contribute positively to provincial patent application. However, previous studies usually use aggregate FDI or patent application data and suffer from endogeneity issues. These studies also did not consider patent citations to measure innovation quality.

Second, literature abounds in identifying spillover effects of FDI, with mixed findings from different studies. Liu (2002) investigated whether FDI affects domestic firms' productivity using data on 29 manufacturing industries over 1993-1998 in the Shenzhen Special Economic Zone of China. The paper found positive effect from FDI on both the level and growth rate of domestic firms' productivity. Liu (2008) and Lu et al. (2017) found negative effect of horizontal FDI on domestic firms' productivity level but positive effect on productivity growth. Many papers documented significant positive spillovers of vertical FDI through supply chain linkages (Javorcik 2004 and 2008, Havranek and Irsova 2011, Blalock and Gertler 2008, Liu, Wang and Wei 2009). The establishment of MNC affiliates can often benefit upstream firms that supply to them as well as downstream firms that procure from MNC affiliates. The effects are conditioned by a variety of factors, including domestic firms' absorptive capacity (Blyde et al. 2005; Reyes 2017), geographical distance from foreign-owned firms (Bwalya 2006, Halpern and Murakozy 2007), FDI's source country (Javorcik and Spatareanu 2011), motivation, level of foreign ownership, local sourcing

intensity, sectors in which domestic and foreign firms operate in (Havranek and Irsova 2011), technological gaps between domestic firms and foreign firms (Crescenzi et al., 2020; Zhang et al., 2010) and so on.

This paper is most closely related to two papers. Lu et al. (2017) documented negative effect of horizontal FDI on domestic firms' productivity, but positive effect on productivity growth. Our paper corroborates the positive effect on productivity growth due to the positive effect on domestic firms' innovation. As (Hall 2011) points out, the presence of more innovative firms eventually translates into productivity improvements. Our paper focuses on the important source of productivity growth – innovation, and justifies the conclusion in Lu et al. (2017). Jiang et al. (2019) studies the productivity and innovation performance of international joint ventures by exploiting the changes in FDI policy in 2002. Their paper documented benefits from foreign technology in terms of innovation and productivity that go far beyond the joint venture, not only to the Chinese joint venture parent firm but also to entrepreneurs at firms' upstream from and in the same industry as the joint venture. Jiang et al. (2019) used total patent applications and new product share to measure innovation. Our paper uses more detailed innovation metrics, estimates the dynamic effect of FDI exposure, and highlights a novel channel of spillovers – FDI from technologically close industries.

Innovation deserves more attention as productivity measures such as labor productivity and total factor productivity (TFP) are often contaminated by firm-specific input costs, product quality, and market power (Cusolito and Maloney 2018). Innovation measures – in this paper's case patent applications, grants, and citations – better capture the improvement in technology and the introduction of new products, processes, and services to the marketplace.

The rest of the paper is organized as follows: section II introduces the background of FDI liberalization in China, our data and estimation strategy. Section III shows empirical results. Section IV tests the validity of our identification strategy and conducts various robustness checks. Section V explores mechanisms through domestic firms' absorptive capacity, local human capital, and competition vs. agglomeration. Section VI concludes and offers some policy implications.

II. Estimation strategies

2.1 FDI regulations in China

China began its reform and opening up policy in 1978. However, FDI was only allowed in four designated Special Economic Zones (SEZs) in the early 1980s, and foreign investors were required to have local partners. Chinese government first allowed wholly foreign owned enterprises in 1986 and offered tax

incentives to export-oriented joint ventures and foreign enterprises with advanced technologies. Despite these early policy encouragements, FDI inflows remained limited until 1992.

In the spring of 1992, Deng Xiaoping delivered his famous speech on deepening reform and opening-up by attracting foreign investment. Chinese government subsequently made a series of major policy reforms to improve investment climate, with a focus on attracting FDI in infrastructure and manufacturing industries to boost exports. Encouraged by policy supports, more than 48,000 new foreign enterprises were established in 1992, and the actual use of foreign capital reached 11 billion US dollars, a 150 percent jump from 1991. FDI continued to surge in the following years, as more and more multinational corporations (MNCs) accelerated their investment in China. As of 2001, about 400 of the world's top 500 MNCs have entered China. Most of them were in capital and technology-intensive industries, including Motorola, Nokia, Ericsson, Siemens, Volkswagen, and General Motors. However, during 1992 to 2001, only some cities were open to FDI (mostly coastal cities, provincial capital cities and special economic zones). FDI was also restricted or forbidden in a range of industries, especially services sectors such as financial services, wholesale and retail and professional services.

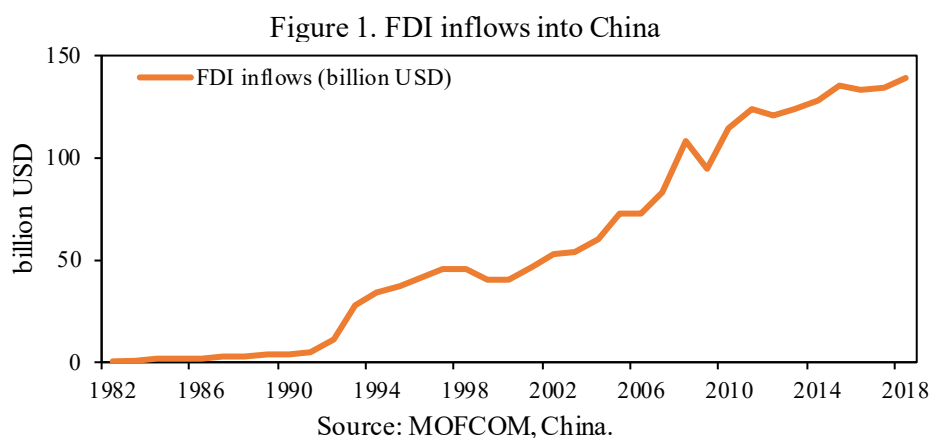
Marked by China's accession to WTO, China's integration into the world economy has come to a new level. To meet the WTO requirements, China substantially revised many laws and regulations on trade and FDI. Average import tariff was reduced from 17.2 in 2001 to 13.8 in 2002, the steepest single year drop in our sample period 1998-2007. China also liberalized FDI in a wide range of sectors and moved from local opening up to the whole country. Chinese government further removed export performance and local content requirement to comply with the "Agreement on Trade-Related Investment Measures (TRIMS)."⁴ Financial services, telecom and communication, construction and a range of services sectors were gradually opened. As a result of these liberalization measures, FDI inflows continued to grow rapidly, average annual FDI inflows during 2001-2009 reached 72 billion US dollars, twice the level during 1992-2000.

The Chinese government also sought to attract high quality FDI in alignment with the transformation of domestic economy. China has used tax incentives and other preferential policies to attract FDI in strategic sectors since 1986, and began to publish the "Catalogue of Industries for Guiding Foreign Investment" since 1995. The catalogue was updated in 1997. On March 11, 2002, Chinese government published the 2002 catalogue to replace the 1997 version, the new catalogue went into effect on April 1, 2002. China

⁴ The Agreement on Trade-Related Investment Measures (TRIMS) recognizes that certain investment measures can restrict and distort trade. It states that WTO members may not apply any measure that discriminates against foreign products or that leads to quantitative restrictions, both of which violate basic WTO principles. A list of prohibited TRIMS, such as local content requirements, is part of the Agreement. The TRIMS Committee monitors the operation and implementation of the Agreement and allows members the opportunity to consult on any relevant matters.

liberalized 112 of its 425 4-digit manufacturing industries for FDI in 2002. These industries have experienced a surge of FDI inflows since 2002. Advanced technologies, know-how, equipment, and products brought by foreign firms greatly accelerated domestic firms' development.

This paper uses an IV-DID approach to mitigate endogeneity issues. Specifically, we use the sectoral FDI liberalization in 2002 as an IV for the presence of foreign-invested enterprises. The paper thus compares the performance of domestic firms in the treatment group (industries that became more open for FDI) with that in the control group (industries that didn't have any changes in FDI regulations, have mixed changes or became more restrictive for FDI) in two periods: before and after China's FDI liberalization in 2002. China continues to revise the catalogue in 2004, 2007, 2011, 2015, 2017 and 2019, but this paper focuses on the 2002 liberalization as it is by far the most significant wave of liberalization in the study period.



The catalogue classifies industries into four types: (1) encouraged; (2) permitted; (3) restricted; and (4) prohibited. This paper assigns values from 1 to 4 to the four types and compares how the score changed from the 1997 catalogue to 2002 catalogue. Positive changes mean FDI in the industry became more encouraged after 2002, while negative changes indicate the industry became more restricted in terms of FDI after 2002. Among the 425 4-digit industries, 112 became more encouraged, 300 remained unchanged, 5 industries had mixed changes, and 7 became more restricted. The government had multiple objectives for changes in FDI regulations. While a primary goal was to promote export and industry upgrading, the central government also encouraged FDI in less-developed areas, tried to protect infant domestic industries from foreign competition, improved environmental standards and weighed potential labor market effects. As a result, many industries that became more open to FDI were not knowledge-intensive industries, such as manufacturing of food and beverages, dairy products, manufacturing of animal feed etc.

2.2 Estimation specification

This paper focuses on two measures of FDI presence: horizontal FDI, which is FDI in the same 4-digit industry; and FDI in technologically close industries. The section below explains how the two FDI variables are defined and measured, as well as estimation specification.

Horizontal FDI

One of the key variables of interest in this paper is FDI presence in each four-digit industry. We follow Javorcik (2004) and define horizontal FDI as the output-weighted foreign equity share in each industry:

$$FDI_sector_{it} = \frac{\sum_{f \in \Omega_{it}} FDI_firm_{fit} \times Output_{fit}}{\sum_{f \in \Omega_{it}} Output_{fit}} \quad (1)$$

Where FDI_firm_{fit} is the foreign equity share of firm f of industry i in year t . Ω_{it} is the set of firms in industry i in year t . $Output_{fit}$ is the total sales of firm f of industry i in year t .

Technologically close FDI

Firms could benefit more from other firms that have similar technology domains. By the same token, domestic firms in industries that are technologically close to liberalized industries stand to gain more. Following Jaffe (1986), Bloom et al. (2013) and Fons-Rosen et al. (2017), this paper calculates the closeness between industries in technology space as the uncentered correlation between 4-digit industry pairs. The measure is constructed as follows: (1) we calculate the average share of patent applications (including the utility model patent and invention patent) each 4-digit industry filed in each of the 121 3-digit technology spaces over the period 1998-2002. For each industry i , we have a vector of i 's technological distribution $t_i = (t_{i1}, t_{i2}, \dots, t_{i121})$, where t_{ix} is the share of patent applications of industry i in technology class x . (2) For each industry pair i, j in the 425 4-digit manufacturing industries, we calculate their bilateral technology closeness as the uncentered correlation of patent application share vectors t_i and t_j following Jaffe (1986), Bloom et al. (2013):

$$tech_{ij} = \frac{(t_i t_j')}{(t_i t_i')^{1/2} (t_j t_j')^{1/2}} \quad (2)$$

We use the time-invariant technological closeness that largely pre-date the treatment to avoid potential endogeneity. We included year 2002 because some industries had zero patent applications before 2002. The value of $tech_{ij}$ falls between 0 and 1. When $tech_{ij} = 0$, it means industry i and industry j have completely uncorrelated technology space distribution, they are technologically distant; when $tech_{ij} = 1$, it means industry i and industry j have identical technology space distribution. We consider two industries i and j are technologically close if $tech_{ij} \geq 0.5$. For each 4-digit industry, we calculate the average sectoral FDI presence in its technologically close industries:

$$FDI_{techclose}_{it} = \frac{\sum_{j \in \Omega, j \neq i} FDI_{sector}_{jt}}{n} \quad (3)$$

Ω is the set of industries that are technologically close to industry i ; n is the number of industries in Ω . While China liberalized 112 manufacturing industries in 2002, we expect industries that are technologically close to these treatment industries to benefit more from knowledge spillovers.

Technologically close FDI is a new channel that lies at the core of innovation spillovers. It is distinct from input-output linkages through vertical FDI, it directly captures knowledge spillovers from similar technology spaces. This paper estimates the impact of horizontal and technologically close FDI in the main regressions, and controls vertical FDI as a robustness check to show that knowledge spillovers from technologically close FDI exist even when vertical FDI spillovers are controlled for.

This paper uses the following baseline specification:

$$y_{fit} = \alpha_f + \gamma_t + \delta_1 FDI_{sector}_{it} + \delta_2 FDI_{techclose}_{it} + X'_{fit} \beta + \varepsilon_{fit} \quad (4)$$

Where f , i , and t denote the firm, four-digit industry and year respectively. y_{fit} measures the innovation output of domestic firms, which includes total patent application, design patent application, utility model patent application, invention patent application, invention patent grant, cumulative citation of invention patent after 5 years of publication. α_f is firm fixed effect; γ_t is year fixed effect; FDI_{sector}_{it} is the horizontal FDI measure defined as output-weighted foreign equity share in each four-digit industry; $FDI_{techclose}_{it}$ is the simple average of FDI presence in all industries that are technologically close to industry i in year t . X'_{fit} are time varying firm level controls, including firm sales, firm capital-labor ratio, exporter status, and SOE dummy.

Industries that have more technological breakthroughs could be more likely to attract FDI. This will bias the OLS estimate upward. On the contrary, FDI may prefer to enter industries where Chinese firms are less competitive, this can lead to downward biases in the OLS estimation. To alleviate the endogeneity of horizontal FDI, the paper instruments horizontal FDI with changes in sectoral FDI policies in 2002. We also construct an IV for technologically close FDI: $IV_{techclose}_{it} = \sum_{j \in \Omega, j \neq i} Techclose_{ij} \times treatment \times post02_{it} / N$. $Techclose_{ij}$ is a dummy variable that equals one if industry i and industry j are technologically close. N denotes the total number of technologically close industries for industry i .

The first stage regressions are shown below:

$$FDI_sector_{it} = \alpha_f + \gamma_t + \theta_1 treatment \times post02_{it} + \theta_2 IV_techclose_{it} + X'_{fit}\beta + \varepsilon_{it} \quad (5)$$

$$FDI_techclose_{it} = \alpha_f + \gamma_t + \theta_3 treatment \times post02_{it} + \theta_4 IV_techclose_{it} + X'_{fit}\beta + \varepsilon_{it} \quad (6)$$

α_f is firm fixed effect, γ_t is year fixed effect. $treatment \times post02_{it}$ is the interaction between the treatment dummy and the post 2002 dummy, $IV_techclose_{it}$ is the IV for technologically close FDI, X'_{fit} are time varying firm level controls. Firm level controls are the same as in specification (1). Treatment is defined as whether FDI in an industry became more encouraged after 2002. It takes the value of 1 if yes, and 0 if otherwise.

2.3 Data

Panel data on industrial firms

The main data used in this paper is the Annual Survey of Industrial Firms (ASIF). The ASIF database is a nationwide mandatory survey administered annually by the National Bureau of Statistics (NBS) in China to firms in mining industries, manufacturing industries and utility industries. NBS uses the ASIF database to compute China's GDP, and the aggregate information is published in the official China Statistics Yearbooks. It contains many firms distributed across more than 600 four-digit industries and throughout China's 31 provinces, autonomous regions, and municipalities. Firms in the sample account for 95 percent of total Chinese industrial output and 98 percent of total Chinese industrial exports (Eberhardt, Helmers, and Yu, 2011). We use the ASIF database for the 1998-2007 period. The sample covers all state-owned enterprises (SOEs) and private companies with annual sales above 5 million RMB (about 600,000-660,000 US dollars based on exchange rate during that period). The number of firms covered in the sample increased steadily from around 165,000 in 1998 to 336,000 in 2007.

The database contains more than 100 variables covering firms' basic information, financial and operational information. Basic information includes the unique identifier, firm name, legal representative, detailed address, year of incorporation, main product, industry affiliation, and ownership structure. Financial and operational information cover most items in firms' balance sheet, profit and loss statement, as well as cash flow statement.

This paper constructs a ten-year panel based on the unique firm identifier, firm name, firm legal representative, telephone number, address and industry. For sample period 1998 to 2002, the database used China's 1994 industry classification (GB/T 4754-1994). From 2003 and onwards, the sample adopted the 2002 industry classification (GB/T 4754-2002). We use a concordance table developed by Brandt et al. (2012) to convert industry code for 1998-2002 period to 2002 industry classification. The final sample has 425 four-digit manufacturing industries.

Patent application data

China grants three types of patents: design patent, utility model patent, and invention patent. The invention patent protects “any new technical solution relating to a product, a process or improvement”. The State Intellectual Property Office of China (SIPO) conducts a thorough investigation as to the novelty, inventiveness, and usefulness of the innovation before issuing the patent. It could take years to grant an invention patent. A utility model patent protects “any new technical solution relating to the shape, structure, or combination thereof, of a product which is fit for practical use”. It is not subject to a substantive examination as in the case of an invention patent. The utility model patent is often seen as an improvement in functionality rather than an entirely new solution. A design patent protects “any new design of the shape, pattern, color, or combination thereof, of a product, which creates an aesthetic feeling and is fit for industrial application”.

This paper used the linked database for SIPO patents and ASIF firms from 1998 to 2009 to obtain firm level patent applications for all three types of patents. This database was constructed under the “Chinese Patent Data Project” and is publicly available. The paper matches firm names in the ASIF database (1998-2009) with patent assignees from SIPO database. This exact matching was supplemented with strict substring matching to limit loss of potentially true matches. The paper also adopted manual checks to ensure match quality. Eventually, the paper obtained more than 1.1 million matches for firms in the ASIF database. Among these matches, nearly 400,000 were design patents, more than 424,000 were utility model patents, and about 332,000 were invention patents. Please see He et al. (2016) (Construction of a database linking SIPO patents to firms in China’s annual survey of industrial enterprises 1998-2009) for details on this database.

Patent citation data

The patent citation data tracks all forward citations of each utility model and invention patent filed in China. As the universe of patents are limited to patents filed in China, citation by scholarly articles or patents filed in foreign countries are not counted. This paper calculated the cumulative citation of each patent after 5 years of publication. The number of citations a patent receives often reflects the technological importance of the patent for the development of subsequent technologies, and thus measures the economic value of inventions (Hall et al. 2005).

FDI regulations data

We manually constructed the FDI regulations data by comparing the 1997 and 2002 Catalogue for the Guidance of Foreign Investment Industries. The 2002 revision was substantial and in strict accordance with the commitments made by China’s central government in its negotiations with WTO members before 2001. The changes are plausibly exogenous to China’s domestic situations, as the process took 15 years and involved numerous negotiations with many WTO member countries.

The Catalogue classifies sectors and products into four categories: (1) FDI was encouraged; (2) FDI was permitted, these industries and products are not listed in the Catalogue; (3) FDI was restricted; and (4) FDI was prohibited. We first map each industry and product to the 4-digit industry in 2002 industry classification, then assign value 1 to all industries that are encouraged, 2 to permitted industries, 3 to restricted industries, and 4 to prohibited industries. We do these two steps for the 1997 and 2002 Catalogue respectively, and then calculate the change in FDI policy for each industry from 1997 to 2002. Positive changes indicate the industry became more restricted after 2002, while negative changes mean the industry became more open to FDI. About 300 industries experienced no changes in FDI regulations. Five industries had mixed changes, where one or more products in the industry became more open while one or more products became more restricted. We consider the industries that became more open to FDI the treatment group, all other industries are the control group.

Prefecture level human capital stock data

To test how local human capital stock affects FDI spillovers, we use China’s population census data in 2000 and calculate the share of adult population aged between 18-55 with a bachelor’s degree or above at the prefecture level. We used the 2000 data to mitigate endogeneity, as FDI liberalization in 2002 could induce labor migration, which affects local human capital stock afterwards.

Summary statistics

From pre-treatment period to post-treatment period, FDI presence intensified in most sectors (Table 1). The increase was most notable in electronics and telecommunication equipment, the industry was already dominated by foreign firms before 2002 and foreign equity share further grew by 17.4 percentage points. This was followed by optical equipment (8.4 percentage points), special purpose machinery (7.5 percentage points) and chemicals (7 percentage points). Foreign equity share shrank slightly in tobacco, food manufacturing, chemical fiber, wood and leather products, and dropped by 32 percentage points in recycling.

Table 1. Changes in output-weighted foreign equity share at 2-digit industry level

2-digit Industry	1998-2001	2002-2007	Diff
Food processing	17.3%	19.7%	2.4%
Food manufacturing	31.0%	30.6%	-0.4%

Beverage manufacturing	21.9%	26.9%	5.1%
Tobacco	0.2%	0.1%	-0.1%
Textiles	15.6%	17.5%	1.9%
Garment and footwear	33.5%	36.1%	2.6%
Leather, furs and related products	44.7%	41.3%	-3.4%
Wood and wood products	19.7%	16.7%	-3.0%
Furniture	34.2%	40.6%	6.4%
Paper and paper products	21.7%	25.2%	3.5%
Printing	20.7%	23.2%	2.4%
Cultural and sports goods	50.0%	51.4%	1.4%
Petroleum and coke	6.2%	8.8%	2.6%
Chemicals and chemical products	13.2%	20.1%	7.0%
Pharmaceuticals	14.8%	17.7%	2.9%
Chemical fiber	16.7%	14.6%	-2.1%
Rubber products	23.1%	29.1%	5.9%
Plastic products	31.4%	33.6%	2.1%
Non-metallic mineral products	11.0%	13.2%	2.2%
Ferrous metal processing	4.4%	9.1%	4.8%
Non-ferrous metal processing	7.1%	9.9%	2.8%
Metal products	24.5%	26.5%	1.9%
General purpose machinery	16.0%	19.3%	3.3%
Special purpose machinery	10.7%	18.2%	7.5%
Transport equipment	18.2%	23.6%	5.5%
Electrical machinery and equipment	24.9%	29.5%	4.6%
Electronics and telecommunication equipment	53.6%	71.0%	17.4%
Optical instruments	51.5%	59.8%	8.4%
Art and other manufacturing	32.0%	33.1%	1.1%
Recycling	58.1%	26.3%	-31.8%

Note: This table shows the output-weighted foreign equity share at 2-digit manufacturing industry level during the pre-treatment (1998-2001) and post-treatment (2002-2007) periods, and their differences.

Table 2 shows the summary statistics on domestic firm characteristics and their patenting behavior in pre-treatment and post-treatment periods. Compared with pre-treatment period, domestic firms in the post-treatment sample are much younger, have higher sales, much higher capital-labor ratio, less export-oriented, and much less likely to be SOEs. Domestic firms' patent application also skyrocketed during the study period. Average annual patent applications nearly quadrupled from 12,812 during 1998-2001 to 47,755 during 2002-2007. Invention patent applications increased most rapidly. In pre-treatment period, the

probability of a firm applying for invention patent was merely 0.51 percent. The probability more than doubled during 2002-2007, to 1.38 percent. Among firms that applied for invention patents, each firm on average filed 3.55 invention patent applications per year in 1998-2001, and 6.18 invention patent applications per year during 2002-2007. Utility model patent applications also ballooned.

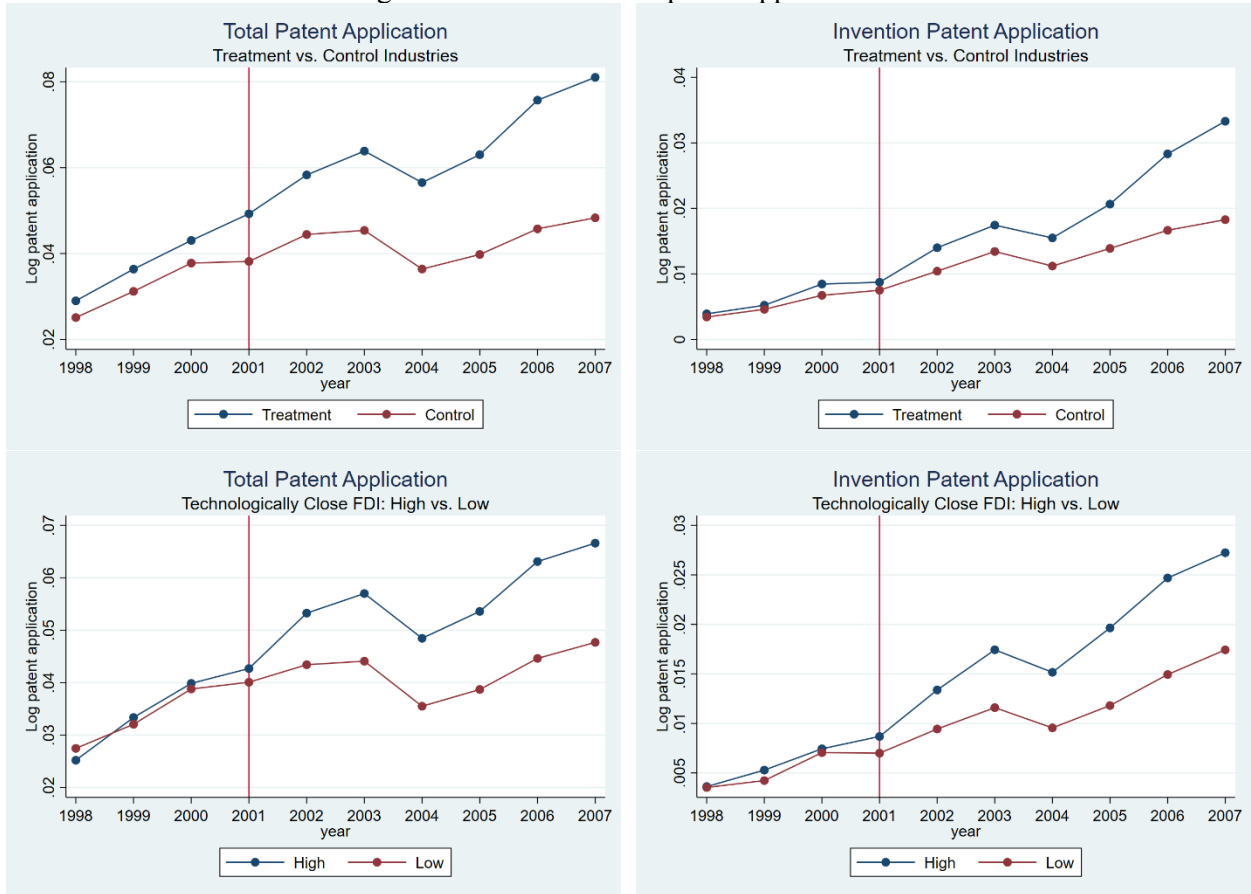
Table 2. Summary statistics of key variables

	1998-2001	2002-2007	Diff
Firm age	14.14	8.91	-5.23***
Sales	9.59	9.99	0.4***
Capital-labor ratio	144.71	212.89	68.18***
Exporter status	19.37%	16.42%	-2.95%***
New product share	2.91%	2.88%	-0.03%
SOE	24.44%	6.39%	-18.05%***
Prob. Of applying for design patent	1.14%	1.18%	0.04%
Prob. Of applying for utility model patent	1.42%	2.03%	0.62%***
Prob. Of applying for invention patent	0.51%	1.38%	0.87%***
Avg. design patent application	6.04	8.32	2.28***
Avg. utility patent application	3.66	4.8	1.14***
Avg. invention patent application	3.55	6.18	2.63**
Avg. invention patent grant	3.7	5.8	2.1**
Avg. invention patent citation	0	0.0175	0.0175***

Note: This table compares firm characteristics and their patent application, invention patent grant and citation between pre-treatment and post-treatment periods.

We provide graphical evidence of the effect of FDI liberalization and test the parallel trend assumption. Patent application patterns in treatment and control groups are largely in parallel during the pre-treatment period, but total patent applications and invention patent applications in treatment industries began to outpace those in control industries since FDI liberalization (Figure 2, upper panel). Similarly, industries that are more technologically close to liberalized industries experience faster growth in their patent applications after 2002 (Figure 2, bottom panel).

Figure 2. Domestic firms' patent application trends



Note: Figure 2 plots the trend in domestic firms' total and invention patent application by group over time. The upper panel shows how domestic firms in industries that opened up for FDI in 2002 compare with domestic firms in other industries in patent application. The bottom panel compares patent application patterns in domestic firms that have a above median technological closeness (High) to liberalized industries with those that have below median technological closeness (Low).

III. Empirical results

3.1 Event study

We first conduct an event study to show the effect of FDI liberalization on domestic firms' patent applications over time. As the liberalization happened in 2002, we use 2001 as the baseline, and estimate the panel fixed effects (FE) model below:

For horizontal FDI:

$$\ln patent_{fit} = \alpha_f + \gamma_t + \sum_{t=-3}^6 T_{2001+t} \times treatment_i + X'_{fit} \beta + \varepsilon_{fit} \quad (7)$$

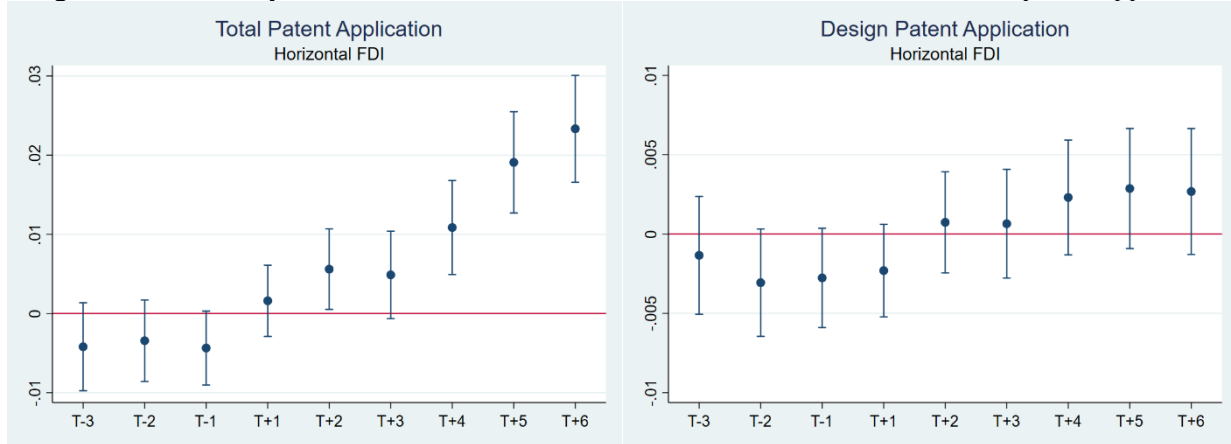
To deal with the large number of zero in patent applications, we use $\ln(1 + patent_{fit})$ as $\ln patent_{fit}$. α_f is firm fixed effect, γ_t is year fixed effect. We control year dummies to reflect common shocks to all firms in each year, and time varying firm characteristics X'_{fit} , which includes firm sales, capital-labor ratio, exporter status, and SOE dummy. $\sum_{t=-3}^6 T_{2001+t} \times treatment_i$ estimates the dynamic treatment effect.

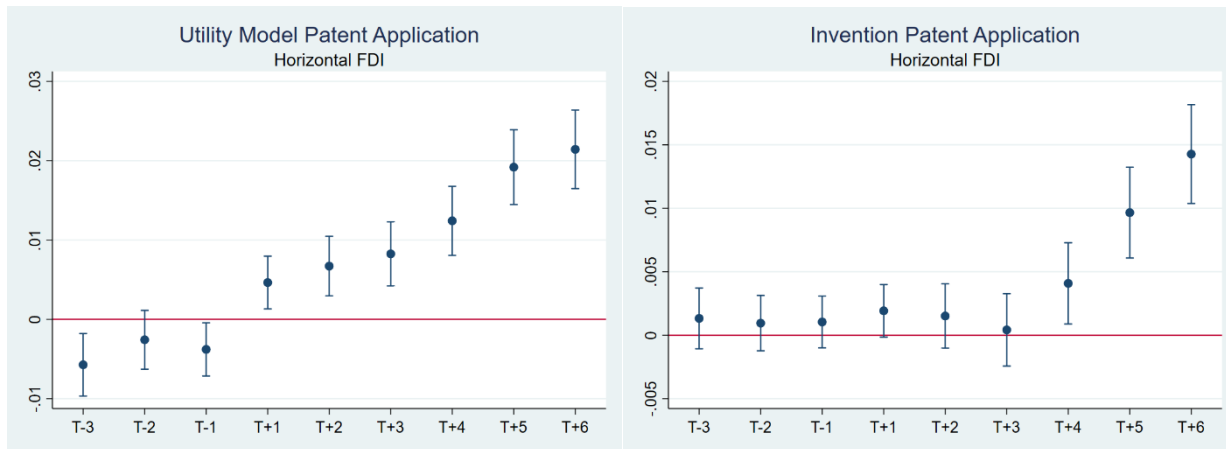
For technologically close FDI, we divide industries into two groups based on $IV_techclose_{i2002}$. Industries with above median $IV_techclose_{i2002}$ in 2002 have higher FDI presence in their technologically close industries post 2002, while industries with below median $IV_techclose_{i2002}$ have lower exposure to FDI in technologically close industries. We compare the two groups of industries' patent application pattern as follows:

$$\ln patent_{fit} = \alpha_f + \gamma_t + \sum_{t=-3}^6 T_{2001+t} \times above\ median\ IV_techclose_i + X'_{fit}\beta + \varepsilon_{fit} \quad (8)$$

The graphical results are presented in Figure 3 and Figure 4. Total patent applications in treatment industries were similar to that in control industries before 2001 but shows a clear upward trend since T+1, indicating positive spillovers from FDI exposure in the same industry. The upper right panel shows the effect on design patent applications. Horizontal FDI seems to have no major effect on domestic firms' design patent applications, the coefficients remained insignificant throughout the study period. The effects are much stronger and more significant for utility model patent and invention patent applications. Treatment industries show a similar pre-trend as control industries, suggesting that the two groups are largely comparable. Utility model patent application in treatment group jumped immediately after FDI liberalization and the gap continued to widen, while it took more time for domestic firms in treatment industries to file more invention patent applications. This makes sense as it is easier for domestic firms to start minor innovations (utility model patent) after initial FDI exposure.

Figure 3. Event study estimation: Horizontal FDI liberalization and domestic firms' patent application

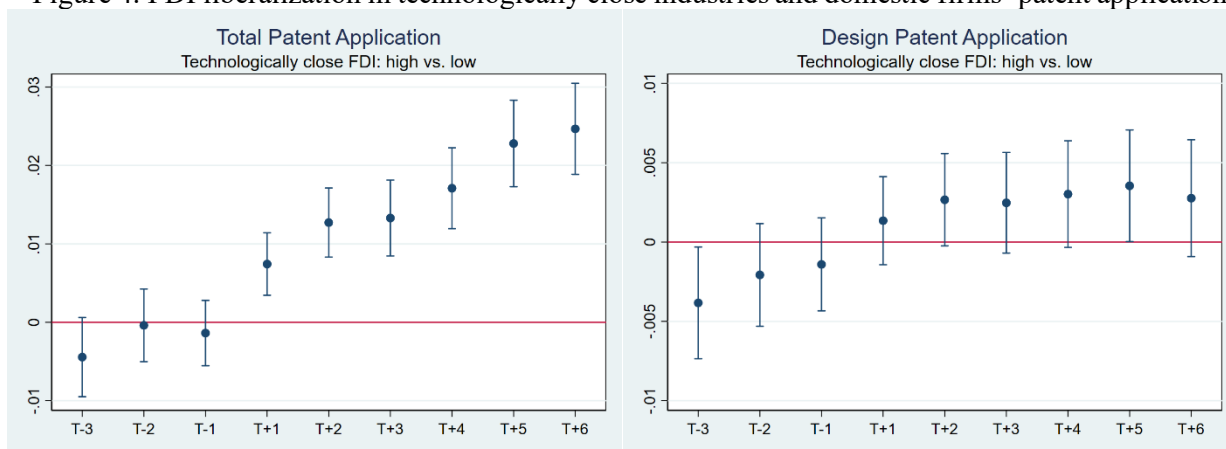


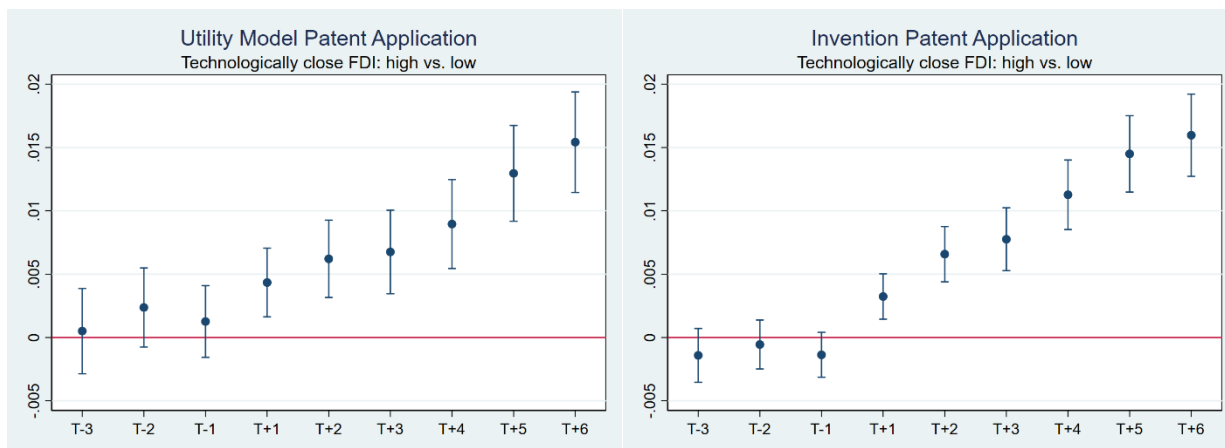


Note: The figure displays the estimated coefficients on patent application difference between industries that were opened up for FDI in 2002 and those that did not (control group) and the 95% confidence interval.

Similarly, our event study manifests that domestic firms that are technologically close to liberalized industries have parallel trends in patent applications with domestic firms that are technologically distant (Figure 4). Exposure to FDI in technologically close industries still has no effect on domestic firms' design patent applications but demonstrates strong and persistent positive effects on utility model patent and invention patent applications. Unlike horizontal FDI, FDI presence in technologically close industries generate positive effects on domestic firms' utility model and invention patent applications immediately after exposure. This is probably because foreign firms in the same industry compete directly with domestic firms, therefore it could take longer for domestic firms to adapt and benefit from horizontal FDI.

Figure 4. FDI liberalization in technologically close industries and domestic firms' patent application





Note: The figure displays the estimated coefficients on patent application difference between industries that have a above median $IV_techclose_{i2002}$ and those that are below median (control group) and the 95% confidence interval. Above median $IV_techclose_{i2002}$ indicates the industry is more technologically close to liberalized industries.

3.2 Main results

As invention patent represents the most high-quality innovation, the empirical results below will primarily focus on the effect of FDI presence on domestic firms' invention patent application. Table 3 reports the results from reduced form regression. Column 1 shows the simultaneous effect of exposure to FDI, and column 2-4 shows the lagged effect from FDI exposure after 1 to 3 years. As our patent application data is only up to 2009, 3-year lagged patent application is missing for firms in 2007 ASIF database. That is why the number of observations for column 4 is smaller. Invention patent application from domestic firms in treatment industries will be 0.3 percent higher than that from control groups in the same year of FDI exposure. The effect grows steadily to 0.9 percent three years after exposure. The effect is much larger for domestic firms in industries that are technologically close to liberalized industries. The contemporaneous effect on domestic firms in technologically close industries is 3.55 percent, ten times the effect of horizontal FDI. The effect from technologically close FDI remains stable even after three years of exposure.

Table 3. Reduced Form results: invention patent application

	(1)	(2)	(3)	(4)
	T	T+1	T+2	T+3
Dependent variable: Invention patent application				
Treatment × Post02	0.00320** (0.00144)	0.00394** (0.00160)	0.00756*** (0.00177)	0.00913*** (0.00182)
Treatment × Post02 × Techclose	0.0355*** (0.00443)	0.0398*** (0.00508)	0.0433*** (0.00545)	0.0383*** (0.00560)
Observations	1,383,715	1,383,715	1,383,715	1,151,980

Firm FE	Y	Y	Y	Y
Year FE	Y	Y	Y	Y
Time varying firm controls	Y	Y	Y	Y

Note: Table 3 reports dynamic effects of exposure to horizontal and technologically close FDI on domestic firms' invention patent application based on reduced form regression. The dependent variable is domestic firms' invention patent application. Column (1) reports the effect in the year of exposure, while column (2)-(4) reports lagged effect after 1-3 years of exposure. Time varying firm controls include firm sales, capital-labor ratio, export status and SOE dummy. Robust standard errors in parentheses. *** p<0.01, ** p<0.05, * p<0.1.

Fixed effects results

Results from panel fixed effects regressions show that both horizontal and technologically close FDI are positively associated with domestic firms' invention patent application (Table 4). A one percentage point increase in an industry's foreign equity share is associated with 0.06 percent increase in domestic firms' total patent application in the same year. The positive effect increases over time, which is largely expected as it takes time for technological spillovers to diffuse. After 2 years the effect is nearly twice as large as the simultaneous effect. A one percentage point increase in foreign equity share in technologically close industries raises domestic firms' invention patent application in the same year by 0.15 percent, three times the effect of horizontal FDI. The positive effect from technologically close FDI also increases over time. The coefficients are all significant at 1% confidence level, and the magnitudes are economically significant.

Table 4. Fixed Effects model: invention patent application

	(1)	(2)	(3)	(4)
	T	T+1	T+2	T+3
Dependent variable: Invention patent application				
FDI_sector	0.0577*** (0.00687)	0.0781*** (0.00759)	0.0978*** (0.00834)	0.0909*** (0.00905)
FDI_techclose	0.148*** (0.0123)	0.157*** (0.0129)	0.165*** (0.0138)	0.162*** (0.0153)
Observations	1,383,715	1,383,715	1,383,715	1,151,980
Firm FE	Y	Y	Y	Y
Year FE	Y	Y	Y	Y
Time varying firm controls	Y	Y	Y	Y

Note: Table 4 reports dynamic effects of exposure to horizontal and technologically close FDI on domestic firms' invention patent application based on firm fixed effects model. The dependent variable is domestic firms' invention patent application. Column (1) reports the effect in the year of exposure, while column (2)-(4) reports lagged effect

after 1-3 years of exposure. Time varying firm controls include firm sales, capital-labor ratio, export status and SOE dummy. Robust standard errors in parentheses. *** p<0.01, ** p<0.05, * p<0.1.

IV model

Table 5 reports our baseline results using the IV-DID approach. First stage regression results are reported in the Appendix. A one percentage point increase in foreign equity share in the same industry results in a 0.27 percent increase in domestic firms' invention patent application in the same year. The effect increases to 0.53 percent after three years. A one percentage point increase in foreign equity share in technologically close industries can lead to a 0.52 percent increase in domestic firms' invention patent application in the same year of exposure. The coefficients on technologically close FDI also persists even three years after exposure. The above results indicate that knowledge spillover from FDI is much larger in technologically close industries than in the same industry.

Table 5. IV model: invention patent application

	(1)	(2)	(3)	(4)
	T	T+1	T+2	T+3
Dependent variable: Invention patent application				
FDI_sector	0.267*** (0.0545)	0.313*** (0.0614)	0.462*** (0.0681)	0.530*** (0.0753)
FDI_techclose	0.517*** (0.0812)	0.574*** (0.0918)	0.561*** (0.0986)	0.458*** (0.109)
Observations	1,383,715	1,383,715	1,383,715	1,151,980
Firm FE	Y	Y	Y	Y
Year FE	Y	Y	Y	Y
Time varying firm controls	Y	Y	Y	Y

Note: Table 5 reports dynamic effects of exposure to horizontal and technologically close FDI on domestic firms' invention patent application based on IV model. The dependent variable is domestic firms' invention patent application. Column (1) reports the effect in the year of exposure, while column (2)-(4) reports lagged effect after 1-3 years of exposure. Time varying firm controls include firm sales, capital-labor ratio, export status and SOE dummy. Robust standard errors in parentheses. *** p<0.01, ** p<0.05, * p<0.1.

3.3 Different types of patent application

The above results show that FDI from the same industry and technologically close industries both have positive effects on domestic firms' invention patent application. Next, we explore if the effect varies by patent type.

Table 6 presents IV results on domestic firms' design patent application and utility model patent application. Horizontal FDI seems to have positive effect on domestic firms' design patent application initially, but the effect disappears two years after FDI exposure. FDI in technologically close industries does not have a significant effect on design patent application in the first three years, but can be negative in the fourth year. Panel B shows the effect on utility model patent application. Both horizontal and technologically close FDI have strong, positive, and increasing effect on domestic firms' utility model patent application, but the effect from horizontal FDI is larger. This is contrary to the case for invention patent application, where the effect of horizontal FDI is smaller in the beginning of exposure and only exceeds the effect from technologically close FDI three years after exposure. This is intuitive as it is easier to conduct minor innovation through imitating the technology of foreign competitors.

Table 6. IV model: patent application by type

	(1)	(2)	(3)	(4)
	T	T+1	T+2	T+3
Panel A. Dependent variable: Design patent application				
FDI_sector	0.130** (0.0576)	0.109* (0.0595)	0.0759 (0.0617)	-0.00205 (0.0677)
FDI_techclose	0.0744 (0.0873)	0.0152 (0.0849)	-0.0756 (0.0873)	-0.209** (0.0973)
Panel B. Dependent variable: Utility model patent application				
FDI_sector	0.645*** (0.0725)	0.678*** (0.0769)	0.814*** (0.0829)	0.836*** (0.0921)
FDI_techclose	0.318*** (0.106)	0.418*** (0.116)	0.455*** (0.124)	0.430*** (0.135)
Observations	1,383,715	1,383,715	1,383,715	1,151,980
Firm FE	Y	Y	Y	Y
Year FE	Y	Y	Y	Y
Time varying firm controls	Y	Y	Y	Y

Note: Table 6 reports dynamic effects of exposure to horizontal and technologically close FDI on domestic firms' design and utility model patent application based on IV model. Column (1) reports the effect in the year of exposure, while column (2)-(4) reports lagged effect after 1-3 years of exposure. Time varying firm controls include firm sales, capital-labor ratio, export status and SOE dummy. Robust standard errors in parentheses. *** p<0.01, ** p<0.05, * p<0.1.

3.4 Patent quality: Invention patent grant and invention patent citation

Previous results have shown that exposure to FDI – both in the same industry and in technologically close industries – could stimulate domestic firms’ invention and utility model patent application. While patent application is often used to measure innovation output, the simple count of patent applications does not reflect the true value of these innovations. Patent grants are more suitable than patent applications in measuring the usefulness or creativity of a firm’s innovation because the approval requirements are usually much higher than the application requirements for a patent (Santacreu and Zhu 2018). Patent citation is also widely used to measure the quality of patents. We obtained patent citation data from TekGlory and calculated the cumulative citation for every published invention patent citation five years after the publication date. This section uses invention patent grant and invention patent citation to test if exposure to FDI promotes high-quality innovation.

FDI in technologically close industries has a large and significant effect on invention patent grant and citation (Table 7). A one percentage point increase in FDI from technologically close industries leads to a 0.44 percent increase in domestic firms’ invention patent grant in the same year of exposure. The effect remains stable around 0.4 percent till three years later. Technologically close FDI has a larger and increasing effect on invention patent citation, the simultaneous effect is 0.02 and insignificant, but it becomes highly significant since T+1, and grows to 0.26 three years after exposure. This is also largely expected as it takes a longer time for high quality patents to be recognized and widely cited. The effect of horizontal FDI remains significant and increases over time for invention patent grant, it also becomes large and significant two years after exposure for invention patent citation. These results suggest that FDI not only boosts the quantity of domestic firms’ innovation, but also the quality of such innovations.

Table 7. IV model: patent quality

	(1)	(2)	(3)	(4)
	T	T+1	T+2	T+3
Panel A. Dependent variable: Invention patent grant				
FDI_sector	0.218*** (0.0434)	0.234*** (0.0485)	0.329*** (0.0529)	0.351*** (0.0573)
FDI_techclose	0.441*** (0.0670)	0.486*** (0.0734)	0.446*** (0.0776)	0.380*** (0.0852)
Panel B. Dependent variable: Invention patent citation				
FDI_sector	0.000954 (0.00279)	0.0130 (0.0103)	0.139*** (0.0281)	0.185*** (0.0366)
FDI_techclose	0.0154 (0.0110)	0.0552** (0.0240)	0.212*** (0.0485)	0.255*** (0.0611)

Observations	1,383,715	1,383,715	1,383,715	1,151,980
Firm FE	Y	Y	Y	Y
Year FE	Y	Y	Y	Y
Time varying firm controls	Y	Y	Y	Y

Note: Table 7 reports dynamic effects of exposure to horizontal and technologically close FDI on domestic firms' innovation quality based on IV model. The dependent variable in panel A is invention patent grant and the dependent variable in panel B is cumulative citation for invention patents five years after publication. Column (1) reports the effect in the year of exposure, while column (2)-(4) reports lagged effect after 1-3 years of exposure. Time varying firm controls include firm sales, capital-labor ratio, export status and SOE dummy. Robust standard errors in parentheses. *** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$.

IV. Validity of IV and robustness checks

The validity of our identification strategy hinges on two conditions: (1) FDI liberalization led to an increase in foreign equity share in the industry; (2) variations across industries in the changes in FDI regulations do not affect domestic firms' patent application through channels other than FDI entry. In previous regressions we already demonstrated the first condition. This section will test if treatment and the timing of treatment are correlated with unobservable factors that affect domestic firms' innovation. We also conduct other robustness checks to rule out the effect of vertical FDI, tariff changes, and the threshold for technologically close FDI.

4.1 Expectation effect before treatment

While we have included year fixed effects in all the regressions, the estimation could still be biased if the Chinese government chose to liberalize FDI regulations in 2002 in anticipation of diverging innovation patterns in the treatment and control industries.

However, as Lu et al. (2017) has shown, the FDI deregulation in 2002 was part of the requirements of China's WTO accession, the lengthy and unpredictable negotiations dragged on for more than 15 years with the 150 WTO member countries. There should not be any anticipation of China's WTO accession in previous years. We conduct a placebo test as Lu et al. (2017) did using the pre-treatment sample (1998-2001), and assign year 1999, 2000 and 2001 as the time of treatment respectively. If the two groups of industries show significantly different innovation behavior during pre-treatment period, this could suggest anticipation effect.

Table 8 reports results from the placebo test. All the coefficients are insignificant, indicating no expectation effect prior to 2002.

Table 8. Expectation effect

Fake treatment year	(1)	(2)	(3)
	1999	2000	2001
Dependent variable: Invention patent application			
FDI_sector	0.00344 (0.0522)	0.0380 (0.0538)	-0.0244 (0.0452)
FDI_techclose	0.0859 (0.0865)	0.0343 (0.181)	-0.0224 (0.137)
Observations	362,907	362,907	362,907
Firm FE	Y	Y	Y
Year FE	Y	Y	Y
Time varying firm controls	Y	Y	Y

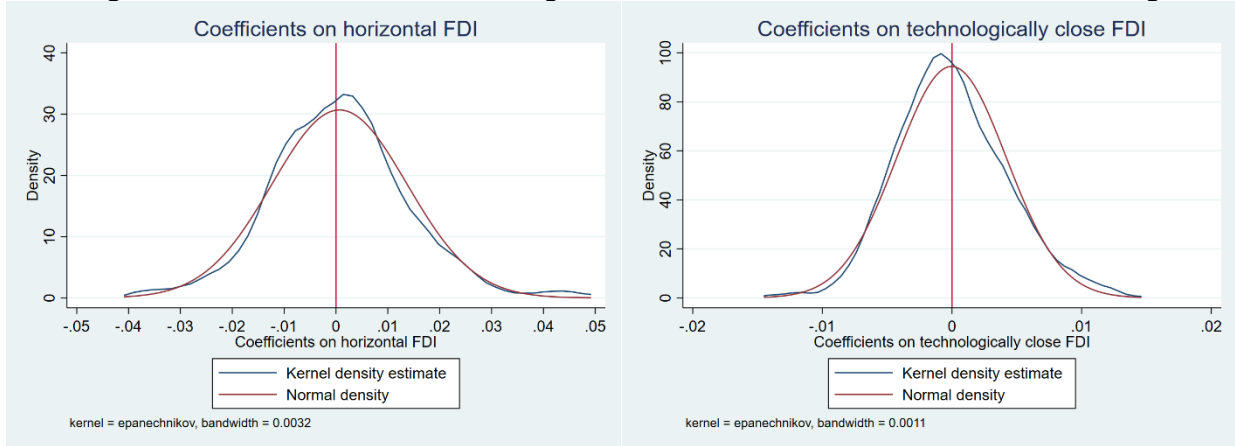
Note: Table 8 reports the expectation effect of FDI liberalization prior to 2002 on domestic firms' innovation based on IV model. The dependent variable is invention patent application. Column (1)-(3) report the effect from fake treatment year 1999, 2000, and 2001 respectively. Time varying firm controls include firm sales, capital-labor ratio, export status and SOE dummy. Robust standard errors in parentheses. *** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$.

4.2 Randomly assign treatment industries and treatment time

We run a placebo test by randomly assigning treatment industries for each year during 1999 to 2006. We leave out 1998 and 2007 so there is at least one year in the pre-treatment and post-treatment period. For each year from 1999 to 2006, we randomly select 112 industries for treatment, and interact the fake treatment dummy with the fake treatment year to generate the fake $treatment \times post02_{it}$. We then calculate the effect on technologically close FDI: $IV_techclose_{it} = \sum_{j \neq i} Techclose_{ij} \times treatment \times post02_{it}/n$.

We then use reduced form to estimate the effect of sectoral FDI liberalization on domestic firms' invention patent application through two channels: horizontal FDI and technologically close FDI. We run the randomized treatment industry assignment for 50 times for each of the eight years. The regression coefficients from the 400 trials are shown in Figure 5. The distribution of both coefficients is centered around zero. Coefficients from the true treatment is 0.003 for $treatment \times post02$ and 0.0355 for $IV_techclose$. The coefficient on horizontal FDI from the true treatment is significantly different from the mean coefficient from randomized trials at 95% level, while the coefficient on technologically close FDI is significantly different from the mean coefficient from randomized trials at 99% level. These observations suggest that the positive and significant effect of horizontal and technologically close FDI on domestic firms' patent application is unlikely to be driven by omitted variables.

Figure 5. Placebo test with random assignment of treatment industries and treatment timing



Note: To test if the positive and significant effect of horizontal and technologically close FDI on domestic firms' patent application is driven by omitted variables, we randomly assign 112 industries as treatment industries, and use the same reduced form specification to estimate the coefficients of $treatment \times post02$ and $IV_techclose$. We run the randomized trial 50 times for each year during 1999 to 2006. The figure shows the distribution of estimated coefficients from the 400 trials. The left panel has a mean of 0.00068 and standard deviation of 0.013, while the right panel has a mean of -0.00003 and a standard deviation of 0.004.

4.3 Vertical spillovers from FDI

Previously we focused on the effect of horizontal and technologically close FDI. Many studies have documented positive spillovers on domestic firms' TFP and patent application from vertical FDI (Havranek and Irsova 2011; Blalock and Gertler 2008; Liu, Wang, and Wei 2009; Javorcik 2004, 2008; Fons-Rosen et al. 2017; Lu et al. 2017; Liu et al. 2019). How does vertical FDI affect domestic firms' patent application? Is the effect from technologically close FDI robust when vertical FDI is controlled for? The paper calculates upstream and downstream FDI based on China's 2002 Input-Output Table. There are only 72 manufacturing industries in the 2002 IO table, we use a concordance table to map each four-digit industry from the manufacturing firm dataset to an industry in the IO table.

Upstream FDI

$$FDI_{sector_{st}}^{upstream} = \sum_{m \text{ if } m \neq s} \beta_{sm} \times FDI_{sector_{mt}} \quad (9)$$

Where β_{sm} is the ratio of inputs purchased by sector s from sector m .

Downstream FDI

$$FDI_{sector_{jt}}^{downstream} = \sum_{k \text{ if } k \neq j} \beta_{jk} \times FDI_{sector_{kt}} \quad (10)$$

Where β_{jk} is the ratio of sector j 's output supplied to sector k .

Instruments for upstream and downstream FDI are $\sum_{m \neq s} \beta_{sm} \times treatment \times post02_{it}$, $\sum_{k \neq j} \beta_{jk} \times treatment \times post02_{kt}$, respectively.

Table 9 reports the effect of four FDI channels on domestic firms' invention patent application. Horizontal and technologically close FDI still have large and highly significant effects on domestic firms' invention patent application. The coefficients are also very similar to those in our baseline IV model, indicating that knowledge spillovers from technologically close FDI is distinct from vertical spillovers through input-output linkages. FDI from upstream industries start to generate positive effects on domestic firms' invention patent application after two years of initial exposure, and the effect is larger than all other channels. FDI in upstream industries could provide higher quality inputs, equipment, and machinery for domestic firms, which are essential for innovation. FDI from downstream industries does not have any significant effect.

Table 9. IV model: Four measures of FDI presence

	(1)	(2)	(3)	(4)
	T	T+1	T+2	T+3
Dependent variable: Invention patent application				
FDI_sector	0.269*** (0.0517)	0.285*** (0.0596)	0.372*** (0.0659)	0.400*** (0.0715)
FDI_techclose	0.539*** (0.0949)	0.544*** (0.109)	0.482*** (0.116)	0.341*** (0.125)
FDI_upstream	-0.0246 (0.141)	0.195 (0.149)	0.623*** (0.158)	0.884*** (0.162)
FDI_downstream	-0.0498 (0.0653)	0.0171 (0.0683)	0.0119 (0.0701)	0.0432 (0.0747)
Observations	1,383,715	1,383,715	1,383,715	1,151,980
Firm FE	Y	Y	Y	Y
Year FE	Y	Y	Y	Y
Time varying firm controls	Y	Y	Y	Y

Note: Table 9 tests if vertical FDI affects the coefficients on horizontal and technologically close FDI. The dependent variable is invention patent application. Column (1)-(4) report the simultaneous effect, and the effect after 1-3 years of FDI exposure respectively. Time varying firm controls include firm sales, capital-labor ratio, export status and SOE dummy. Robust standard errors in parentheses. *** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$.

4.4 Control changes in output and input tariff

During our study period, there were also significant tariff reductions for both imports and exports. Average tariffs on Chinese exports were reduced from 10 in 1998 to 8.13 in 2007, and the average tariff China imposed on imported goods was cut from 18.67 in 1998 to 10.77 in 2007. The cut was most dramatic in 2002, from 17.11 in 2001 to 13.84. Several papers have shown that changes in tariffs have significant impact on domestic firms' innovation (Liu et al. 2021; Liu and Qiu 2016; Bombardini et al. 2018). To control for the effect of tariff changes on firm innovation, we add changes in export, import, and input import tariffs in the baseline regression. We obtained export and import tariff data from WITS-TRAINS database at four-digit ISIC level, then mapped each ISIC industry to a four-digit industry. We calculated changes in tariff rate from 2000 to the midpoint in post-treatment period (2005) for each four-digit Chinese industry. For input import tariff, we use China's 2002 Input-Output Table to impute changes in imported input tariffs. Specifically, we ran the regression below using the same IV in the baseline regression:

$$\ln y_{fit} = \alpha_f + \gamma_t + \delta_1 FDI_sector_{it} + \delta_2 FDI_techclose_{it} + \delta_3 FDI_upstream_{it} + \delta_4 FDI_downstream_{it} + X'_{fit}\beta + \Delta exp_tariff_{2000-2005} \times Post02 + \Delta imp_tariff_{2000-2005} \times Post02 + \Delta input_imp_tariff_{2000-2005} \times Post02 + \varepsilon_{fit} \quad (11)$$

The coefficients are largely the same with previous results when tariff changes were controlled for (Table 10). This shows the positive effect on innovation is not due to tariff reductions during the study period. Reduction in export tariff has a significant positive impact on domestic firms' patent application for all patent types, while reduction in input tariff tends to have a negative impact.

Table 10. IV model: four channels of FDI and control for tariff changes

	(1)	(2)	(3)	(4)
	T	T+1	T+2	T+3
Dependent variable: Invention patent application				
FDI_sector	0.311*** (0.0479)	0.332*** (0.0555)	0.403*** (0.0614)	0.432*** (0.0663)
FDI_techclose	0.549*** (0.0994)	0.551*** (0.113)	0.458*** (0.120)	0.294** (0.128)
FDI_upstream	-0.160 (0.155)	0.0435 (0.162)	0.456*** (0.171)	0.710*** (0.173)
FDI_downstream	-0.101 (0.0653)	-0.0412 (0.0672)	-0.0376 (0.0684)	-0.00806 (0.0731)
Observations	1,383,715	1,383,715	1,383,715	1,151,980
Firm FE	Y	Y	Y	Y
Year FE	Y	Y	Y	Y

Tariff changes	Y	Y	Y	Y
Time varying firm controls	Y	Y	Y	Y

Note: Table 10 tests if the positive effect of horizontal and technologically close FDI on domestic firms' innovation still exists when tariff changes are controlled for. The dependent variable is invention patent application. Column (1)-(4) report the simultaneous effect, and the effect after 1-3 years of FDI exposure respectively. Time varying firm controls include firm sales, capital-labor ratio, export status and SOE dummy. Tariff changes include export, import and input import tariff changes from 2000 to 2005. Robust standard errors in parentheses. *** p<0.01, ** p<0.05, * p<0.1.

4.5 Robustness of technological closeness

This paper considers two industries are technologically close if the correlation of their technology space distribution is equal to or greater than 0.5. How sensitive are the results to the choice of technological closeness cutoff point? Table 11 displays the results when the cutoff point is set at 0.4 and 0.6 respectively. The coefficients of horizontal FDI remains similar to baseline IV results. When the cutoff point is 0.4, technologically close FDI have a much smaller positive effect on domestic firms' innovation. When the cutoff point is 0.6, the coefficient of FDI_techclose is around 0.7 from T to T+2, significantly above 0.5 in the baseline results. The effect also becomes more significant. This suggests that knowledge spillovers from technologically close FDI increase with technological closeness between sectors.

Table 11. Robustness check: Technological closeness cutoff point

Dependent var: invention patent application	(1)	(2)	(3)	(4)
	T	T+1	T+2	T+3
Panel A. Technological closeness cutoff point = 0.4				
FDI_sector	0.241*** (0.0510)	0.305*** (0.0579)	0.461*** (0.0652)	0.523*** (0.0713)
FDI_techclose	0.114*** (0.0371)	0.158*** (0.0429)	0.165*** (0.0467)	0.118** (0.0497)
Panel B. Technological closeness cutoff point = 0.6				
FDI_sector	0.276*** (0.0587)	0.314*** (0.0660)	0.462*** (0.0730)	0.541*** (0.0813)
FDI_techclose	0.734*** (0.0926)	0.754*** (0.106)	0.724*** (0.112)	0.634*** (0.119)
Observations	1,383,715	1,383,715	1,383,715	1,151,980
Firm FE	Y	Y	Y	Y
Year FE	Y	Y	Y	Y
Time varying firm controls	Y	Y	Y	Y

Note: Table 11 tests if our results are robust using different cutoff points for technological closeness. The dependent variable is invention patent application. Panel A defines technological closeness as any pair of

industries with a closeness index above 0.4, Panel B defines technological closeness with a cutoff point of 0.6. Column (1)-(4) report the simultaneous effect, and the effect after 1-3 years of FDI exposure respectively. Time varying firm controls include firm sales, capital-labor ratio, export status and SOE dummy. Tariff changes include export, import and input import tariff changes from 2000 to 2005. Robust standard errors in parentheses. *** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$.

V. Mechanism

This section explores the mechanisms of innovation spillovers, including domestic firms' absorptive capacity, availability of talent in the local labor market, as well as competition effect through local and non-local FDI.

5.1 Domestic firms' absorptive capacity

Domestic firms do not benefit from the presence of FDI equally. Domestic firms that have higher absorptive capacity stand to gain more than domestic firms that are unable to assimilate advanced technology from foreign firms. A domestic firm's absorptive capacity is usually defined as the firm's ability to recognize the value of new information, assimilate it, and apply it to commercial ends (Cohen and Levinthal, 1990). Domestic firm's absorptive capacity determines the extent to which it can utilize knowledge spillovers from FDI. Various literature has documented this phenomenon (Girma, 2005; Kinoshita, 2000; Castellani and Zanfei, 2003; Zhang et al., 2010; Lu et al., 2017). Kokko (1994) used industry level data in Mexico to test whether FDI spillovers depend on the technological distance between foreign and domestic firms. The results suggested that advanced MNC technologies or large technology gaps alone do not constitute unsurmountable obstacles to spillovers, but that spillovers are less likely in industries with both large technology gaps and high foreign equity share. Using ASIF data during 1998-2003, Zhang et al. (2010) found that the positive effect of FDI on domestic firms' productivity is stronger when domestic firms are larger, and when the technology gap between FDI and the domestic firms is intermediate. Using a cross-section of more than 25,000 domestic manufacturing firms in 78 low- and middle-income countries from the World Bank's Enterprise Survey, Farole and Winkler (2015) found that domestic firms with low and high productivity level benefit more from FDI spillovers than domestic firms with medium productivity. Lu et al. (2017) found that horizontal FDI has negative and statistically significant effects on both SOEs and domestic non-SOEs, but the negative effect is slightly smaller for SOEs.

Previous studies have used various indicators to measure the absorptive capacity of domestic firms. Some papers measure the technology gap between foreign and domestic firms as the difference of the average TFP of foreign firms in an industry and the TFP of a domestic firm (Kokko, 1994; Zhang et al.,

2010). Some used R&D expenditure and ownership structure as proxies for absorptive capacity (Lu et al., 2017). As R&D expenditure is not available in our data set until 2005, we define firms with high absorptive capacity as firms that have above-zero new product share. The dummy variable equals zero if a firm reports zero sales from new products. Among the 1,390,390 observations in our sample, 1,279,018 observations reported zero new product share. We interact the high absorptive capacity dummy with $treatment \times post02_{it}$ in the regression to test if firms with high absorptive capacity benefits more from horizontal FDI. the results are presented in Table 12.

Domestic firms with above zero new product share benefit more from horizontal and technologically close FDI. Coefficients of the interaction terms are highly significant and orders of magnitude larger than coefficients on horizontal and technologically close FDI. Compared with domestic firms that do not launch any new products, firms that have new products have much higher invention patent applications. This corroborates literature that found larger FDI spillovers on domestic firms with higher absorptive capacity.

Table 12. IV results: domestic firms' absorptive capacity

Dependent var: invention patent application	(1)	(2)	(3)	(4)
	T	T+1	T+2	T+3
Panel A. Horizontal FDI interacted with a bsorptive capacity				
FDI_sector	0.0115 (0.0586)	0.0240 (0.0669)	0.115 (0.0766)	0.265*** (0.0783)
FDI_techclose	0.623*** (0.0912)	0.692*** (0.103)	0.703*** (0.115)	0.606*** (0.119)
FDI_sector \times absorptive capacity	4.865*** (0.568)	5.485*** (0.638)	6.593*** (0.744)	5.186*** (0.612)
Panel B. Technologically close FDI interacted with a bsorptive capacity				
FDI_sector	0.243*** (0.0560)	0.285*** (0.0629)	0.432*** (0.0697)	0.502*** (0.0769)
FDI_techclose	0.425*** (0.0816)	0.471*** (0.0923)	0.448*** (0.0994)	0.385*** (0.110)
FDI_techclose \times absorptive capacity	3.347*** (0.215)	3.734*** (0.237)	4.107*** (0.258)	4.112*** (0.263)
Observations	1,383,715	1,383,715	1,383,715	1,151,980
Firm FE	Y	Y	Y	Y
Year FE	Y	Y	Y	Y
Time varying firm controls	Y	Y	Y	Y

Note: Table 12 shows how domestic firms' a bsorptive capacity affects FDI spillovers. The dependent variable is invention patent application. Column (1)-(4) report the simultaneous effect, and the effect after 1-3 years of FDI

exposure respectively. Absorptive capacity equals one if a firm sold new products in that year, and zero otherwise. Time varying firm controls include firm sales, capital-labor ratio, export status and SOE dummy. Robust standard errors in parentheses. *** p<0.01, ** p<0.05, * p<0.1.

5.2 Local human capital stock

Related to domestic firms' absorptive capacity, the availability of talent in the local labor market is instrumental for maximizing knowledge spillovers generated by FDI. This paper uses the share of population aged between 18 and 55 with a bachelor's degree or above at the prefecture level as a measure of talent availability. We calculated prefecture level college population share using the population census in 2000. The pre-treatment talent availability mitigates endogeneity issues. We then add college population share and its interaction term with horizontal FDI and technologically close FDI in the baseline IV regression. Results are reported in Table 13. The coefficients on horizontal and technologically close FDI remains significant but become smaller than the baseline results. The interaction terms have large and highly significant impact on domestic firms' invention patent application. A unit increase in the interaction term of horizontal FDI and college population share results in a 5.7-6.2 percent increase in invention patent application. A unit increase in the interaction term between technologically close FDI and college population share leads to a 6.6-8 percent increase in invention patent application. These results highlight the importance of human capital in learning and absorbing knowledge spillovers from FDI.

Table 13. IV results: local human capital

Dependent var: invention patent application	(1)	(2)	(3)	(4)
	T	T+1	T+2	T+3
Panel A. Horizontal FDI interacted with human capital				
FDI_sector	0.0892 (0.0586)	0.156** (0.0671)	0.289*** (0.0752)	0.334*** (0.0839)
FDI_techclose	0.500*** (0.0815)	0.559*** (0.0921)	0.544*** (0.0990)	0.440*** (0.109)
FDI_sector × college share	5.732*** (1.051)	5.051*** (1.159)	5.586*** (1.297)	6.166*** (1.395)
Panel B. Technologically close FDI interacted with human capital				
FDI_sector	0.247*** (0.0544)	0.294*** (0.0614)	0.445*** (0.0681)	0.515*** (0.0754)
FDI_techclose	0.252*** (0.0836)	0.324*** (0.0950)	0.335*** (0.103)	0.239** (0.112)
FDI_techclose × college share	8.047*** (0.942)	7.558*** (1.038)	6.825*** (1.083)	6.581*** (1.131)

Observations	1,382,897	1,382,897	1,382,897	1,151,377
Firm FE	Y	Y	Y	Y
Year FE	Y	Y	Y	Y
Time varying firm controls	Y	Y	Y	Y

Note: Table 13 shows how prefecture level human capital affects FDI spillovers. The dependent variable is invention patent application. Column (1)-(4) report the simultaneous effect, and the effect after 1-3 years of FDI exposure respectively. College share is the share of population aged between 18-55 that has a Bachelor's degree or above at prefecture level in 2000. Time varying firm controls include firm sales, capital-labor ratio, export status and SOE dummy. Robust standard errors in parentheses. *** p<0.01, ** p<0.05, * p<0.1.

5.3 Competition vs. agglomeration: Local vs. non-local FDI

Many studies found FDI spillovers tend to be larger for domestic firms that are in proximity to foreign firms (Lu et al., 2017; Wang and Wu, 2016; Audretsch and Feldman, 2004). The agglomeration effect could magnify FDI spillovers for nearby domestic firms through labor pooling, sharing suppliers, economy of scale and scope, frequent and spontaneous knowledge exchange (Krugman, 1991; Jaffe et al., 1993; Glaeser et al., 1992; Beaudry and Schiffauerova, 2009). However, domestic firms also suffer from higher competition if they are close to foreign firms, especially if their products are primarily sold in the local markets. Foreign firms may also attract the best talents in the same region, straining domestic firms' innovative capacity.

To test if local FDI affects domestic firms' innovation differently from non-local FDI, we construct local and non-local FDI measures as follows:

$$FDI_sector_local_{ict} = \frac{\sum_{f \in \Omega_{ict}} FDI_firm_{fict} \times Output_{fict}}{\sum_{f \in \Omega_{ict}} Output_{fict}} \quad (12)$$

$$FDI_sector_nonlocal_{ict} = \frac{\sum_{f \in \Omega_{it}} FDI_firm_{fit} \times Output_{fit} - \sum_{f \in \Omega_{ict}} FDI_firm_{fict} \times Output_{fict}}{\sum_{f \in \Omega_{it}} Output_{fit} - \sum_{f \in \Omega_{ict}} Output_{fict}} \quad (13)$$

Where c denotes city. $FDI_sector_local_{ict}$ is the output-weighted foreign equity share in industry i in city c at time t . $FDI_sector_nonlocal_{ict}$ is the output-weighted foreign equity share in industry i at time t in all other cities excluding city c . We use $\frac{Output_{ic2001}}{\sum_c Output_{ic2001}} \times treatment \times post02_{it}$ as the IV for local FDI and $\left(1 - \frac{Output_{ic2001}}{\sum_c Output_{ic2001}}\right) \times treatment \times post02_{it}$ as the IV for non-local FDI. The results of local and non-local FDI on domestic firms' invention patent application and citation are reported in table 14.

Exposure to horizontal FDI in the same city has a negative effect on domestic firms' innovation. A one percentage point increase in local foreign equity share could reduce a domestic firm's invention patent

application by 1.6 percent in the same year. The negative effect declines over time, though the magnitude remains large. Horizontal FDI from other cities generates large and increasing spillovers on domestic firms' invention patent application. The coefficient increases from 0.66 in the same year to 0.78 three years after exposure. This suggests that the competition effect dominates in local market. Foreign firms in the same city not only take a slice of business away from domestic firms, but also attract the best talents. The double whammy impedes domestic firms' innovation efforts. The positive effect of technologically close FDI remains highly significant over time, the magnitude becomes smaller than horizontal FDI in other cities.

Table 14. Heterogeneous treatment effect: local vs. nonlocal FDI

	(1)	(2)	(3)	(4)
	T	T+1	T+2	T+3
Dependent variable: Invention patent application				
FDI_sector_local	-1.609*** (0.475)	-1.392*** (0.428)	-1.211*** (0.448)	-1.033** (0.465)
FDI_sector_non-local	0.656*** (0.148)	0.649*** (0.141)	0.753*** (0.147)	0.777*** (0.154)
FDI_techclose	0.367*** (0.108)	0.443*** (0.109)	0.444*** (0.113)	0.355*** (0.120)
Observations	1,383,713	1,383,713	1,383,713	1,151,978
Firm FE	Y	Y	Y	Y
Year FE	Y	Y	Y	Y
Time varying firm controls	Y	Y	Y	Y

Note: Table 14 reports the effect of local horizontal FDI, non-local horizontal FDI and technologically close FDI on domestic firms' innovation. The dependent variable is invention patent application. Column (1)-(4) report the simultaneous effect, and the effect after 1-3 years of FDI exposure respectively. Time varying firm controls include firm sales, capital-labor ratio, export status and SOE dummy. Robust standard errors in parentheses. *** p<0.01, ** p<0.05, * p<0.1.

VI. Conclusion

This paper estimated how exposure to FDI affects domestic firms' innovation behavior through multiple channels. Leveraging China's revision of the "Catalogue of Industries for Guiding Foreign Investment" in 2002, the paper used a difference-in-differences approach to mitigate the endogeneity issues. Among the 425 four-digit manufacturing industries in our sample, 112 industries became more open to FDI after 2002. FDI policy changes strongly predict FDI presence in the 425 industries since 2002. Using a matched firm-patent database and patent citation database, this paper found significant positive spillovers from FDI on domestic firms' quantity and quality of innovation outputs. A one percentage point increase

in foreign equity share in the same four-digit industry could raise domestic firms' utility model patent applications by 0.65 percent in the same year, and raise invention patent applications by 0.27 percent in the same year. The positive effect increases over time. In addition to horizontal FDI, FDI from technologically close industries generates a much larger impact on domestic firms' invention patent applications. FDI in technologically close industries can generate twice as large knowledge spillovers as horizontal FDI does. This result is not driven by input-output linkages with FDI and tariff changes.

Our identification strategy is valid as demonstrated through a battery of robustness checks. The event study confirms treatment and control groups had parallel trends in patent applications before treatment. There was no expectation effect before treatment, the effect is unlikely to be driven by unobservable factors, and it remains robust when vertical FDI and tariff changes are controlled for. The results are also robust to different technological closeness cutoff points. The more technologically close industries are to liberalized industries, the more domestic firms benefit from FDI liberalization. Finally, the paper also sheds light on possible mechanisms, including the absorptive capacity of domestic firms, local human capital stock, and competition vs. agglomeration. We found larger spillovers for domestic firms with higher absorptive capacity. A higher share of adult population with at least a bachelor's degree proves instrumental for maximizing knowledge spillovers from FDI. Horizontal FDI in the same city negatively affects domestic firms' innovation through the competition effect.

Our results have important policy implications. We found that FDI not only benefits domestic firms in the same industry, it generates much larger spillovers in technologically close industries and downstream industries. Only considering horizontal spillovers would underestimate the overall effect of FDI on domestic firms. Our findings also underscore the various factors that condition such knowledge spillovers and emphasize the role of human capital in absorbing and assimilating knowledge spillovers from FDI. The stock of human capital hugely magnifies the positive knowledge spillovers. To maximize the benefits FDI brings, governments need to invest in human capital and help domestic firms develop enough absorptive capacity.

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Appendix

Table A1. IV regressions: first stage results

	(1)	(2)	(3)	(4)
Panel A. Horizontal FDI and technologically close FDI				
	FDI_sector	FDI_techclose		
Treatment×Post02	0.0237*** (0.00043)	-0.0061*** (0.00022)		
IV_techclose	0.0283*** (0.00125)	0.0539*** (0.00087)		
Anderson-Rubin Wald test	37.08***			
Stock-Wright LM S statistic	82.84***			
Panel B. Four types of FDI				
	FDI_sector	FDI_techclose	FDI_upstream	FDI_downstream
Treatment×Post02	0.0249*** (0.0004)	-0.0062*** (0.00023)	0.0012*** (0.00008)	-0.0017*** (0.000053)
IV_techclose	0.0200*** (0.00128)	0.0481*** (0.00088)	0.0013*** (0.00030)	-0.0009*** (0.00020)
Treatment×Post02×Up	-0.0217*** (0.00340)	0.0294*** (0.00206)	0.1052*** (0.00076)	0.0116*** (0.00057)
Treatment×Post02×Down	0.0738*** (0.00091)	0.0231*** (0.00047)	-0.0016*** (0.00015)	0.1400*** (0.00118)
Anderson-Rubin Wald test	20.39***			
Stock-Wright LM S statistic	92.17***			
Panel C. Local vs. nonlocal FDI				
	Local FDI	Nonlocal FDI	FDI_techclose	
Treatment*Post02*Local	-0.1581*** (0.0093)	-0.0602*** (0.0046)	-0.1352*** (0.0038)	
Treatment*Post02*Nonlocal	0.0101*** (0.0006)	0.0257*** (0.0003)	-0.0032*** (0.0002)	
Treatment×Post02×Techclose	0.0015 (0.0015)	0.0289*** (0.0008)	0.0534*** (0.0005)	
Anderson-Rubin Wald test	56.63***			
Stock-Wright LM S statistic	181.61***			