Knowledge Spillover from Green FDI: Evidence from Green Innovation in China

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Abstract

China has witnessed rapid development in green industries over the past two decades, with foreign direct investment playing an important role in bringing cutting-edge green technologies to Chinese domestic firms. However, accurately estimating the contributions of FDI to green knowledge spillovers becomes challenging without distinguishing whether an FDI involves environmentally-friendly commercial activities, i.e., green FDI. Using a new dataset that provides comprehensive coverage and detailed information on FDI activities in China, this paper develops four new definitions of green FDI by text-mining business descriptions and tracking patenting activities of foreign-invested firms. I identify the impacts of knowledge stocks resulting from green FDI firms on domestic firms' green innovation using Chinese firm-level data, along with an instrumental variable based on the changes in China's FDI opening-up policy. The results show no impact of green FDI firms' knowledge stocks on domestic firms' green innovation when green FDI firms operate within the same industry as domestic firms. In contrast, I find that a 1% increase in knowledge stocks resulting from green FDI firms in downstream industries contributes to a roughly 0.732% increase in green patenting activities of domestic firms. This knowledge spillover effect from downstream green FDI is more pronounced on domestic high-quality green innovation. Further investigation into the factors influencing green FDI knowledge spillovers reveals that the location of green FDI firms, technological proximity between industries, and environmental regulation stringency of green FDI origins contribute to the varying strength of the knowledge spillovers from downstream green FDI.

Keywords: Foreign Direct Investment; Green Innovation; Knowledge Spillover; China

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1 Introduction

China has undergone explosive growth in green industries such as solar and wind energy starting in the early 2000s (Linster and Yang, 2018). This surge came as a surprise to many observers given that most green industries in China only emerged in the late 1990s but rapidly rose to become one of the world's largest markets within two decades.[1] Such a remarkable expansion of China's green industries closely followed a large scale opening up to foreign direct investment (FDI) after China joined the World Trade Organisation (WTO) in 2001 (Davies, 2013). The increased inflows of foreign investment facilitated Chinese domestic manufacturers' integration into multinationals' supply chains (Ueno, 2009). Along with industrial policies such as public procurement and local content requirement, foreign multinationals deepened the engagement of Chinese domestic firms in production and technology, fostering technology transfer (Lema et al., 2011; Urban, Nordensvärd, and Zhou, 2012). Over time, Chinese domestic firms managed to build up production capacities and develop indigenous innovation during their engagement in supply chains led by foreign multinationals (Fu and Zhang, 2011; Lema and Lema, 2012). To gain insights into how Chinese domestic manufacturers achieved a competitive edge in both domestic and global green industries, it is informative to delve into the origin of this green industry boom. Exploring the reasons behind the early phase of the explosive growth of China's green industries entails understanding how Chinese firms caught up with cutting-edge green technologies by participating in multinationals' supply chains. Therefore, this paper aims to identify the contributions of FDI to the development of China's green industries, with a particular focus on green knowledge spillover via supply chains.

There are two primary challenges in identifying the contributions of FDI to green

[1] For example, the cumulative installed wind capacity in China was approximately 0.3 Gigawatts (GW) in 2000 but surged to 44.7 GW in 2010, surpassing the United States as the world's largest wind energy market (Ru et al., 2012). Similarly, the cumulative installed photovoltaic (PV) capacity was around 0.7 GW in 2000 but skyrocketed to 180 GW in 2014 (Zhang and Gallagher, 2016).

knowledge spillovers. First, most existing literature on FDI and the environment treats FDI as generic and does not rigorously differentiate whether an FDI project involves clean, pro-environment investment. However, generic FDI includes a substantial amount of foreign investment that is irrelevant to environmentally-friendly commercial activities or even negatively contributes to environmental performance. Consequently, analyses based on generic FDI contain considerable ambiguities in quantifying the extent to which FDI contributes to green knowledge spillovers. Such ambiguities also potentially explain the mixed results observed in many previous studies on FDI and the environment (Cole, Elliott, and Zhang, 2017). Second, the relationship between domestic green innovation and knowledge spillovers from FDI is likely to be endogenous. This is primarily due to self-selection on investment targets by foreign investors and the reverse impacts of domestic firms' growth as suppliers, customers or competitors on foreign-invested firms or foreign investors. Without a proper identification strategy, the estimation may result in correlation but not causality evidence, biasing the estimated magnitude of green knowledge spillovers from FDI to domestic firms (Lu, Tao, and Zhu, 2017). To resolve these research challenges, I put forward new approaches to defining "green FDI" (i.e., FDI involving environmentally-friendly commercial activities) based on more granular information on FDI in China. Additionally, I leverage the Chinese FDI opening-up policy as an exogenous shock to causally identify the knowledge spillover effects of green FDI.

In this paper, I compile a new comprehensive FDI dataset with detailed information on FDI activities in China, integrating this data with Chinese firm-level fundamental and patenting information spanning the period 2000-2013. The rich information on foreign investment enables a more precise recognition of foreign-invested firms (FDI firms) with environmentally-friendly commercial activities. Specifically, I develop four approaches to defining if foreign-invested firms are involved in environmentally-friendly commercial activities (green FDI firms) by analysing textual descriptions of investment business and tracking patenting activities in foreign-invested firms. Building upon the newly defined green FDI, I construct measures to assess the extent of domestic firms' exposure to knowledge stocks resulting from green FDI during participation in multinationals' supply chains. This allows me to estimate the impacts of green FDI knowledge stocks on domestic firms' green innovation, which captures the knowledge spillovers from green FDI via supply chains. To examine the knowledge spillovers from various parts of supply chains, I categorise knowledge stocks resulting from green FDI firms into three types based on the industrial linkage between domestic firms and green FDI firms: knowledge stocks resulting from green FDI firms in the same industry (horizontal industry), green FDI firms in downstream industries, and green FDI firms in upstream industries, thereby distinguishing the knowledge spillovers from different supply chain channels. To overcome the endogeneity concerns in identification, I utilise the changes in the *Catalogue for the Guidance of Foreign Investment Industries*, reflecting the openness of specific industries to FDI in China, as exogenous shocks to construct instrumental variables for the knowledge stocks resulting from green FDI firms. The validity of the instrumental variables is further consolidated by controlling possible non-random selections of FDI openness and other causality paths through which the FDI opening-up policies affect domestic green innovation.

I observe a significant discrepancy in green technological capabilities between newly defined green FDI and other generic FDI. This disparity cannot be well explained by generic factors such as firm size or generic technologies but is distinctly captured by the new definitions of green FDI. The discrepancy implies that estimating the contributions of FDI to green knowledge spillovers may include considerable noise if the focus is solely on generic FDI but not on green FDI. Based on the new green FDI definitions, there is no evidence that green innovation of domestic firms benefits from knowledge stocks of green FDI firms within the same industry. In contrast, the results show that a 1% increase in the knowledge stocks of green FDI firms in downstream industries contributes to around 0.732% increase in green patenting activities of domestic firms, which indicates knowledge spillovers from downstream green FDI. The positive impacts of downstream green FDI firms' knowledge imply that domestic firms benefit from knowledge stocks of green FDI firms by becoming suppliers to green FDI firms. Moreover, the knowledge spillovers from downstream green FDI predominantly boost the generation of the most innovative patents (i.e., invention patents). Further evidence on patent citations supports the positive spillover effects on the quality of domestic firms' green innovation. When breaking down technological fields, the positive knowledge spillover effects of green FDI appear to be more pronounced for domestic innovation in alternative energy and sustainable transportation. In addition, I further examine the possible mechanisms for the knowledge spillover effects of downstream green FDI. The findings suggest that green FDI firms located in the same regions as domestic firms generate more pronounced knowledge spillovers than green FDI firms located in different regions. The closer technological proximity between industries facilitates knowledge spillovers via supply chains from downstream green FDI firms to domestic firms. I also find higher stringency of environmental regulations in green FDI origin countries enhances knowledge spillovers in the host countries. Most of the results survive under various robustness checks.

This paper contributes to the literature on how to define and measure green FDI. There is so far little discussion on the definitions of green FDI, with only a few policy discussions offering rough guidelines, such as FDI related to environmentally-friendly sectors, mitigation of climate damage, or research and production of clean goods and services (Golub, Kauffmann, and Yeres, 2011; UNCTAD, 2016; Johnson, 2017). However, these guidelines do not provide concrete approaches to developing precise definitions and measures for green FDI. Several previous empirical studies have made pioneering efforts to distinguish green FDI. For example, Glachant and Dechezleprêtre (2017) and Dussaux, Dechezleprêtre, and Glachant (2017) define low-carbon FDI based on whether foreign investing firms own at least one low-carbon patent. Another study by Castellani et al. (2022) defines green-tech FDI as the cross-border investment occurring in sectors that are most specialised in green technologies. A major limitation of these definitions is their reliance on indirect proxies, lacking a direct capture of specific characteristics and activities of FDI projects. Considerable measurement errors of green FDI may be included due to ambiguities in these green FDI measures.[2] I develop four new definitions of green FDI, building upon the previous efforts. The new definitions focus on the specific characteristics and activities of FDI projects, including textual descriptions of FDI firms' business related to environmentally-friendly activities, FDI firms' green patenting activities, prior arts of FDI firms' patents, and FDI firms' investor patenting activities. The newly defined green FDI measures more accurately capture FDI projects that are likely to involve green knowledge spillovers.

This paper also relates to the extensive literature on the relationship between FDI and domestic production, innovation and environmental performance in the host countries. Earlier studies such as Aitken and Harrison (1999) raise the point that domestic firms may enjoy a positive spillover effect but also suffer from a negative competition effect brought by FDI. The mixed effects of FDI stimulate subsequent research exploring the connection between FDI and various aspects of domestic firms' activities, including output (Liang, 2017), productivity (Javorcik, 2004), R&D (Sun, Deng, and Wright, 2021), export (Bajgar and Javorcik, 2020), and product upgrade (Javorcik, Lo Turco, and Maggioni, 2018; Bai et al., 2020). Moreover, not consistent with the conventional pollution haven hypothesis, more empirical research on FDI and the environment finds that FDI can contribute to domestic environmental performance by fostering corporate social responsibility (Kellenberg, 2009; Poelhekke and Van der Ploeg, 2015) and improving energy efficiency (Brucal, Javorcik, and Love, 2019). This paper extends to examining the impacts of FDI knowledge spillovers on domestic green innovation performance and attempts to differentiate the

[2]For example, an FDI project in China invested by Siemens, which owns a variety of clean energy related patents around the world, may be a manufacturing factory producing household appliances irrelevant to clean energy. Additionally, although the household appliance sector overall involves a decent level of green specialisation (e.g., energy-saving appliances), a specific FDI project in this sector does not necessarily specialise in energy-saving appliances.

supply chain channels through which the knowledge spillovers exert.

Finally, this paper adds to a growing body of literature that develops new identification strategies to estimate the impacts of FDI spillovers. Many earlier studies on FDI produce correlation evidence, raising concerns about the reliability of the results and prompting more emphasis on proper identification strategies that provide causality evidence. Several new identification strategies have been employed in existing literature, including merger and acquisition (M&A) (Guadalupe, Kuzmina, and Thomas, 2012), export orientation (Crescenzi, Gagliardi, and Iammarino, 2015), joint venture partner (Jiang et al., 2018), geographic distance (Lin, Qin, and Xie, 2021), and FDI regulations (Lu, Tao, and Zhu, 2017; Chen et al., 2022). However, most existing identification strategies are tailored for generic FDI or a few individual FDI cases. Building upon the identification strategy proposed by Lu, Tao, and Zhu (2017), I utilise the changes in FDI opening-up policy in China to develop an instrumental variable specifically for green FDI. I further discuss the potential concerns in the validity of this instrumental variable and the corresponding methods to address the concerns.

The rest of this paper is organised as follows. Section 2 describes the data and the key measures used in this study. Section 3 presents the identification strategy and discusses the potential challenges to the identification. Section 4 reports the main empirical results, robustness checks, results for innovation heterogeneity, and discussions on mechanisms of green FDI knowledge spillovers. Section 5 concludes.

2 Data and Measures

2.1 China's Industrial Firms

The main firm-level panel data is from the Annual Survey of Industrial Enterprises (ASIE), conducted by the National Bureau of Statistics of China. This survey covers all state-owned enterprises and non-state-owned enterprises in China with annual sales above 5 million Yuan (around US$ 620000), involving mining, manufacturing and public utility sectors. Abundant firm-level fundamental, operation and financial information are included, such as identification number, 4-digit industry code, location code, output, sales, asset, employment, wage, export, and ownership. The dataset used in this paper spans the period 2000-2013.

There are some caveats to using this data. First, the industry classification during the sample period was modified from the version GB/T 4754-1994 (adopted during 1994-2001) to GB/T 4754-2002 (adopted during 2002-2010) and finally to GB/T 4754-2011 (adopted during 2011-2016). To address this issue, I link the three classifications and develop a consistent classification system throughout my entire sample period.[3] Second, some firms re-appear in the data after several years of missing. To avoid the possible impacts of the inconsistency of the data collection, I drop firms with missing observations for three consecutive years. Third, I drop observations where firms' identification number, location code and industry code are missing as the missing information affects the merge of datasets and construction of variables.

2.2 Green Innovation

Firms' innovation is measured by patenting activities in this study. I retrieve Chinese patent data from the China National Intellectual Property Administration (CNIPA), which has full coverage of all patent applications and publications filed in China since 1985. The CNIPA provides detailed bibliographic information on each patent, including applicants, application and publishing number, application and publishing date, and the International Patent Classification (IPC) code. In addition, I complement the information on patent priority, patent claim, patent citation, and Cooperative Patent Classification (CPC) code by the EPO Worldwide Patent Statistical Database (PATSTAT), which is the largest global

[3] Brandt, Van Biesebroeck, and Zhang (2012) have constructed a concordance table that well links GB/T 4754-1994 to GB/T 4754-2002. I follow their process and extend the linkage to the version GB/T 4754-2011.

patent database covering all of the world's major patent offices.

There are two widely-used definitions of green patents: (1) The IPC Green Inventory, developed by the World Intellectual Property Organization (WIPO)'s IPC Committee of Experts. The IPC Green Inventory covers a list of IPC codes that are closely relevant to environmentally sound technologies. (2) The Y02 category in the Cooperative Patent Classification (CPC) system, which tags technologies with contributions to climate change adaptation and mitigation (Haščič and Migotto, 2015). To have more comprehensive coverage of green technologies, I identify patents pertaining to green technologies by combining the two definitions, where a patent is green if either its IPC lies in the IPC Green Inventory or its CPC belongs to the Y02 category.

In the raw Chinese patent data, one patent innovation may correspond to multiple patent applications when they cover several different patent claims. To avoid double-counting of patents, I aggregate patent applications to the patent family level (DOCDB family code by PATSTAT), which identifies a group of patent applications that derive from the same patent innovation.[4]

2.3 Green Foreign Direct Investment

Although the dataset from ASIE includes information on firms' ownership, it only provides the share of ownership by state, foreign, and other domestic private entities. The lack of details on FDI creates a large barrier to differentiating the specific features of FDI and identifying green FDI accordingly. Therefore, I further retrieve the details of foreign-invested firms archived by The Ministry of Commerce of China, which fully covers FDI establishment and modification in China during 1980-2016 and records fundamental information such as names of firms receiving foreign direct investment, type of FDI, investors, investment amount, the origin of country, and text description of business scope. These

[4]The time dimension of each patent family is the patent priority year, which is the year when the earliest application in the patent family is filed.

details of FDI records allow me to identify green FDI more accurately.

Although there is currently no consensus on the green FDI definition, a green FDI is generally deemed to involve environmentally-friendly commercial activities, including production, operation or technology transfer in the mitigation of pollution and climate change (Golub, Kauffmann, and Yeres, 2011; UNCTAD, 2016; Johnson, 2017). Accordingly, I developed four new approaches to defining which foreign-invested firm is green FDI.

Textual description of foreign-invested firms' business. First, leveraging the textual description of each foreign-invested firm's business scope, I define a foreign-invested firm as a green FDI firm if its business scope contains keywords related to environmental governance, clean production, clean energy, or green technology.[5] The text of business scope disclosed by FDI reveals the specific business focus of each FDI firm, allowing me to detect whether a foreign-invested firm is involved in environmentally-friendly commercial activities.[6]

Green patents in foreign-invested firms. Second, I employ the patenting activities of foreign-invested firms and identify a foreign-invested firm as a green FDI firm if it files green patents in China. To relieve the concern that green patents derive from a firm's pre-existing knowledge rather than new knowledge brought in by FDI, only green patents that are filed after foreign investment enters the firm are counted. The existence of new green patenting activities after foreign investment enters helps to capture whether a foreign-invested firm acquires new green knowledge from foreign investment.

Prior arts of green patents in foreign-invested firms. One may question that green patents in foreign-invested firms may be mainly driven by domestic knowledge outside the foreign-invested firms and do not convincingly demonstrate green technology transfers

[5]For a more precise keyword search, I break down environmentally-friendly commercial activities into more than 200 keywords, as listed in Table A1.

[6]It is acknowledged that some textual descriptions, though not exactly including the keywords from the current keyword list, may actually involve green commercial activities. As an ongoing effort, a natural language processing (NLP) algorithm is being developed to train a neural network model that associates FDI textual business descriptions with environmentally-friendly commercial activities. This new NLP algorithm approach would provide a more refined and comprehensive measure of green FDI based on textual data.

via foreign investment. To respond to this concern, I further trace the prior arts of green patents in each foreign-invested firm and define a foreign-invested firm as a green FDI firm if its green patents cite prior arts invented outside China. The prior arts of FDI firms' green patents indicate where the knowledge enclosed in the green patents originates from and helps to further demonstrate that the new green knowledge of foreign-invested firms derives from foreign investment.

Green patents of foreign investors. In the fourth approach, I focus on patenting activities of foreign investors and define a foreign-invested firm as a green FDI firm if the firm's foreign investors have filed green patents in China. If foreign investors intend to utilise their existing technologies in China, they may file new applications of these technologies to the Chinese patent office to better protect the intellectual property rights of these technologies in China. This approach may capture stronger evidence of green technology transfers to China, though some technology transfers may be omitted as foreign investors probably resort to other ways rather than new patent applications to protect their existing technologies.

Figure 1 compares the performance of identifying green FDI by different approaches. The value in the left panel of the figure displays the ratio of foreign-invested firms defined as green FDI firms to all foreign-invested firms in China.[7] The value in the right panel is the average stock of green patents (depreciation rate 15%) owned by green FDI firms. The first definition (based on the text description of foreign-invested firms' business scope) achieves the largest coverage of green FDI firms (about 13% of all foreign-invested firms), while these green FDI firms have relatively lower green patent stocks compared to other green FDI definitions. The second definition (based on green patents in foreign-invested firms) extracts a slightly lower number of green FDI firms (about 12% of all foreign-invested firms) because it excludes the FDI firms operating in green commercial activities but not filing green patents. The third definition (based on prior arts of green patents in

[7]Figure 1 is drawn based on cross-section data in 2007, but the performances are very similar in other years during the sample period.

foreign-invested firms) narrows down to the FDI firms with stronger evidence of cross-border green technology transfers. Only focusing on green FDI firms that have green patents originating from foreign knowledge extracts the foreign-invested firms with higher specialisation in green innovation, though at the expense of a lower coverage of firms identified as green FDI. The fourth definition (based on green patents of foreign investors in China) does not perform well in identifying green FDI with respect to the coverage of FDI firms and the level of green patent stocks. One possible reason for the poor performance of the fourth definition is that foreign investors' green knowledge is not necessarily transferred via publicly filing and using patents in the host countries but in less conspicuous or codifiable channels such as trade secrets, technical specialists, or management experience.

In addition, I also compare the performances when using combinations of different green FDI definitions. The overlap of green FDI identified by the first and second definitions extracts a smaller pool of foreign-invested firms but ensures the identified green FDI firms have a higher level of specialisation in green technologies. The combinations of the first and third or fourth definitions similarly lead to a lower firm coverage while a higher green technology level of green FDI. Overall, using text description of FDI business scope helps to have the largest coverage of FDI firms involving environmentally-friendly commercial activities, while using patenting activities of FDI firms is conducive to capturing FDI specialisation in green technologies and possible technology transfers.

This study uses the first approach (keywords searching in the text description of foreign-invested firms' business) to define whether a foreign-invested firm is green FDI because environmentally-friendly commercial activities cover the transfers in green technologies and provide a business basis for possible green technology transfers. In contrast, green FDI definition based on patent activities may not reflect well the business focus of a foreign-invested firm even if this firm owns a few green patents.[8] Although the first

[8] Since there is currently no consensus on green FDI definition in both academic and policy research, more discussions on how to properly define green FDI are still strongly needed.

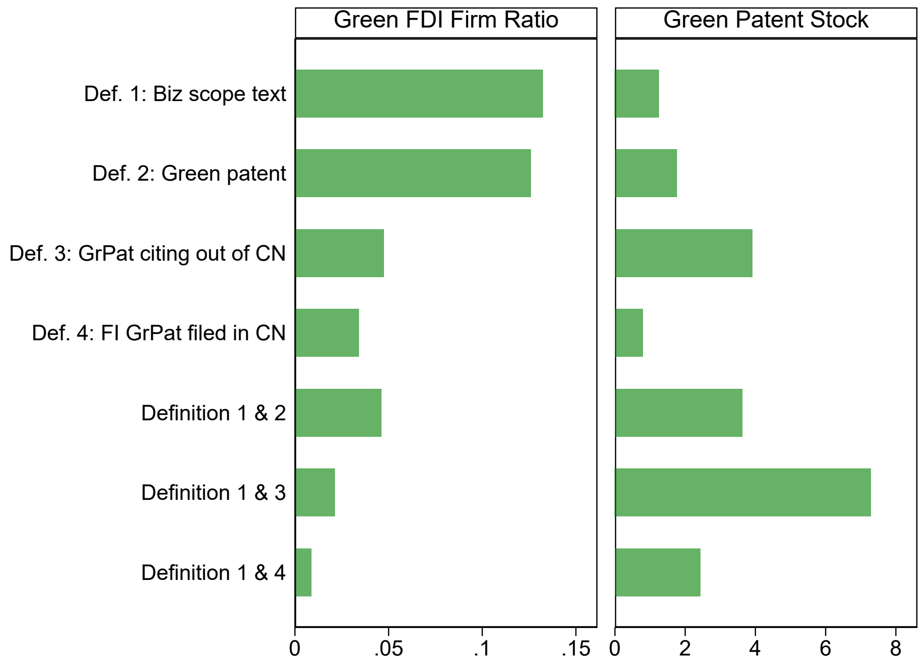

Figure 1: Comparison of Different Green FDI Definitions

Notes: The value in the left panel is the ratio of foreign-invested firms defined as green FDI firms to all foreign-invested firms in China. The value in the right panel is the average stock of green patents (depreciation rate 15%) owned by green FDI firms. Green FDI definition 1 is whether the text description of FDI firms' business scope includes keywords related to environmental governance, clean production, clean energy, or green technology (Def. 1: Biz scope text). Green FDI definition 2 is whether FDI firms own green patents (Def. 2: Green patent). Green FDI definition 3 is whether FDI firms own green patents that cite prior arts from foreign countries outside China (Def. 3: GrPat citing out of CN). Green FDI definition 4 is whether FDI firms' foreign investors have filed green patents in China (Def. 4: FI GrPat filed in CN). Definition 1 & 2 indicates the intersection of Green FDI definitions 1 and 2. Definition 1 & 3 indicates the intersection of Green FDI definitions 1 and 3. Definition 1 & 4 indicates the intersection of Green FDI definitions 1 and 4.

definition of green FDI is used in the main analysis, other alternative definitions of green FDI are also examined in robustness checks.

Figure 2 compares foreign-invested firms identified as green FDI firms and other foreign-invested firms (non-green FDI firms). The four graphs reveal the differences between green FDI and non-green FDI firms with respect to economic and technological characteristics. The generic factors such as the size of assets, size of labour, or overall technology capacities still cannot explain well the huge discrepancy of green technologies between green and non-green FDI firms.[9] Hence, only focusing on generic FDI in analyses, even controlling generic factors, may bring considerable noise in estimating the contributions of FDI to green knowledge transfer in the host countries. By developing specific definitions of green FDI, this paper can remove the noise from non-green FDI and refine the estimation of how much FDI contributes to green knowledge spillovers in China.[10]

2.4 FDI Opening-up Policy in China

Which industry is opened up to FDI and how much the opening-up is allowed in China are regulated by the *Catalogue for the Guidance of Foreign Investment Industries*, compiled by the National Development and Reform Commission and Ministry of Commerce of China. Since the first edition of the Catalogue appeared in 1995, the Catalogue was modified every few years to adapt to the need of the increasingly globalised Chinese economy. Figure 3 displays the timeline of the Catalogue that develops from the first edition to the seventh edition. Each new edition of the Catalogue contains the modifications of which products become more open to FDI and which ones become less open. The several modifications of the Catalogue offer a series of policy shocks that can be used as an instrumental variable and help to identify the knowledge spillovers from green FDI. Since the sample period covers 2000-2013, this study takes advantage of the FDI changes in the 3rd edition (2002), 4th edition (2004), 5th edition (2007), and 6th edition (2011).

As displayed in Figure 3, the Catalogue regulates FDI opening-up at the product level and classifies products into four categories: (1) Products where FDI is supported;

[9]The abnormal drop in firms' assets in 2010 is probably caused by the measurement issues of production and financial variables including output, asset, sales, wages, and material inputs in the data compilation of ASIE for 2010 by the National Bureau of Statistics of China (Brandt, Van Biesebroeck, and Zhang, 2014). However, the key dependent and independent variables in this paper are constructed by the information on innovation and foreign direct investment, which are not built upon ASIE. Hence, the potential measurement issues in the data of ASIE for 2010 do not influence the estimations in this paper.

[10]The definition of green FDI used in Figure 2 is based on the first approach, i.e., text description of FDI firms' business. There are much larger discrepancies in green technologies between green and non-green FDI firms when using other green FDI definitions.

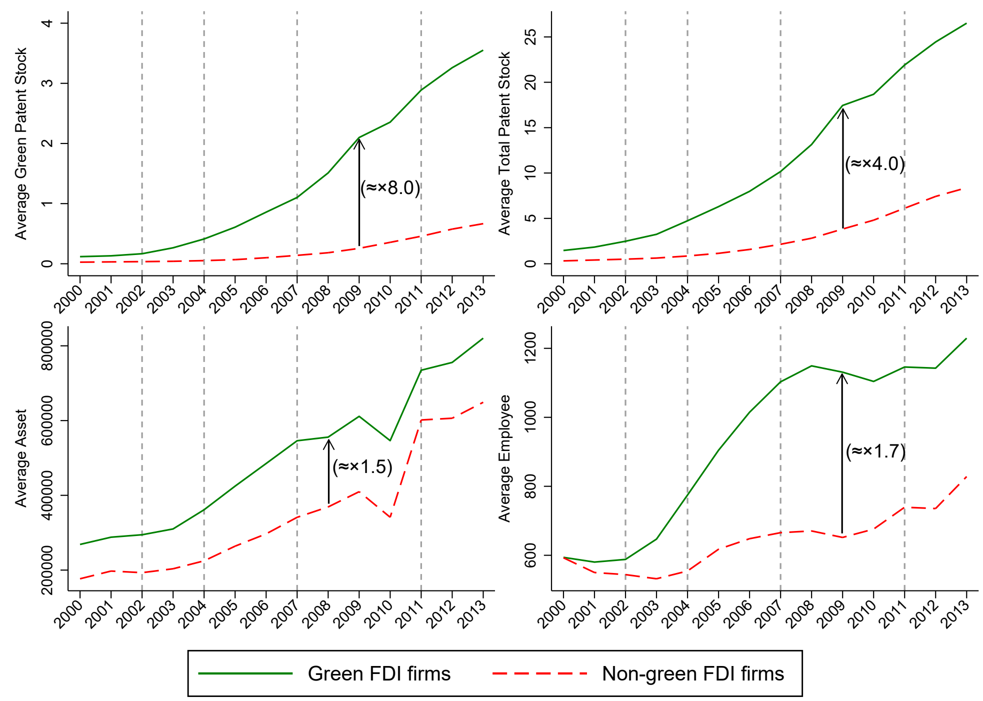

Figure 2: Green FDI vs. Non-green FDI

Notes: The four plots present the trends of the average green patent stock, average total patent stock, average asset, and average employee of green FDI firms (solid) and non-green FDI firms (dash). The four vertical lines indicate the time points of the four waves of FDI opening-up policy changes: 3rd Edition FDI Catalogue published in 2002, 4th Edition FDI Catalogue published in 2004, 5th Edition FDI Catalogue published in 2007, 6th Edition FDI Catalogue published in 2011. Each updated edition opened up more products and industries to FDI. Further details of the FDI opening-up policy changes are discussed in Section 2.4.

FDI in such products enjoys preferential investment policies such as tax credits, the lower interest of loans and the cheaper land rents. (2) Products where FDI is permitted; FDI in such products is not subject to extra restrictions. (3) Products where FDI is restricted; FDI in such products is subject to restrictions such as ownership limits or more scrutiny. (4) Products where FDI is prohibited; FDI in such products are completely banned. FDI is most welcome in product category (1) while least welcome in product category (4).

By comparing each edition of the Catalogue, I can identify whether a product becomes more open or less open to FDI. According to the changes in FDI opening-up regulations at the product level, there are three possible scenarios for each product during each modification of the Catalogue: (1) FDI becomes more open, i.e., a product is changed from a less FDI-welcome to a more FDI-welcome category. (2) FDI becomes less open, i.e., a product is changed from a more FDI-welcome to a less FDI-welcome category. (3) No change in the openness to FDI, i.e., a product does not have any change in the openness to FDI before and after a modification of the Catalogue. Since this study focuses on green FDI, I identify products relevant to environmental governance, clean production, clean energy or green technology as green products based on the Catalogue. Each green product is classified into the three possible scenarios of the change in FDI openness according to the modification of four Catalogue versions (3rd to 6th edition) during 2000-2013.

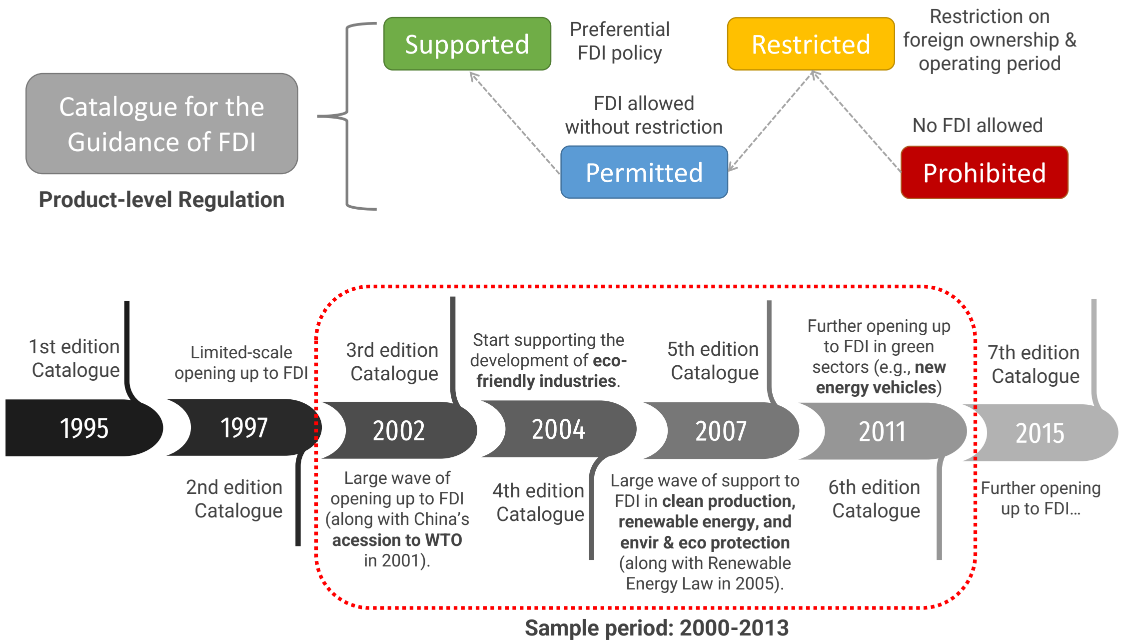

Figure 3: FDI Opening-up Policy Change in China

Notes: The Catalogue classifies products into four categories: FDI in "supported" category can enjoy preferential investment policies, FDI in "permitted" category is not subject to restrictions, FDI in "restricted" category is subject to extra investment restrictions, and FDI in "prohibited" category is not allowed. In each wave of the Catalogue update, a large number of products are moved from a less FDI-welcome category to a more FDI-welcome category, while very few products are moved from a more FDI-welcome category to a less FDI-welcome category. Our sample period (2000-2013) covers four waves of the Catalogue update (3rd, 4th, 5th, 6th edition Catalogue).

However, the changes in the Catalogue are at the product level, while the firm-level data by ASIE do not provide detailed product information of each firm but only industry classifications.[11] Hence, I need to aggregate the changes in FDI opening-up regulations from the product level to the industry level. Following Lu, Tao, and Zhu (2017), I use the Industrial Product Catalogue from the National Bureau of Statistics of China to map each product classification to the four-digit industry classification. It is worth noting that multiple products from the Catalogue may be mapped to one industry classification. Hence, the aggregation process generates four industry categories during each modification of the Catalogue:

(1) Green FDI No-change Industry: All green products mapped to the industry keep unchanged in the openness to FDI.

(2) Green FDI Encouraged Industry: For all green products belonging to the industry, there is at least one green product becoming more open to FDI, while no green products becoming less open to FDI.

(3) Green FDI Disencouraged Industry: For all green products belonging to the industry, there is at least one green product becoming less open to FDI, while no green products becoming more open to FDI.

(4) Green FDI Mixed Industry: For all green products belonging to the industry, there is at least one green product becoming more open to FDI, while also at least one green product becoming less open to FDI.

Figure 4 visualises the definition of four industry categories in a Catalogue change. Since this study covers four waves of the Catalogue changes, first, I only designate an industry as "Green FDI No-change Industry" only when all green products mapped to the industry keep unchanged in the openness to FDI throughout the four waves of the Catalogue changes. Second, an industry is classified as "Green FDI Encouraged Industry" only after at least one green product mapped to the industry becomes more open to FDI in one modification of the Catalogue, while no green product becomes less open to FDI in all later modifications of the Catalogue. Third, an industry is classified as "Green FDI

[11]Product classifications in the Catalogue for the Guidance of Foreign Investment Industries are more disaggregated than the four-digit Chinese industry classifications.

Disencouraged Industry" only after at least one green product mapped to the industry becomes less open to FDI in one modification of the Catalogue, while no green product becomes more open to FDI in all later modifications of the Catalogue. All other industries are assigned to "Green FDI Mixed Industry".

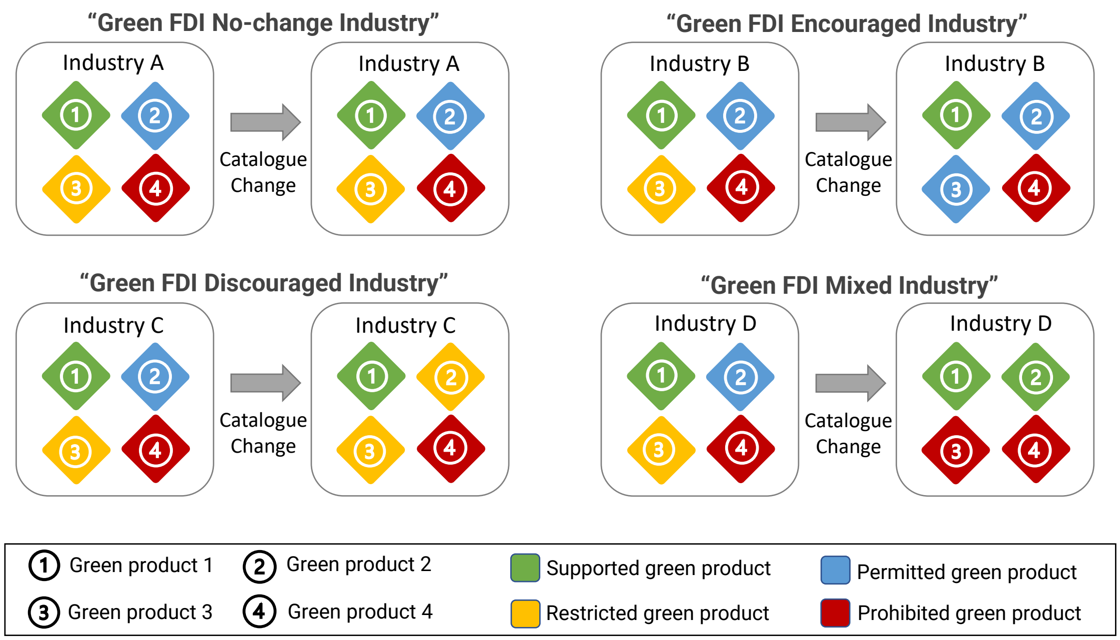

Figure 4: FDI Policy Change Aggregation from a Product Level to an Industry Level

Notes: This figure illustrates how to define the "Green FDI No-change Industry", "Green FDI Encouraged Industry", "Green FDI Disencouraged Industry", and "Green FDI Mixed Industry" based on the change of FDI openness at the product level during a wave of the Catalogue change. An industry is defined as "Green FDI No-change Industry" if all green products mapped to the industry keep unchanged in the openness to FDI. An industry is defined as "Green FDI Encouraged Industry" if it includes at least one green product becoming more open to FDI while no green product becoming less open to FDI. An industry is defined as "Green FDI Disencouraged Industry" if it includes at least one green product becoming less open to FDI while no green product becoming more open to FDI. An industry is defined as "Green FDI Mixed Industry" if it includes at least one green product becoming more open to FDI while at least one green product becoming less open to FDI. "More open to FDI" stands for a product is changed from a less FDI-welcome to a more FDI-welcome category (e.g., from restricted to permitted), and "less open to FDI" stands for a product is changed from a more FDI-welcome to a less FDI-welcome category (e.g., from restricted to prohibited).

Among the 506 four-digit Chinese industries, 293 industries do not contain any green products or contain green products that do not change the openness to FDI throughout the sample period, categorised as "Green FDI No-change Industry"; 192 industries contain green products that become more open to FDI while no green products that become less open to FDI throughout the sample period, categorised as "Green FDI Encouraged Industry"; 21 industries are categorised as "Green FDI Disencouraged Industry" or "Green FDI Mixed Industry".[12] Since this study mainly focuses on the knowledge spillover effect of green FDI on green innovation of domestic firms, the analysis only includes "Green FDI No-change Industry" and "Green FDI Encouraged Industry" and excludes the other two industry groups.

3 Empirical Strategy

3.1 Econometric Specification

In most FDI literature, the spillover effect of FDI is tested by estimating the relationship between the presence of foreign-invest firms in the host countries and the performance of other domestic firms (Aitken and Harrison, 1999; Javorcik, 2004). Following this idea, I start with the regression model that examines whether green innovation of domestic firms is enhanced by the knowledge stocks resulting from green FDI firms.[13] More specifically, for domestic firm f in four-digit industry i located in province p at year t, the baseline model is:

$$E[Y_{fipt}|GrFDIKnow_{it}, X_{ft}] = exp(\beta_0 + \beta_1 GrFDIKnow_{it} + \beta_2 X_{ft} + \gamma_f + \lambda_t + \delta_i + \eta_p), \quad (1)$$

[12]Each wave of the modification of the Catalogue for the Guidance of Foreign Investment Industries since 2002 is basically opening up more products to FDI because of the commitments made by the Chinese central government for the accession to WTO in 2001. Therefore, there are very few industries categorised as "Green FDI Disencouraged Industry" and "Green FDI Mixed Industry".

[13]One implied assumption of this specification is that green FDI brings new knowledge to foreign-invested firms, and then the knowledge stocks in those foreign-invested firms spread to other domestic firms and promote domestic green innovation. Such assumption is tested and reported in Table A2, where the results show that the entry of green FDI leads to more green innovation in foreign-invested firms except using the fourth definition of green FDI.

where Y_{fipt} denotes green innovation of domestic firm f in industry i, province p and year t, measured by the number of green patent families filed in China in the main results.[14] Domestic firm f includes firms that are only invested by domestic investors in China and do not contain any foreign-invested firms. X_{ft} is a vector of time-varying firm characteristics, including asset, employee, and sales revenue. γ_f, λ_t, δ_i and η_p denote firm, year, industry, and province fixed effects. The standard errors are clustered at the four-digit industry level. Since the dependent variable Y_{fipt} is a count variable, I use the conditional fixed effects Poisson regression (FE Poisson) and compute coefficients by Poisson Pseudo Maximum Likelihood (PPML) estimators.

$GrFDIKnow_{it}$ is the main regressor of interest, which consists of three indicators that capture how much the domestic firms in industry i are exposed to the knowledge from green FDI firms that belong to the same industry i, the downstream industries of i, and the upstream industries of i, respectively. First, the exposure of domestic firms to the knowledge from green FDI firms within the same industry i is measured by the aggregation of knowledge stocks of green FDI firms operating in industry i (named as "horizontal green FDI knowledge stocks"). Specifically, for industry i at year t, it is constructed as:

$$GrFDIKnow_{it}^{Hori} = \sum_{j \; for \; all \; j \in i} I(GrFDI_{jt}) \times GrPatStock_{jt}, \quad (2)$$

where $I(GrFDI_{jt})$ is a binary indicator equalling one if foreign-invested firm j received green FDI at year t or before (i.e., green FDI firms), and zero otherwise. $GrPatStock_{jt}$ is the stock of green patents filed by foreign-invested firm j, adjusted with a 15% yearly depreciation rate (Hall, Jaffe, and Trajtenberg, 2005). The summation of $I(GrFDI_{jt}) \times$

[14] Other green patent measures are used in the discussion on innovation heterogeneity, including the number of green invention patent families, the number of green utility patent families, the number of forward citations received by green patent families, the number of green patent families cited by patents outside China, and the number of patent family in the fields of alternative energy, sustainable transportation, and energy conservation.

$GrPatStock_{jt}$ within industry i aggregates green patent stocks of all foreign-invested firms that have received green FDI up to year t (i.e., green FDI firms).[15]

Second, the exposure of domestic firms in industry i to the knowledge from green FDI firms that belong to the downstream industries of i can help to capture how much domestic firms can benefit from the knowledge of downstream green FDI. Built upon Javorcik (2004), for domestic firms in industry i, such exposure is measured by the weighted aggregation of knowledge stocks of green FDI firms operating in all downstream industries of i (named as "downstream green FDI knowledge stocks"). For industry i at year t, it is constructed as:

$$GrFDIKnow_{it}^{Down} = \sum_{k\ if\ k\neq i} \alpha_{ik} GrFDIKnow_{kt}^{Hori} \tag{3}$$

where k stands for a downstream industry of industry i. $GrFDIKnow_{kt}^{Hori}$ is the knowledge stocks of green FDI firms operating in i's downstream industry k at year t. As one industry i can have multiple downstream industries, the knowledge stocks of green FDI firms in each downstream industry need to be further aggregated to measure the total exposure of domestic firms in industry i to knowledge from downstream green FDI. The weight α_{ik} determines the importance of each downstream industry k to industry i's selling activities, representing the share of industry i's output supplied to its downstream industry k.

Third, for domestic firms in industry i, their exposure to the knowledge of upstream green FDI can be measured by the weighted aggregation of knowledge stocks of green FDI firms operating in all upstream industries of i (named as "upstream green FDI knowledge

[15]The term $I(GrFDI_{jt}) \times GrPatStock_{jt}$ reflects the stock of green patents filed by foreign-invested firm j at year t given that firm j has received green FDI up to year t. If a foreign-invested firm j has not received green FDI up to year t, $I(GrFDI_{jt}) \times GrPatStock_{jt}$ would be zero. In other words, the summation does not take into account the green patent stocks of foreign-invested firms that have not received green FDI up to year t, as their $I(GrFDI_{jt}) \times GrPatStock_{jt}$ are zero.

stocks"). Similarly, such exposure can be constructed as:

$$GrFDIKnow_{it}^{Up} = \sum_{m\ if\ m \neq i} \beta_{im} GrFDIKnow_{mt}^{Hori} \tag{4}$$

where m stands for an upstream industry of industry i. $GrFDIKnow_{mt}^{Hori}$ is the knowledge stocks of green FDI firms operating in i's upstream industry m at year t. Similar to the previous case in Eq (3), since one industry can have multiple upstream industries, the knowledge stocks of green FDI firms in each upstream industry need to be further aggregated to measure the total exposure of domestic firms in industry i to knowledge from upstream green FDI. The weight β_{im} is used to determine the importance of each upstream industry m to industry i's purchase activities, representing the share of industry i's input purchased from its upstream industry m. The input-output linkage between industries is obtained from China's 2007 Input-Output Table.[16]

$GrFDIKnow_{it}$ represents $GrFDIKnow_{it}^{Hori}$, $GrFDIKnow_{it}^{Down}$, and $GrFDIKnow_{it}^{Up}$. Hence, the coefficient β_1 in Eq (1) captures the relationship between domestic firms' green innovation and knowledge stocks of green FDI firms that belong to the same industry i, to industry i's downstream industries, and to industry i's upstream industries, respectively. However, this relationship cannot be interpreted as the impacts of green FDI yet as $GrFDIKnow_{it}^{Hori}$, $GrFDIKnow_{it}^{Down}$, and $GrFDIKnow_{it}^{Up}$ are not uncorrelated with the error term, even conditional on a group of control variables and fixed effects.[17]

To tackle the endogeneity issue, inspired by Lu, Tao, and Zhu (2017), I resort to the variations across industries in the changes of FDI opening-up policy in China as an instrumental variable for the knowledge stocks of green FDI firms. The instrumental

[16]The inter-industry Input-Output Table in China is published every five years. Considering the sample period covers 2000-2013, this study uses the input-output information in the middle point of the sample period in the analysis.

[17]For example, the decision of whether a green FDI enters an industry in China might be driven by a selective strategy based on their own and the invested entities' competitiveness. Additionally, the increase in knowledge stocks of green FDI firms could also be influenced by the innovation capacities of domestic firms rather than solely relying on knowledge from foreign investors.

variable serves as a quasi-random shock that determines whether a larger scale of green FDI enters a specific industry and consequently leads to more knowledge stocks of green FDI firms within the industry.[18] Specifically, industry i is assigned to the treatment group if it is categorised as the "Green FDI Encouraged Industry", and assigned to the control group if it is categorised as the "Green FDI No-change Industry", based on the category definition in Section 2.4. The treatments occur in 2002, 2004, 2007 and 2011, by the timeline of the four waves of the FDI Catalogue changes in China. For the endogenous variable $GrFDIKnow_{it}^{Hori}$, the first-stage estimation of the instrumental variable is based on a difference-in-differences (DID) strategy:

$$GrFDIKnow_{it}^{Hori} = \beta_0 + \beta_1 GrFDIOpen_{it}^{Hori} + \beta_2 X_{ft} + \gamma_f + \lambda_t + \delta_i + \eta_p + \varepsilon_{fipt}, \quad (5)$$

where $GrFDIOpen_{it}^{Hori}$ is a binary variable that indicates whether industry i is categorised as a "Green FDI Encouraged Industry" at year t. The intuition behind the instrumental variable is that an industry i receives more green FDI if green products in this industry become more open to FDI, and consequently the domestic firms are more exposed to the knowledge stocks of green FDI firms within the same industry i.

The instrumental variable for the knowledge stocks of green FDI firms in downstream industries $GrFDIKnow_{it}^{Down}$ can be constructed by computing the overall openness of green FDI in industry i's downstream industries, similar to Eq (3). Specifically, $GrFDIOpen_{it}^{Down} = \sum_{k\ if\ k \neq i} \alpha_{ik} GrFDIOpen_{kt}^{Hori}$, where α_{ik} represents the weights of industry i's exposure to its each downstream industry k. Similarly, the instrumental variable for the knowledge stocks of green FDI in upstream industries $GrFDIKnow_{it}^{Up}$ can be constructed as: $GrFDIOpen_{it}^{Up} = \sum_{m\ if\ m \neq i} \beta_{im} GrFDIOpen_{mt}^{Hori}$, where β_{im} represents the weights of industry i's exposure to its each upstream industry k. With controlling the endogeneity of $GrFDIKnow_{it}$ by using instrumental variables, the coefficient β_1 in Eq (1)

[18] The decision regarding whether an industry becomes more open to green FDI is determined by the previous negotiation of China's accession to WTO and high-level government policies. These factors are much less influenced by the strategies of foreign investors or the capacities of invested domestic firms.

captures the impacts of knowledge stocks resulting from green FDI firms on domestic firms' green innovation. Such impacts by green FDI firms' knowledge stocks from the same industry (as domestic firms), downstream industries, and upstream industries can be interpreted as the knowledge spillover effects of green FDI via horizontal, downstream and upstream linkages, respectively.

Table 1: Summary Statistics

Variables	N	Mean	SD	Min	Max
Panel A: Innovation Indicator					
Total Patent Family Count	387059	0.824	24.300	0.000	5607
Green Patent Family Count	387059	0.104	4.504	0.000	2023
Total Patent Family Citation	387059	2.265	126.200	0.000	35059
Green Patent Family Citation	387059	0.305	11.100	0.000	2229
Panel B: Green FDI Knowledge Stock					
Horizontal GrFDI Know (Text)	387059	28.330	116.000	0.000	1971
Horizontal GrFDI Know (GrPat)	387059	52.290	142.000	0.000	2020
Horizontal GrFDI Know (GrPatOutCN)	387059	34.800	124.900	0.000	1933
Horizontal GrFDI Know (FIGrPatCN)	387059	3.292	20.070	0.000	254.4
Downstream GrFDI Know (Text)	387059	24.300	41.470	0.000	384.7
Downstream GrFDI Know (GrPat)	387059	44.450	70.350	0.000	550.7
Downstream GrFDI Know (GrPatOutCN)	387059	31.380	58.000	0.000	526.8
Downstream GrFDI Know (FIGrPatCN)	387059	4.284	9.345	0.000	143.9
Upstream GrFDI Know (Text)	387059	21.190	38.960	0.013	431.6
Upstream GrFDI Know (GrPat)	387059	36.230	59.930	0.121	528.1
Upstream GrFDI Know (GrPatOutCN)	387059	24.700	48.950	0.002	467.7
Upstream GrFDI Know (FIGrPatCN)	387059	1.448	3.407	0.000	48.02
Panel C: Other Firm Atrributes					
Firm Age	386089	26.340	13.750	3.000	66
Output (1 million Yuan)	356787	286.200	2562.000	0.001	258799
Asset (1 million Yuan)	386077	300.400	3015.000	0.001	276431
Sale Revenue (1 million Yuan)	386078	283.500	2750.000	0.001	258206
Employee	384310	517.000	2450.000	1.000	161654

Notes: Panel A shows the indicators of innovation. Panel B presents the knowledge stocks of green FDI by different definitions and channels. In Panel B, *Horizontal* denotes the knowledge stocks resulting from green FDI firms within the same industry, *Downstream* indicates the knowledge stocks resulting from green FDI firms in downstream industries, and *Upstream* represents the knowledge stocks resulting from green FDI firms in upstream industries. "Text" denotes the first green FDI definition: whether the text description of FDI business scope includes keywords related to environmental governance, clean production, clean energy, or green technology. "GrPat" is the second green FDI definition: whether FDI firms own green patents. "GrPatOutCN" stands for the third green FDI definition: whether FDI firms own green patents that cite prior arts from foreign countries. "FIGrPatCN" represents the fourth green FDI definition: whether FDI firms' foreign investors have filed green patents in China. Panel C reports other firm-level attributes.

Table 1 presents the summary statistics of key variables in the following analyses, including innovation indicators, measures of knowledge stocks of green FDI, and other firms' characteristics. Panel A shows that green patents take around 10% to 20% of total patents in each firm on average, and the low value of means and much larger standard deviations suggest that a large share of domestic firms do not have patenting activities. The fact that patenting activities happen at a small group of firms further justifies the use of Poisson regression rather than OLS for estimation of the baseline model Eq (1). Panel B displays the difference in the knowledge stock of green FDI firms across different green FDI definitions. In the main analyses, I focus on the green FDI definition based on the "Text" approach, i.e., defined by the text description of FDI business scope. Results of using other green FDI definitions are discussed in the robustness checks. Panel C shows that firms in the sample are relatively large, with total assets equivalent to around 300 million Yuan and output equivalent to around 286 million Yuan. Such large sizes result from the fact that ASIE mostly covers firms above annual sales above 5 million Yuan rather than small size firms in China. Therefore, the conclusion of this paper is more applicable to the knowledge spillover effects on large size domestic firms in the host countries, and one should be cautious in extrapolating the conclusion to small size domestic firms.

3.2 Validity of Instrumental Variable

The validity of the DID instrumental variable heavily relies on the exclusion restriction condition, which requires: (1) the green products opened up to FDI are randomly selected in the FDI opening-up policy; (2) no other major channels through which the FDI opening-up policy affects the domestic firms' green innovation other than the increasing presence of green FDI firms' knowledge stocks.

Unfortunately, the selection of when and which green products become more open to FDI is likely to be non-random. One defence for the quasi-random selection of products is that the FDI opening-up policy in China was generally aligned with the agreement from lengthy negotiations of China's accession to WTO, which was not largely determined by China and still uncertain prior to the accession (Lu, Tao, and Zhu, 2017; Chen et al., 2022). However, the Chinese government might still wield considerable influence on the implementation of the opening-up policy and cherry-pick specific green products to be opened up at specific desired timelines due to specific industrial factors.[19] In such cases, the selection of whether and when a green product is opened up to FDI is not random, and the validity of the instrumental variable is impaired.

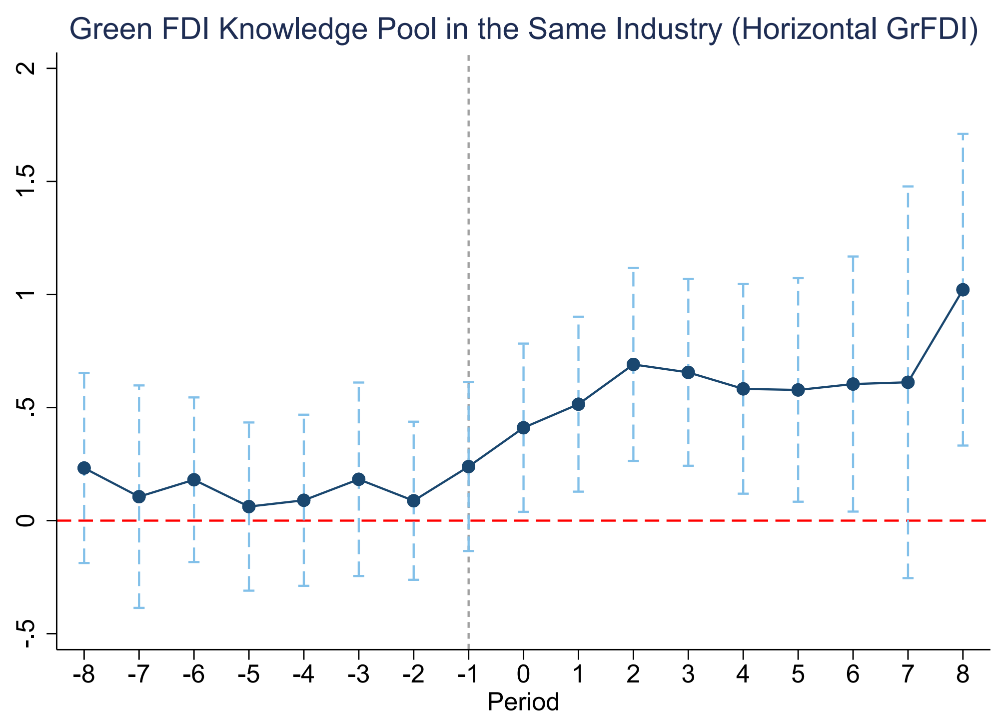

Figure 5: Dynamic Effect of Green FDI Opening-up Policy Changes

Notes: Dependent variable is the knowledge stocks of green FDI firms in the same industry (Horizontal GrFDI), which is measured in logarithms. The dot indicates the point estimates for each period before and after the industry-level green FDI opening-up policy changes, i.e., if the industry becomes "Green FDI Encouraged Industry" (includes green products more opened up to FDI while no green products less opened up to FDI during FDI regulation changes). The intercept indicates the 95% confidence interval. The estimation is based on the two-stage DID strategy designed by Gardner (2022). Specific numbers of coefficients are shown in Table A5.

I adopt two strategies to alleviate this concern. First, I conduct an event study and

[19]For instance, if there is an important technology discovery regarding a green product in a particular industry, the government might choose to protect that industry for a longer period and therefore delay its opening-up to green FDI. Moreover, other green industrial policies promoting domestic green innovation could also lead to a synergistic effect, impacting the timing of opening-up to green FDI.

plot the dynamic effects based on the DID model in Eq (5), to examine whether there is a significant difference in green FDI firms' knowledge stocks between the treatment and control groups prior to the time points when an industry encourages green FDI. It is worth noting that the DID model in Eq (5) is a staggered DID setting, under which the coefficients of the treatments may not be reliable measures of the treatment effects if directly estimated by the ordinary least squares (OLS) (Borusyak and Jaravel, 2017; Callaway and Sant'Anna, 2021; Sun and Abraham, 2021; Gardner, 2022). I use the two-stage DID strategy designed by Gardner (2022) to estimate the dynamic effects of Eq (5).[20] The estimated coefficients over periods before and after the treatments are displayed in Figure 5. The plot indicates that the treatment and control groups are balanced in green FDI firms' knowledge stocks in the pre-treatment periods. In contrast, the treatment group experiences a gradual and persistent increase in green FDI firms' knowledge stocks in the post-treatment periods and generates a significant difference compared with the control group. The specific magnitude of corresponding coefficients is displayed in Table A5.

Second, inspired by Gentzkow (2006), I control for industrial factors that explain as much as possible whether an industry encourages green FDI (i.e., the selection of the treatment group).[21] However, a manual search and selection of key industrial factors involve considerable subjective judgement, which cannot well ensure most of the key determinants are covered. I resort to the least absolute shrinkage and selection operator (LASSO) to perform an automatic variable selection, to largely avoid the subjective bias in the selection of key factors. Specifically, I add to the model 14 pre-open (prior to 2002,

[20]The two-stage DID requires a clear binary DID setting as the estimation in the first stage is targeted to the units never treated. However, it is unable to apply this strategy to the indicators of the openness to downstream and upstream green FDI $GrFDIOpen_{it}^{Down}$ and $GrFDIOpen_{it}^{Up}$ because they are the aggregations of the treatment variables across multiple downstream and upstream industries. I therefore compare the results of the horizontal knowledge spillover effects between the conventional DID and two-stage DID, which are shown in Table A3 in the Appendix. The horizontal spillover results of the two-stage DID are very close to the results of conventional DID, which suggests the results of downstream and upstream knowledge spillover effects can be reliable even if they are unable to be estimated by the two-stage DID strategy.

[21]While it may not completely eliminate the possibility of other policy confounders, this approach can control for the majority of potential confounders that influence the selection of the treatment assignment and enhance the exogeneity of the estimation as much as possible.

i.e., the first wave of the Catalogue change during the sample period 2000-2013) industry-level factors that have abundant pre-open observations and capture most of the important dimensions of industrial development.[22] The variable selection process ultimately singles out 8 industrial factors as the key determinants (number of firms, output, average number of employees, average wage, HHI, new product intensity, R&D expense, and green patent stock), which possess the largest explanatory power to the selection of the treatment group while avoiding the overfitting of the model.[23] Then I add the interaction terms between year fixed effects λ_t and the 8 industry-level key determinants in pre-open periods (average in 2000 and 2001) to the regression models to control for endogenous selection of which industry encourages green FDI.[24] The results are discussed in the robustness checks and do not challenge the conclusion.

There is another considerable concern that the FDI opening-up policy may affect the domestic firms' green innovation via other channels beyond the increasing presence of green FDI firms' knowledge stocks. For example, when an industry encourages green FDI, it not only increases the knowledge stocks of green FDI firms but also the knowledge stocks of non-green FDI. The non-green FDI firms' knowledge stocks may indirectly influence domestic firms' green innovation. To control this additional channel, I construct the

[22]The 14 industry factors include the number of firms, the average age of firms, output, sales, capital, the average number of employees, average wage per employee, new production intensity, export, export intensity, Herfindahl-Hirschman Index (HHI), R&D expense, total patent stock, green patent stock. They are taken average over 2000 and 2001.

[23]Among three major methods of the LASSO, I choose the adaptive method because it provides nearly the lowest deviance while further reducing the overfitting issue compared with the cross-validation method. The plug-in method does not perform well in the variable selection.

[24]There are two reasons of adding the interactions between year fixed effects and pre-open key determinants rather than directly adding the time-varying key determinants as controls to the model: (1) Some key determinants have missing values in several periods (e.g., R&D expense, export), and therefore using these time-varying control variables will largely shrink the observations. (2) These time-varying key determinants are very likely to be also affected by the treatments. Such reverse impacts by the treatments may open new spurious paths between the treatments and the outcomes and therefore deliver poorer estimates of the causal effects, which is known as the "bad control" problem (Zeldow and Hatfield, 2021; Callaway, 2022; Caetano et al., 2022). Hence, adding more time-varying control variables probably affected by the treatments leads to higher possibilities of bringing in extra biases of the estimations. The strategy of using interaction terms not only confine key determinants to pre-treatment periods but also takes into account the changes of key determinants in future periods, which is an alternative way to capture the time-variation of key controls while avoiding the "bad control" problem.

knowledge stocks of non-green FDI firms in the horizontal, downstream, and upstream industries.[25] Then I add the measures of the non-green FDI firms' knowledge stocks as additional covariates to the regression models, to control for the possible impacts via the non-green FDI channel.

The second possible channel is associated with firm sorting behaviour. Firms may decide to adjust their operating industries in response to the FDI policy changes when certain industries become more open to FDI. The green innovation of domestic firms is likely to be influenced by some firms moving in or out of certain industries. I remove all of the firms that change industries throughout the sample period to avoid the possible channel via the firm sorting behaviour. I discuss the robustness checks of the two tests that eliminate additional channels through which the FDI opening-up policy may affect domestic firms' green innovation, and the two tests do not change the main results.

4 Empirical Results

4.1 Main Results

Table 2 summarises the main results for the knowledge stocks of green FDI and green innovation of domestic firms. I start with estimating the baseline model Eq (1) without using the instrumental variables. Columns (1) to (3) reports the correlation between green FDI firms' knowledge stocks and domestic firms' green patent family count. The explanatory variable in Columns (1) to (3) represents the knowledge stocks of green FDI firms in the same (horizontal) industry, the downstream industries, and the upstream industries, respectively. The coefficients in the first three columns are statistically insignificant and seemingly indicate that domestic green innovation is not associated with knowledge resulting from green FDI firms. However, the coefficients in Columns (1) to (3) do not tease

[25] The construction of non-green FDI knowledge stocks is similar to Eq (2), (3), and (4), and the only change is the binary indicator from $I(GrFDI_{jt})$ to $I(NonGrFDI_{jt})$, which denotes if foreign-invested firm j having received non-green FDI at year t.

out the impacts of green FDI firms' knowledge stocks but contain many unclear factors that both influence green FDI and domestic green innovation, even if conditional on a group of control variables and fixed effects. Such endogeneity problems create difficulties in identifying how much green FDI firms' knowledge stocks affect domestic firms' green innovation.

Table 2: Knowledge Stocks of Green FDI Firms and Green Innovation of Domestic Firms

Dependent Variable:	Green Patent Family Count					
Knowledge Stock of:	Horizontal GrFDI (1)	Downstream GrFDI (2)	Upstream GrFDI (3)	Horizontal GrFDI (4)	Downstream GrFDI (5)	Upstream GrFDI (6)
					Second-stage Estimation	
GrFDI Know	0.148	0.026	0.237	0.000	0.732**	2.512*
	(0.091)	(0.149)	(0.236)	(0.263)	(0.357)	(1.393)
Observations	51,296	51,296	51,296	51,296	51,296	51,296
					First-stage Estimation Dependent Variable: GrFDI Know	
GrFDI Open				0.845***	1.570***	0.376*
				(0.157)	(0.385)	(0.208)
Observations				384,297	384,297	384,297
CD Wald F-statistic				33165	55003	15849
KP Wald F-statistic				29.07	16.60	9.131
Estimation	Poisson	Poisson	Poisson	Poisson&IV	Poisson&IV	Poisson&IV
Firm Controls	Y	Y	Y	Y	Y	Y
Firm FE	Y	Y	Y	Y	Y	Y
Year FE	Y	Y	Y	Y	Y	Y
Industry FE	Y	Y	Y	Y	Y	Y
Province FE	Y	Y	Y	Y	Y	Y

Notes: Dependent variable is firm green patent family count. Columns (1) to (3) show results for Poisson regression. $GrFDIKnow$ is classified into three types: the knowledge stocks of green FDI firms in the same industry (Horizontal GrFDI), in downstream industries (Downstream GrFDI), and upstream industries (Upstream GrFDI). All knowledge stocks indicators are in logarithms. Columns (4) to (6) show results for two-stage IV estimation: the first-stage estimation is OLS, and the second-stage estimation is Poisson regression. $GrFDIOpen$ is the instrumental variable used in the first-stage estimation and captures if the same industry (Horizontal GrFDI), downstream industries (Downstream GrFDI), and upstream industries (Upstream GrFDI) are identified as "Green FDI Encouraged Industry" (i.e., includes green products more opened up to FDI while no green products less opened up to FDI during FDI regulation changes). CD Wald F-statistic denotes Cragg-Donald Wald F-Statistic, and KP Wald F-statistic denotes Kleibergen-Paap rk Wald F-statistic. Stock-Yogo critical values for weak identification test (Cragg-Donald and Kleibergen-Paap rk Wald F statistics) are 16.38 at 10% and 8.96 at 15% maximal IV size. All columns contain firm control variables, firm fixed effects, year fixed effects, industry fixed effects, and province fixed effects. Standard errors in the parentheses are clustered at the industry level. ***, **, *, indicate significance at 1% level, 5% level, and 10% level, respectively.

Therefore, I correct the endogeneity problems by using instrumental variables of green FDI firms' knowledge stocks. The corresponding results are reported in Columns (4) to (6) of Table 2. The explanatory variable in the first-stage estimation captures the openness of an industry covering green products to FDI after the changes in the FDI opening-up policy in China. Column (4) in the first-stage estimation shows that the instrument $GrFDIOpen_{it}^{Hori}$ has a positive and statistically significant effect on $GrFDIKnow_{it}^{Hori}$, confirming the relevance of the instrument that more knowledge stocks of green FDI firms exist in an industry if this industry becomes more open to green FDI. Moreover, I report the Cragg-Donald Wald F-statistic and Kleibergen-Paap rk Wald F-statistic to detect the weak instrumental variable problem. Cragg-Donald Wald F-statistic is valid when errors are independent and identically distributed (i.i.d), while Kleibergen-Paap rk Wald F-statistic is valid when errors are not i.i.d. The result in Column (4) shows that the Cragg-Donald statistic and Kleibergen-Paap statistic are both larger than the 10% critical value by Stock and Yogo (2002), rejecting the null hypothesis that the instrumental variable for horizontal green FDI firms' knowledge stocks is subject to the weak IV problem. After being instrumented, the explanatory variable of Column (4) in the second-stage estimation identifies the impact of green FDI firms' knowledge stocks on domestic firms' green patent counts. The coefficient suggests that knowledge stocks of green FDI within the same industry has an insignificant effect on the green innovation of domestic firms. The muted horizontal knowledge spillover effects of green FDI echoes the mixed conclusions in the existing literature of whether domestic firms benefit from or suffer from FDI in the same industry. (Aitken and Harrison, 1999; Javorcik, 2004; Newman et al., 2015; Lu, Tao, and Zhu, 2017; Chen et al., 2022). On one hand, domestic firms may benefit from foreign entrants by observing, imitating, or reverse-engineering the new products and technologies brought by FDI. On the other hand, the entry of FDI may crowd out domestic firms in the market due to the advantages of new products or technologies and lead to the market-stealing effect. The two simultaneous but opposite effects may be offset and lead to an insignificant effect of knowledge stocks resulting from green FDI firms within the same industry.

Column (5) reports the results for knowledge stocks of green FDI firms in downstream industries. After being instrumented, the coefficient in Column (5) in the second-stage estimation reports a positive and statistically significant effect of green FDI firms' knowledge stocks from downstream industries on domestic firms' green patents. This finding suggests the knowledge spillovers from downstream green FDI to domestic firms and a 1% increase in downstream green FDI firms' knowledge stocks can lead to roughly 0.732% increase in green patents of domestic firms.[26] Such finding implies that domestic firms can benefit from green FDI firms' knowledge by becoming suppliers to green FDI firms, which echoes some flagship industrial policies in China, such as public procurement and local content requirement in renewable energy industries. Although not specialising in green products initially, Chinese domestic firms took advantage of their lower cost of manufacturing and entered the supply chains as suppliers of components to foreign companies. During the integration into the supply chains of green products, domestic firms can benefit from absorbing green knowledge resulting from FDI firms. This process helps domestic firms gradually build up their own green innovation capacities, take a more important role in the supply chains, develop new green products with more competitiveness, and ultimately dominate local and penetrate global green markets.

Column (6) presents the results for knowledge stocks of green FDI firms in upstream industries. In the first-stage estimation, the coefficient shows a much weaker correlation between the openness of upstream industries to green FDI $GrFDIOpen_{it}^{Up}$ and the knowledge stocks of green FDI firms in upstream industries $GrFDIKnow_{it}^{Up}$. Although the Cragg-Donald statistic is larger than the 10% critical value, the Kleibergen-Paap statistic is only larger than the 15% critical value but smaller than the 10% critical value. The Kleibergen-Paap statistic offers a more valid test as the standard errors in my regression are clustered at the industry level and are not i.i.d. The weak identification test raises

[26]Since the independent variable is transformed into the logarithm and the estimated model is Poisson regression, the estimated coefficients can be interpreted as the elasticity of the outcome variable (domestic firms' green patents) with respect to the independent variable (green FDI firms' knowledge stocks).

the concern of the weak instrumental variable problem for the knowledge stocks of green FDI firms in upstream industries. After being instrumented, the coefficient in Column (6) displays a slightly positive and statistically significant effect of upstream green FDI firms' knowledge stock on domestic firms' green innovation. This finding indicates that domestic firms may learn green technologies embedded in the intermediate goods supplied by green FDI firms. The inputs supplied by upstream green FDI may be accompanied by additional services or technical supports that also facilitate the knowledge absorption of domestic customers and users. Such learning may as well generate green knowledge spillovers from foreign-invested suppliers to domestic firms. However, the possible existence of the weak instrumental variable problem threatens the solidity of the estimation and reminds the caution in concluding the knowledge spillovers from upstream green FDI. Further tests are conducted in the robustness checks.

4.2 Robustness Checks

I conduct a battery of robustness checks on the main results to examine the stability of the coefficient estimates.

Non-random instrumental variables. As discussed in Section 3.2, the selection of when and which industries become more open to green FDI may be non-random and violates the parallel trend assumption of using the DID instrumental variable. I use two strategies to tackle this issue. First, I conduct an event study to check if there is a significant difference in the pre-treatment periods. Figure 5 shows the estimated coefficients across periods. There is no evidence of significant difference existing in the pre-treatment periods, which provides support for the parallel trend assumption. Second, I use the LASSO to extract key determinants that sufficiently explain the non-random selection in which industries become more open to green FDI during the changes in the FDI opening-up policy. Then I add interaction terms between year fixed effects and the key determinants to control for endogenous selection of the treatment group while avoiding the "bad control" problem as far as possible. The corresponding results, shown in Table A6, are similar to the main results in Table 2.

Instrumental variables affecting outcomes via other channels. The instrument, the FDI opening-up policy, may affect domestic firms' green innovation via the other channels beyond the key endogenous variable green FDI firms' knowledge stocks, according to the discussion in Section 3.2. My robustness checks eliminate two typical channels to alleviate this concern. First, I add the measures of the non-green FDI firms' knowledge stocks as additional controls to remove the possible effect of the FDI opening-up policy on the outcomes via non-green FDI. The corresponding results are shown in Table A7. The results are generally similar to the main results in Table 2, except the insignificant coefficient of the instrumental variable $GrFDIOpen_{it}^{Up}$ for upstream green FDI firms' knowledge stocks $GrFDIKnow_{it}^{Up}$ in Column (3). The insignificant coefficient of the instrument in Column (3) and the Kleibergen-Paap statistic much lower than the 15% critical value suggest the weak instrumental variable problem for upstream green FDI knowledge stocks and hinder the further interpretation of knowledge spillovers from upstream green FDI. Second, I remove firms that change industries during the sample period to eliminate the possible effect of the FDI opening-up policy on the outcomes via firms' sorting behaviour. Such robustness test is based on the concern that some firms may adjust their operating industries in response to the openness of certain industries to green FDI, and ultimately influence green innovation of domestic firms. The corresponding results are reported in Table A8. The robustness check further supports the evidence of knowledge spillover effects of green FDI in downstream industries on domestic firms' green innovation.

Controlling for Subsidies. Some literature finds that a large scale of subsidy programmes are launched by Chinese central and local governments to support R&D activities of domestic firms (Li, 2012; Haley and Haley, 2013). Particularly, many subsidy programmes are targeted to renewable energy sectors such as solar and wind energy and catalyse firms' investment in the relevant technologies (Wang, Qin, and Lewis, 2012; Xiong and Yang, 2016). These subsidy programmes boost domestic firms' generic and green innovation while probably also affecting green FDI firms' knowledge stocks. Omitting such an important policy confounder may bias the results when I estimate the knowledge spillover effects of green FDI on domestic firms' green innovation. To relieve this concern, I include the total amount of subsidies that each firm receives as an additional control variable in the regressions.[27] The corresponding results are shown in Table A9. Although the sample size shrinks due to the incomplete coverage of firm-level subsidy information, the estimated coefficients are similar to the main results and do not change the conclusion.

Alternative thresholds of foreign ownership. The knowledge spillover effects of green FDI may vary due to the ratio of foreign ownership in green FDI firms. Two important ownership thresholds may have influences. First, a foreign-invested firm with foreign ownership less than 25%, though contains foreign investment, is not entitled to preferential corporate taxation offered for FDI according to China's Foreign Investment Law. This difference in the FDI preferential policy may impact the knowledge spillover effects of green FDI. I therefore reconstruct the knowledge stocks of green FDI by defining $I(GrFDI_{jt}) = 1$ if foreign-invested firm j is identified as a green FDI firm and has foreign ownership greater than 25% at year t in Eq (2). The corresponding results are reported in Columns (1) to (3) of Table A10. Second, the majority foreign ownership (greater than 50%) can ensure the foreign investors' absolute control in the operation and management of FDI firms. This controlling position may alleviate the worries of foreign investors about the enforced technology transfer to domestic partners and impact the green knowledge spillovers via FDI. To capture the knowledge stocks of green FDI firms under the majority foreign ownership, I re-define that $I(GrFDI_{jt}) = 1$ only if foreign ownership greater than

[27]It would be ideal to extract each specific subsidy policy regarding R&D and green sectors in China, but Chinese subsidy policies are implemented by governments at different levels and it is very challenging to collect data on a wide variety of subsidy programmes. Moreover, there is currently no available firm-level dataset that differentiates the subsidies based on the purposes of subsidies. Although not perfect, firms' total amount of subsidies can still be a feasible proxy that to some extent controls the effect of subsidies on domestic firms' green innovation.

50% in the construction of green FDI firms' knowledge stocks. The corresponding results are reported in Columns (4) to (6) of Table A10. The coefficients in Columns (2) and (5) further support the main results that the knowledge stocks of downstream green FDI firms generate knowledge spillovers to domestic firms, while results in Columns (3) and (6) further warn that the upstream green FDI may not generate clear knowledge spillovers.

Alternative definitions of green FDI. This study constructs four approaches to defining green FDI as discussed in Section 2.3. I use the first approach to define green FDI in the main analyses, i.e., keywords searching in the text description of foreign-invested firms' business. To check the robustness, I use other developed definitions to define green FDI and reconstruct the knowledge stocks of green FDI firms. Specifically, I use the second approach (whether foreign-invested firms own green patents), third approach (whether foreign-invested firms own green patents that cite prior arts from foreign countries), fourth approach (whether foreign investors have filed green patents in China), and the intersection of the first and second approach to defining green FDI in $I(GrFDI_{jt}) = 1$ from Eq (2), respectively. The corresponding second-stage estimation results are presented in Table A11. The coefficient estimates based on different green FDI definitions, though vary in coefficient magnitude, do not significantly change the main conclusion.

4.3 Heterogeneity of Innovation

In this subsection, I investigate the knowledge spillover effects of green FDI on the quality of domestic green innovation, and on innovation in different technological fields.

There are three categories under the Chinese patent system: invention, utility model, and design patents (Wei, Xie, and Zhang, 2017). The invention patent requires a more substantial improvement related to practical, inventive, and new technical innovations. The utility model patent corresponds to the improvement in technical solutions to the shape or structure of an object. The design patent only involves the external appearance of products. Among the three categories, the invention patent contains the highest requirement of novelty, and inventiveness, which stands for a higher quality than other categories. I distinguish green invention and utility model patents as separate dependent variables.[28] With the number of green invention and utility model patent families as dependent variables, Panel A and B in Table 3 report the corresponding results. The coefficients in Column (2) indicate that the knowledge stocks of green FDI firms in downstream industries promote domestic firms' green invention patents but do not has a clear effect on green utility patents. This finding suggests that the knowledge spillovers from downstream green FDI contribute more to the most innovative green patents of domestic firms.

The number of forward citations received by patents is another widely-used indicator of patent quality (Hall, Jaffe, and Trajtenberg, 2005). Hence, I use the domestic firms' green patent family citations as the dependent variable to examine how knowledge stocks of green FDI affect domestic green innovation quality. The corresponding results are kept in Panel C of Table 3. The positive and statically significant coefficient in Column (2) suggests that downstream green FDI firms' knowledge stocks promote domestic high-quality green innovation.

Although overall citations can reflect the value of patents, the citations across borders may indicate a distinct value compared with the citations within borders because the cross-border citations imply a wider applicability and commercial value. Particularly, most of the Chinese patents are only used within China and do not contribute much to the global technology frontier. This also casts a doubt on the quality of Chinese patents. To better capture the quality of green innovation, I extract green patent families that receive citations outside China, which indicates a clear technology diffusion across borders. Panel D in Table 3 shows the results. The similar results as Panel C further justify the knowledge spillover effects of downstream green FDI.

Due to the variance in innovation features and business models, green FDI firms'

[28]The design patent is not related to environmental governance, clean production, climate mitigation or adaptation functionality. Hence, the analysis excludes the design patent.

Table 3: Heterogeneity of Green Innovation Quality

Knowledge Stock of: *Second-stage Estimation*	Horizontal GrFDI (1)	Downstream GrFDI (2)	Upstream GrFDI (3)
Panel A: Dependent Variable: Green Invention Patent Family			
GrFDI Know	0.139	1.305*	4.086**
	(0.383)	(0.673)	(1.833)
Observations	30,581	30,581	30,581
Panel B: Dependent Variable: Green Utility Patent Family			
GrFDI Know	0.007	0.101	1.383
	(0.199)	(0.370)	(1.388)
Observations	39,080	39,080	39,080
Panel C: Dependent Variable: Green Patent Family Cititation			
GrFDI Know	0.285	0.877***	4.011***
	(0.260)	(0.313)	(1.325)
Observations	43,145	43,145	43,145
Panel C: Dependent Variable: Green Patent Family Cited by Patents outside China			
GrFDI Know	0.450	1.186***	4.144**
	(0.320)	(0.330)	(1.816)
Observations	12,356	12,356	12,356
Firm FE	Y	Y	Y
Year FE	Y	Y	Y
Sector FE	Y	Y	Y
Province FE	Y	Y	Y

Notes: Panel A shows the results for the second-stage estimation, which is Poisson regression. Dependent variable is firm green invention patent family count in Panel A, green utility patent family count in Panel B, green patent family citation in Panel C, and green patent family cited by patents outside China in Panel D. $GrFDIKnow$ is classified into three types: the knowledge stocks of green FDI firms in the same industry (Horizontal GrFDI), in downstream industries (Downstream GrFDI), and upstream industries (Upstream GrFDI). All knowledge stock indicators are in logarithms. The first-stage estimation results are not shown in the table for the sake of brevity. All columns contain firm control variables, firm fixed effects, year fixed effects, industry fixed effects, and province fixed effects. Standard errors in the parentheses are clustered at the industry level. ***, **, *, indicate significance at 1% level, 5% level, and 10% level, respectively.

knowledge spillovers may have heterogenous impacts on domestic green innovation across green technological fields. I break down green patents into a more disaggregated level and focus on three main fields: alternative energy, sustainable transportation, and energy conservation. The results are presented in Table 4. The statistically significant coefficients in Panel A indicate that domestic innovation in alternative energy is enhanced by the knowledge stocks of green FDI in the same industry, downstream and upstream industries. The effects on domestic sustainable transportation innovation are not salient by green FDI firms' knowledge within the same industry. In contrast, there is no evidence that green

Table 4: Heterogeneity across Green Technological Fields

Knowledge Stock of: *Second-stage Estimation*	Horizontal GrFDI (1)	Downstream GrFDI (2)	Upstream GrFDI (3)
Panel A: Dependent Variable: Alternative Energy Patent Family			
GrFDI Know	0.509**	0.867**	5.424***
	(0.253)	(0.398)	(1.877)
Observations	21,304	21,304	21,304
Panel B: Dependent Variable: Sustainable Transportation Patent Family			
GrFDI Know	0.296	0.432**	2.460**
	(0.210)	(0.201)	(1.156)
Observations	9,635	9,635	9,635
Panel C: Dependent Variable: Energy Conservation Patent Family			
GrFDI Know	-0.083	0.424	1.765
	(0.308)	(0.440)	(1.852)
Observations	30,429	30,429	30,429
Firm FE	Y	Y	Y
Year FE	Y	Y	Y
Sector FE	Y	Y	Y
Province FE	Y	Y	Y

Notes: Panel A shows the results for the second-stage estimation, which is Poisson regression. Dependent variable is alternative energy patent family count in Panel A, sustainable transportation patent family count in Panel B, and energy conservation patent family count in Panel C. $GrFDIKnow$ is classified into three types: the knowledge stocks of green FDI firms in the same industry (Horizontal GrFDI), in downstream industries (Downstream GrFDI), and upstream industries (Upstream GrFDI). All knowledge stock indicators are in logarithms. The first-stage estimation results are not shown in the table for the sake of brevity. All columns contain firm control variables, firm fixed effects, year fixed effects, industry fixed effects, and province fixed effects. Standard errors in the parentheses are clustered at the industry level. ***, **, *, indicate significance at 1% level, 5% level, and 10% level, respectively.

FDI can effectively promote domestic innovation in energy conservation.

4.4 Mechanisms of Green FDI Knowledge Spillovers

In this subsection, I explore what mechanism factors can explain the difference in knowledge spillover effects of green FDI.

Local vs. non-local green FDI. The effects of green FDI firms' knowledge stocks on domestic firms' green innovation may vary with the geographic distance. Domestic firms located in the regions close to green FDI firms may benefit from a stronger knowledge spillover from green FDI due to the lower cost of communication and shared local talent pool. To test whether the distance to green FDI firms makes a difference, I define a binary variable, $LocalFDI$, which indicates whether the knowledge stocks are from green FDI firms located in the same province as the domestic firms. The corresponding results of the second-stage estimation are reported in the Panel A of Table 5. The interaction term of green FDI firms' knowledge stocks $GrFDIKnow$ and the dummy variable $LocalFDI$ captures whether local knowledge stocks of green FDI firms contribute more to domestic firms' green innovation. The result in Column (2) suggests that domestic firms' green innovation significantly benefit more from local green FDI if domestic firms become local suppliers of green FDI firms, while the results in Columns (1) and (3) indicate local green FDI firms' knowledge does not contribute to domestic green innovation if green FDI is in the same industry or upstream industries.

Technological Proximity. The main results have shown that domestic firms' green innovation significantly benefits from the knowledge stocks of green FDI firms in the downstream industries. The knowledge spillovers across industries may vary with the knowledge similarity of the industries. A closer technology background between a pair of industries indicates innovation activities between the two industries are more relevant. The higher relevance of knowledge basis between industries can facilitate knowledge spillovers and absorptions. Hence, if the knowledge stocks of green FDI firms derive from the downstream industries that are closer in technological spectrums, the knowledge spillovers from such downstream green FDI may contribute more to domestic firms' green innovation.

To capture the effect of technological proximity on green FDI knowledge spillovers, I start with computing the technological proximity across industries, built upon the approach proposed by Jaffe (1986):

$$TechProx_{idt} = \frac{T_{it}T'_{dt}}{\sqrt{T_{it}T'_{it}}\sqrt{T_{dt}T'_{dt}}} \tag{6}$$

where T_{it} is industry i's patent portfolio vector up to year t,[29] defined as $T_{it} = (T_{i1,t}, T_{i2,t}, ..., T_{iC,t})$,

[29]Industry d denotes another industry paired with industry i during the calculation.

Table 5: Mechanisms of Green FDI Knowledge Spillovers

Dependent Variable:	Green Patent Family Count		
Knowledge Stock of: *Second-stage Estimation*	Horizontal GrFDI (1)	Downstream GrFDI (2)	Upstream GrFDI (3)
Panel A: Local FDI vs. Non-local FDI			
GrFDI Know	-0.052	0.413*	0.589
	(0.192)	(0.229)	(0.400)
GrFDI Know×Local FDI	-0.085	0.899*	1.526
	(0.426)	(0.498)	(1.035)
Observations	102,386	102,591	102,594
Panel B: Technological Proximity between Industries			
GrFDI Know	N/A	0.680*	1.440
		(0.369)	(0.963)
GrFDI Know×FDI IndTechProx	N/A	0.059*	-0.080
		(0.032)	(0.053)
Observations		102,596	102,596
Panel C: Environmental Regulation Stringency of Green FDI Origin Countries			
GrFDI Know	-0.111	0.428*	0.550
	(0.479)	(0.239)	(0.376)
GrFDI Know×FDI OriginEPS	0.009	0.292*	0.619
	(0.132)	(0.163)	(0.424)
Observations	102,596	102,596	102,596
Firm Controls	Y	Y	Y
Firm FE	Y	Y	Y
Year FE	Y	Y	Y
Industry FE	Y	Y	Y
Province FE	Y	Y	Y

Notes: Panel A shows the results for the second-stage estimation, which is Poisson regression. Dependent variable is firm patent family count. $GrFDIKnow$ is classified into three types: the knowledge stocks of green FDI firms in the same industry (Horizontal GrFDI), in downstream industries (Downstream GrFDI), and upstream industries (Upstream GrFDI). All knowledge stock indicators are in logarithms. $LocalFDI$ is a binary variable indicating if the knowledge stock is from green FDI firms within the same province. $FDI\ IndTechProx$ is a binary variable indicating if the knowledge stock is from green FDI firms in other industries with large technological proximity (above the median value). $FDI\ IndTechProx$ is not applicable for Horizontal GrFDI as technological proximity is always 1 for the same industry. $FDI\ OriginEPS$ is a binary variable indicating if the knowledge stock is from green FDI that originates from countries with environmental policy stringency index higher than China. The first-stage estimation results are not shown in the table for the sake of brevity. All columns contain firm control variables, firm fixed effects, year fixed effects, industry fixed effects, and province fixed effects. Standard errors in the parentheses are clustered at the industry level. ***, **, *, indicate significance at 1% level, 5% level, and 10% level, respectively.

in which $T_{ic,t}$ is the share of patents of industry i in technology class c up to year t.[30] The proximity indicator ranges between 0 and 1, showing the similarity of a pair of industries' patent distributions across technology classes.

Then I divide each industry pair into high and low groups depending on whether

[30] Technology classes in the analysis rely on International Patent Classification (IPC) 4-digit code.

the technological proximity of an industry pair is larger or smaller than the median value. I define a binary variable, $FDI\ IndTechProx$ indicates whether the knowledge stocks derive from green FDI in the industries with high technological proximity (above the median value) to the domestic firms' industry or in the industries with the low technological proximity (below the median value). The interaction term of $GrFDIKnow$ and $FDI\ IndTechProx$ tests whether technological proximity matters in cross-industry knowledge spillovers of green FDI firms.[31] The corresponding results of the second-stage estimation are presented in the Panel B of Table 5. Similarly, the second-stage estimation result in Column (2) suggests that knowledge from downstream green FDI contributes more to domestic firms' green innovation when such downstream green FDI come from the industries close to domestic firms' industries in terms of technological proximity. The results in Column (3) indicate that industrial technological proximity does not play a role in knowledge spillovers from upstream green FDI.

Environmental regulations in origin countries of green FDI. While environmental regulations can drive green technological changes within the jurisdictions, they may also play a role in knowledge spillovers across borders (Popp, 2006). Once green knowledge has been developed to comply with a specific environmental regulation in one country, it may be transferred to other countries with lower regulation stringency due to its competitive advantage compared to other potential competitors in the lower-regulating countries (Dechezleprêtre, Neumayer, and Perkins, 2015). This provides an incentive for foreign investors to apply their green knowledge in the host countries. Therefore, the discrepancy of the environmental regulation stringency may affect the knowledge spillovers via green FDI.

To examine the role of environmental regulation stringency, I define a binary indicator $FDIOriginEPS$ to indicate whether the knowledge stocks are from green FDI that originates from countries with environmental policy stringency higher than China. The

[31] The effect of the knowledge stocks of green FDI firms within the same industry (Horizontal GrFDI) is not considered in this analysis as the technological proximity is always 1 between the same industry.

environmental policy stringency of green FDI origin countries is measured by the Environmental Policy Stringency (EPS) index, collected from the OECD Statistics database.[32] The interaction term of $GrFDIKnow$ and $FDIOriginEPS$ captures whether environmental regulation stringency plays an important role in knowledge spillovers of green FDI. The corresponding results of the second-stage estimation are displayed in the Panel C of Table 5. The coefficient in Column (2) indicates that domestic firms' green innovation benefit from stronger knowledge spillovers from downstream green FDI that originates from countries with higher environmental regulation stringency.

5 Conclusion

There has been a lack of attention to how to define and measure green FDI. Such neglect leads to considerable noise in quantifying how much FDI contributes to green knowledge spillovers. This partly explains why there is no consensus on the effects of FDI on pollution, energy efficiency, or clean technologies in the host countries. However, these mixed findings may bring troubles for policymaking in many governments of developing countries, because on one hand they are keen to attract FDI to enhance efficiency or absorb technologies, but on the other hand they are facing the ambiguities of how much FDI can contribute to their green economies.

This paper contributes to the literature by developing new definitions of green FDI by utilising the characteristics of FDI projects. Based on the newly defined green FDI, I examine the impacts of green FDI firms' knowledge stocks on domestic firms' green innovation. I further develop an instrumental variable for green FDI firms' knowledge stocks based on the changes in FDI opening-up policy in China to better identify the knowledge spillovers of green FDI. The results show that green innovation of domestic firms does not benefit from the knowledge of green FDI firms within the same industry,

[32]The Environmental Policy Stringency (EPS) index covers all OECD countries and other main non-OECD economies including Brazil, China, India, Indonesia, Russia, and South Africa.

but mostly benefits from the knowledge of green FDI firms in downstream industries. Specifically, a 1% increase in downstream green FDI firms' knowledge stocks contributes to roughly 0.732% increase in domestic firms' green patents. Such knowledge spillovers from downstream green FDI imply that domestic firms absorb green knowledge when they perform as suppliers of green FDI firms. Using different indicators of green innovation, I find that the knowledge spillovers from downstream green FDI contribute more to high-quality domestic green innovation. I further explore some features of knowledge spillovers from downstream green FDI and find that the knowledge spillovers vary with the location of green FDI, the technological proximity between industries, and the environmental regulation stringency of green FDI origin countries. Most of the results remain valid in the robustness checks.

This paper answers how FDI performs as one of the important drivers in the rapid development of green industries in China. During the engagement in supply chains led by foreign companies, Chinese domestic firms strongly focus on the build-up of their own scales and innovation capabilities, to establish the basis of large-scale production, new technology innovation, and competitiveness in the markets. Such model of a rapid expansion in green industries, though along with some debatable measures such as subsidies, public procurement and local content requirement, may provide other emerging economies with some implications for a faster path to the green transition. More rapid progress in green knowledge spillovers and the green transition is critical to achieving global climate targets.

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Appendix A Additional Tables

Table A1: Keywords for Green FDI Definition by the Text-mining of Firms' Business Description

Fields	Keywords
Environmental protection (general)	Environmental protection, environmental governance, environmental treatment, environmental monitoring, environmental testing, environmental countermeasures, environmental restoration, environmental purification, environmental improvement, environmental sanitation, sanitation machinery, environmental engineering, environmental equipment, environmental technology, environmental science, environmental research, new environmental materials, environmental test equipment, low-carbon technology, low-carbon science, low-carbon industry, low-carbon products, green products, green technology, environmentally-friendly, eco-friendly
Pollution control	Pollution control, low-carbon emission; air treatment, flue gas purification, exhaust gas purification, carbon capture, emission control, emission reduction, exhaust gas purification, scrubber, filter material, air purification, dust remover, dust removal equipment, air improvement; water treatment, water governance, water filter, water purifier, water quality monitoring, water quality improvement, wastewater treatment, wastewater reuse, seawater desalination, brackish water desalination, reclaimed water recycle, reclaimed water treatment, filter membrane; soil remediation, soil pollution, soil remediation, desertification prevention, soil erosion control, soil erosion prevention, soil conditioning, ecological restoration
Clean energy	Clean energy, low-carbon energy, new energy, alternative energy, clean fuel, renewable energy, sustainable energy; wind energy, wind power, wind turbines, power generation blades; solar energy, solar electric energy, photovoltaic, solar thermal, wind-solar hybrid; hydropower, hydroelectric power, tidal power, ocean power, geothermal energy; cogeneration, thermoelectric production; hydrogen fuel, hydrogen energy, hydrogen storage; biofuels, biomass fuel, biomass energy, bioenergy, biodiesel
Energy efficiency & management	Energy efficiency, energy management, energy saving, low-energy consumption; compact fluorescent lamp, diode, heat pumps; electric control systems, distribution switch control, low-voltage switchgear, transformers, inductors, transformers, rectifiers, sensors, boosters, electricity meters, sensitive components, electrical control system, uninterruptible power supply, integration of electromechanical equipment, relays, circuit breakers
Battery & sustainable vehicle	Lithium battery, lithium ion battery, lithium polymer battery, nickel metal hydride battery, power battery, fuel cell, green battery, environmentally friendly battery, pollution-free battery; electric vehicle, dual fuel car, hybrid car, charging pile
Sustainable agriculture	Sustainable agriculture, green agriculture, pollution-free agriculture, organic agricultural, organic farming, low-impact farming, eco-agriculture; biomass resource utilization, biofertilizer, drip irrigation, water saving irrigation, genetic engineering
Resource saving & waste management & recycling	Resource saving, recycling, resource recovery, resource regeneration, resource conservation, resource protection, renewable resource, resource regeneration, comprehensive utilization of resources, recycled material recovery, waste resource recovery; waste management, waste treatment power generation, waste incineration power generation, biogas power generation, waste heat recovery, waste heat power generation, waste gas treatment; leftover material production, comprehensive utilization of biology, comprehensive utilization of ash and slag, utilization of waste plastics, exhaust gas turbine, waste liquid treatment, scrap steel, waste dismantling, scrap metal, oil and gas recovery, comprehensive utilization of electricity
Materials and components for renewable energy & energy efficiency & sustainable buildings	Rare metals, rare earths, lithium, cobalt, tantalum, tungsten, platinum, silica, silicon rectifiers, graphite, uranium, permanent magnet materials, high temperature insulation, thermoelectric materials, inorganic heat conduction, monocrystalline silicon, polycrystalline silicon, cross-linked polyethylene, fluorine-free, rare earth hydrogen storage, photoelectric new materials, low-carbon materials, semiconductors, electronic ceramics, UHMWPE fiber, organic heat carrier, glass fiber, optical fiber, liquid crystal display, liquid crystal cell, silicon wafer, single chip, thin film, polyester film, optoelectronic film, electronic glass, optoelectronics, nanocomposite, nanotechnology, ultra-thin glass; lightweight building materials, fire-resistant materials, heat insulation materials, heat preservation materials, thermal insulation materials, fireproof materials, temperature control system equipment, coated glass, adjustable light transmittance glass, glass ceramics, exterior wall insulation, aerated concrete, insulation system materials
Automation & intelligence	Automation control, intelligent control, smart grid, smart city, digital control, power automation, distribution automation, intelligent network, building intelligence, electric power automation, industrial automation

Notes: The table lists the keywords of business activities regarding environmental governance, clean production, clean energy, and green technology. The keywords are used for text-mining the description of foreign-invested firms' business scope, which is the first approach to defining green FDI. If a foreign-invested firm's business description includes keywords listed in the table, this foreign-invested firm is defined as green FDI.

Table A2: Entry of Green FDI and Green Innovation of Foreign-invested Firms

Dependent Variable:	Green Patent Family	
	Patent Count	Patent Citation
	(1)	(2)
GrFDI (Text)	0.649*	0.713**
	(0.390)	(0.351)
GrFDI (GrPat)	2.324***	2.115***
	(0.387)	(0.349)
GrFDI (GrPatOutCN)	1.047***	1.142***
	(0.225)	(0.229)
GrFDI (FIGrPatCN)	-0.117	-0.266
	(0.935)	(0.765)
Observations	28,645	24,352
Firm Controls	Y	Y
Firm FE	Y	Y
Year FE	Y	Y
Industry FE	Y	Y
Province FE	Y	Y

Notes: The table shows the results for the correlation between the entry of green FDI to foreign-invested firms and their green innovation. Dependent variable is firm green patent family count and citation. $GrFDI$ is a dummy variable that indicates whether foreign-invested firms receive green FDI. The regressions for using different green FDI definitions are separately conducted: "Text" is the first green FDI definition: whether the text description of FDI business scope includes keywords related to environmental governance, clean production, clean energy, or green technology. "GrPat" is the second green FDI definition: whether FDI firms own green patents. "GrPatOutCN" stands for the third green FDI definition: whether FDI firms own green patents that cite prior arts from foreign countries. "FIGrPatCN" represents the fourth green FDI definition: whether FDI firms' foreign investors have filed green patents in China. All columns contain firm control variables, firm fixed effects, year fixed effects, industry fixed effects, and province fixed effects. Standard errors in the parentheses are clustered at the industry level. ***, **, *, indicate significance at 1% level, 5% level, and 10% level, respectively.

Table A3: Robustness Checks on Two-stage DID

Knowledge Stock of:	Horizontal GrFDI	
	(1)	(2)
Panel A: Second-stage Estimation (Dependent Variable: Green Patent Family)		
	Patent Count	Patent Citation
GrFDI Know	0.000	0.285
	(0.263)	(0.260)
Observations	51,296	43,145
Panel B: First-stage Estimation (Dependent Variable: GrFDI Know)		
GrFDI Open	0.845***	0.845***
	(0.157)	(0.157)
Observations	384,297	384,297
Firm Controls	Y	Y
Firm FE	Y	Y
Year FE	Y	Y
Industry FE	Y	Y
Province FE	Y	Y

Notes: Panel A shows the results for the second-stage estimation, which is Poisson regression. Dependent variable in Panel A is firm green patent family count and citation. $GrFDIKnow$ is the knowledge stock of green FDI firms in the same industry (Horizontal GrFDI), which is measured in logarithms. Panel B shows the results for the first-stage estimation, which is OLS. Dependent variable in Panel B is the knowledge stock of green FDI firms, which is the main exploratory variable in the second-stage estimation. $GrFDIOpen$ is the instrumental variable used in the first-stage estimation and captures if the same industry (Horizontal GrFDI) is identified as "Green FDI Encouraged Industry" (i.e., includes green products more opened up to FDI while no green products less opened up to FDI during FDI regulation changes). CD Wald F-statistic denotes Cragg-Donald Wald F-Statistic, and KP Wald F-statistic denotes Kleibergen-Paap rk Wald F-statistic. All columns contain firm control variables, firm fixed effects, year fixed effects, industry fixed effects, and province fixed effects. Standard errors in the parentheses are clustered at the industry level. ***, **, *, indicate significance at 1% level, 5% level, and 10% level, respectively.

Table A4: Results for Baseline Model (OLS)

Dependent Variable:	Green Patent Family Count					
Knowledge Stock of:	Horizontal GrFDI (1)	Downstream GrFDI (2)	Upstream GrFDI (3)	Horizontal GrFDI (4)	Downstream GrFDI (5)	Upstream GrFDI (6)
					Second-stage Estimation	
GrFDI Know	0.010***	0.010***	0.020***	0.011**	0.027**	0.050
	(0.002)	(0.003)	(0.004)	(0.006)	(0.012)	(0.039)
Observations	384,297	384,297	384,297	384,297	384,297	384,297
					First-stage Estimation *Dependent Variable: GrFDI Know*	
GrFDI Open				0.845***	1.570***	0.376*
				(0.157)	(0.385)	(0.208)
Observations				384,297	384,297	384,297
CD Wald F-statistic				33165	55003	15849
KP Wald F-statistic				29.07	16.60	9.131
Estimation	OLS	OLS	OLS	2SLS	2SLS	2SLS
Firm Controls	Y	Y	Y	Y	Y	Y
Firm FE	Y	Y	Y	Y	Y	Y
Year FE	Y	Y	Y	Y	Y	Y
Industry FE	Y	Y	Y	Y	Y	Y
Province FE	Y	Y	Y	Y	Y	Y

Notes: Dependent variable is firm green patent family count. Columns (1) to (3) show results for OLS regression. $GrFDIKnow$ is classified into three types: the knowledge stock of green FDI firms in the same industry (Horizontal GrFDI), in downstream industries (Downstream GrFDI), and upstream industries (Upstream GrFDI). All knowledge stock indicators are in logarithms. Columns (4) to (6) show results for 2SLS estimation. $GrFDIOpen$ is the instrumental variable used in the first-stage estimation and captures if the same industry (Horizontal GrFDI), downstream industries (Downstream GrFDI), and upstream industries (Upstream GrFDI) are identified as "Green FDI Encouraged Industry" (i.e., includes green products more opened up to FDI while no green products less opened up to FDI during FDI regulation changes). CD Wald F-statistic denotes Cragg-Donald Wald F-Statistic, and KP Wald F-statistic denotes Kleibergen-Paap rk Wald F-statistic. Stock-Yogo critical values for weak identification test (Cragg-Donald and Kleibergen-Paap rk Wald F statistics) are 16.38 at 10% and 8.96 at 15% maximal IV size. All columns contain firm control variables, firm fixed effects, year fixed effects, industry fixed effects, and province fixed effects. Standard errors in the parentheses are clustered at the industry level. ***, **, *, indicate significance at 1% level, 5% level, and 10% level, respectively.

Table A5: Results for Dynamic Effects

GrFDI Open	Horizontal GrFDI Know
Pre-Open Period 8	0.233
	(0.214)
Pre-Open Period 7	0.106
	(0.250)
Pre-Open Period 6	0.181
	(0.185)
Pre-Open Period 5	0.062
	(0.189)
Pre-Open Period 4	0.090
	(0.193)
Pre-Open Period 3	0.183
	(0.218)
Pre-Open Period 2	0.088
	(0.178)
Pre-Open Period 1	0.239
	(0.190)
Post-Open Period 0	0.411**
	(0.189)
Post-Open Period 1	0.515***
	(0.197)
Post-Open Period 2	0.691***
	(0.217)
Post-Open Period 3	0.656***
	(0.210)
Post-Open Period 4	0.583**
	(0.236)
Post-Open Period 5	0.578**
	(0.252)
Post-Open Period 6	0.604**
	(0.287)
Post-Open Period 7	0.612
	(0.441)
Post-Open Period 8	1.021***
	(0.351)
Observations	384,301
Firm Controls	Y
Firm FE	Y
Year FE	Y
Industry FE	Y
Province FE	Y

Notes: The table shows the coefficients for each point estimate in the dynamic effect plot Figure 5. Dependent variable is the knowledge stock of green FDI firms in the same industry (Horizontal GrFDI), which is measured in logarithms. $PreOpen\ Period\ t$ is a time dummy variable indicating t periods before the industry becomes "Green FDI Encouraged Industry" (i.e., the industry includes green products becoming more open to FDI while no green product becoming less open to FDI during FDI regulation changes). $PostOpen\ Period\ t$ is a time dummy variable indicating t periods after the industry becomes "Green FDI Encouraged Industry". Firm control variables, firm fixed effects, year fixed effects, industry fixed effects, and province fixed effects are included. Standard errors in the parentheses are clustered at the industry level. ***, **, *, indicate significance at 1% level, 5% level, and 10% level, respectively.

Table A6: Robustness Checks on Adding Key Determinants

Knowledge Stock of:	Horizontal GrFDI (1)	Downstream GrFDI (2)	Upstream GrFDI (3)
Panel A: Second-stage Estimation (Dependent Variable: Green Patent Family Count)			
GrFDI Know	0.077	0.546**	3.903***
	(0.246)	(0.276)	(1.310)
Observations	51,296	51,296	51,296
Panel B: First-stage Estimation (Dependent Variable: Green FDI Knowledge Stock: GrFDI Know)			
GrFDI Open	0.638***	1.506***	0.357**
	(0.132)	(0.348)	(0.170)
Observations	384,297	384,297	384,297
CD Wald F-statistic	22360	47319	11305
KP Wald F-statistic	23.24	18.73	9.455
Firm Controls	Y	Y	Y
Key Determinants	Y	Y	Y
Firm FE	Y	Y	Y
Year FE	Y	Y	Y
Industry FE	Y	Y	Y
Province FE	Y	Y	Y

Notes: Panel A shows the results for the second-stage estimation, which is Poisson regression. Dependent variable in Panel A is firm green patent family count. $GrFDIKnow$ is classified into three types: the knowledge stock of green FDI firms in the same industry (Horizontal GrFDI), in downstream industries (Downstream GrFDI), and upstream industries (Upstream GrFDI). All knowledge stock indicators are in logarithms. Panel B shows the results for the first-stage estimation, which is OLS. Dependent variable in Panel B is the knowledge stock of green FDI, which is the main exploratory variable in the second-stage estimation. $GrFDIOpen$ is the instrumental variable used in the first-stage estimation and captures if the same industry (Horizontal GrFDI), downstream industries (Downstream GrFDI), and upstream industries (Upstream GrFDI) are identified as "Green FDI Encouraged Industry" (i.e., includes green products more opened up to FDI while no green products less opened up to FDI during FDI regulation changes). The interaction terms between year fixed effects and eight industry-level key determinants that affect the openness to green FDI are included as controls. CD Wald F-statistic denotes Cragg-Donald Wald F-Statistic, and KP Wald F-statistic denotes Kleibergen-Paap rk Wald F-statistic. Stock-Yogo critical values for weak identification test (Cragg-Donald and Kleibergen-Paap rk Wald F statistics) are 16.38 at 10% and 8.96 at 15% maximal IV size. All columns contain firm control variables, firm fixed effects, year fixed effects, industry fixed effects, and province fixed effects. Standard errors in the parentheses are clustered at the industry level. ***, **, *, indicate significance at 1% level, 5% level, and 10% level, respectively.

Table A7: Robustness Checks on Controlling Non-green FDI

Knowledge Stock of:	Horizontal GrFDI (1)	Downstream GrFDI (2)	Upstream GrFDI (3)
Panel A: Second-stage Estimation (Dependent Variable: Green Patent Family Count)			
GrFDI Know	-0.118	0.996**	3.692**
	(0.350)	(0.411)	(1.460)
Observations	51,296	51,296	51,296
Panel B: First-stage Estimation (Dependent Variable: Green FDI Knowledge Stock: GrFDI Know)			
GrFDI Open	0.642***	1.245***	0.317
	(0.158)	(0.398)	(0.222)
Observations	355,108	384,297	384,297
CD Wald F-statistic	25493	26077	2889
KP Wald F-statistic	23.93	9.789	2.869
Firm Controls	Y	Y	Y
Non-GrFDI Control	Y	Y	Y
Firm FE	Y	Y	Y
Year FE	Y	Y	Y
Industry FE	Y	Y	Y
Province FE	Y	Y	Y

Notes: Panel A shows the results for the second-stage estimation, which is Poisson regression. Dependent variable in Panel A is firm green patent family count. $GrFDIKnow$ is classified into three types: the knowledge stock of green FDI firms in the same industry (Horizontal GrFDI), in downstream industries (Downstream GrFDI), and upstream industries (Upstream GrFDI). All knowledge stock indicators are in logarithms. Panel B shows the results for the first-stage estimation, which is OLS. Dependent variable in Panel B is the knowledge stock of green FDI, which is the main exploratory variable in the second-stage estimation. $GrFDIOpen$ is the instrumental variable used in the first-stage estimation and captures if the same industry (Horizontal GrFDI), downstream industries (Downstream GrFDI), and upstream industries (Upstream GrFDI) are identified as "Green FDI Encouraged Industry" (i.e., includes green products more opened up to FDI while no green products less opened up to FDI during FDI regulation changes). The knowledge stock of non-green FDI is added as a control variable. CD Wald F-statistic denotes Cragg-Donald Wald F-Statistic, and KP Wald F-statistic denotes Kleibergen-Paap rk Wald F-statistic. Stock-Yogo critical values for weak identification test (Cragg-Donald and Kleibergen-Paap rk Wald F statistics) are 16.38 at 10% and 8.96 at 15% maximal IV size. All columns contain firm control variables, firm fixed effects, year fixed effects, industry fixed effects, and province fixed effects. Standard errors in the parentheses are clustered at the industry level. ***, **, *, indicate significance at 1% level, 5% level, and 10% level, respectively.

Table A8: Robustness Checks on Removing Firm Sorting

Knowledge Stock of:	Horizontal GrFDI (1)	Downstream GrFDI (2)	Upstream GrFDI (3)
Panel A: Second-stage Estimation (Dependent Variable: Green Patent Family Count)			
GrFDI Know	0.003	0.842**	2.469
	(0.349)	(0.385)	(1.555)
Observations	27,930	27,930	27,930
Panel B: First-stage Estimation (Dependent Variable: Green FDI Knowledge Stock: GrFDI Know)			
GrFDI Open	0.867***	1.620***	0.437*
	(0.157)	(0.375)	(0.240)
Observations	232,093	232,093	232,093
CD Wald F-statistic	18679	31812	10302
KP Wald F-statistic	30.54	18.63	7.487
Firm Controls	Y	Y	Y
Drop Sorting Firms	Y	Y	Y
Firm FE	Y	Y	Y
Year FE	Y	Y	Y
Industry FE	Y	Y	Y
Province FE	Y	Y	Y

Notes: Panel A shows the results for the second-stage estimation, which is Poisson regression. Dependent variable in Panel A is firm green patent family count. $GrFDIKnow$ is classified into three types: the knowledge stock of green FDI firms in the same industry (Horizontal GrFDI), in downstream industries (Downstream GrFDI), and upstream industries (Upstream GrFDI). All knowledge stock indicators are in logarithms. Panel B shows the results for the first-stage estimation, which is OLS. Dependent variable in Panel B is the knowledge stock of green FDI firms, which is the main exploratory variable in the second-stage estimation. $GrFDIOpen$ is the instrumental variable used in the first-stage estimation and captures if the same industry (Horizontal GrFDI), downstream industries (Downstream GrFDI), and upstream industries (Upstream GrFDI) are identified as "Green FDI Encouraged Industry" (i.e., includes green products more opened up to FDI while no green products less opened up to FDI during FDI regulation changes). Firms changing industries during the sample period are removed. CD Wald F-statistic denotes Cragg-Donald Wald F-Statistic, and KP Wald F-statistic denotes Kleibergen-Paap rk Wald F-statistic. Stock-Yogo critical values for weak identification test (Cragg-Donald and Kleibergen-Paap rk Wald F statistics) are 16.38 at 10% and 8.96 at 15% maximal IV size. All columns contain firm control variables, firm fixed effects, year fixed effects, industry fixed effects, and province fixed effects. Standard errors in the parentheses are clustered at the industry level. ***, **, *, indicate significance at 1% level, 5% level, and 10% level, respectively.

Table A9: Robustness Checks on Subsidies as Control

Knowledge Stock of:	Horizontal GrFDI (1)	Downstream GrFDI (2)	Upstream GrFDI (3)
Panel A: Second-stage Estimation (Dependent Variable: Green Patent Family Count)			
GrFDI Know	0.106	0.859**	3.142**
	(0.285)	(0.347)	(1.471)
Observations	36,874	36,874	36,874
Panel B: First-stage Estimation (Dependent Variable: Green FDI Knowledge Stock: GrFDI Know)			
GrFDI Open	0.749***	1.448***	0.361*
	(0.149)	(0.374)	(0.197)
Observations	320,445	320,445	320,445
CD Wald F-statistic	24101	37410	8449
KP Wald F-statistic	25.12	15.01	6.017
Firm Controls	Y	Y	Y
Subsidy Control	Y	Y	Y
Firm FE	Y	Y	Y
Year FE	Y	Y	Y
Industry FE	Y	Y	Y
Province FE	Y	Y	Y

Notes: Panel A shows the results for the second-stage estimation, which is Poisson regression. Dependent variable in Panel A is firm green patent family count. $GrFDIKnow$ is classified into three types: the knowledge stock of green FDI firms in the same industry (Horizontal GrFDI), in downstream industries (Downstream GrFDI), and upstream industries (Upstream GrFDI). All knowledge stock indicators are in logarithms. Panel B shows the results for the first-stage estimation, which is OLS. Dependent variable in Panel B is the knowledge stock of green FDI firms, which is the main exploratory variable in the second-stage estimation. $GrFDIOpen$ is the instrumental variable used in the first-stage estimation and captures if the same industry (Horizontal GrFDI), downstream industries (Downstream GrFDI), and upstream industries (Upstream GrFDI) are identified as "Green FDI Encouraged Industry" (i.e., includes green products more opened up to FDI while no green products less opened up to FDI during FDI regulation changes). Total amount of subsidies received by each firm is added as an additional control variable. CD Wald F-statistic denotes Cragg-Donald Wald F-Statistic, and KP Wald F-statistic denotes Kleibergen-Paap rk Wald F-statistic. Stock-Yogo critical values for weak identification test (Cragg-Donald and Kleibergen-Paap rk Wald F statistics) are 16.38 at 10% and 8.96 at 15% maximal IV size. All columns contain firm control variables, firm fixed effects, year fixed effects, industry fixed effects, and province fixed effects. Standard errors in the parentheses are clustered at the industry level. ***, **, *, indicate significance at 1% level, 5% level, and 10% level, respectively.

Table A10: Robustness Checks on Alternative Foreign Ownership Thresholds

Ownership Thershold:	Foreign Ownership > 25%			Foreign Ownership > 50%		
Knowledge Stock of:	Horizontal GrFDI	Downstream GrFDI	Upstream GrFDI	Horizontal GrFDI	Downstream GrFDI	Upstream GrFDI
	(1)	(2)	(3)	(4)	(5)	(6)
Panel A: Second-stage Estimation (Dependent Variable: Green Patent Family Count)						
GrFDI Know	-0.069	0.717**	1.892	-0.071	0.561**	1.179
	(0.288)	(0.342)	(1.412)	(0.238)	(0.261)	(0.965)
Observations	51,296	51,296	51,296	51,296	51,296	51,296
Panel B: First-stage Estimation (Dependent Variable: Green FDI Knowledge Stock: GrFDI Know)						
GrFDI Open	0.780***	1.507***	0.385	0.990***	2.004***	0.590
	(0.133)	(0.322)	(0.261)	(0.181)	(0.263)	(0.393)
Observations	384,297	384,297	384,297	384,297	384,297	384,297
CD Wald F-statistic	29401	53916	1548	45653	85352	1143
KP Wald F-statistic	34.59	21.90	4.575	30.06	58.21	3.417
Firm Controls	Y	Y	Y	Y	Y	Y
Firm FE	Y	Y	Y	Y	Y	Y
Year FE	Y	Y	Y	Y	Y	Y
Industry FE	Y	Y	Y	Y	Y	Y
Province FE	Y	Y	Y	Y	Y	Y

Notes: Panel A shows the results for the second-stage estimation, which is Poisson regression. Dependent variable in Panel A is firm green patent family count. $GrFDIKnow$ is classified into three types: the knowledge stock of green FDI firms in the same industry (Horizontal GrFDI), in downstream industries (Downstream GrFDI), and upstream industries (Upstream GrFDI). All knowledge stock indicators are in logarithms. Panel B shows the results for the first-stage estimation, which is OLS. Dependent variable in Panel B is the knowledge stock of green FDI firms, which is the main exploratory variable in the second-stage estimation. $GrFDIOpen$ is the instrumental variable used in the first-stage estimation and captures if the same industry (Horizontal GrFDI), downstream industries (Downstream GrFDI), and upstream industries (Upstream GrFDI) are identified as "Green FDI Encouraged Industry" (i.e., includes green products more opened up to FDI while no green products less opened up to FDI during FDI regulation changes). Only firms with foreign ownership larger than 25% are regarded as FDI in Columns (1)-(3) and firms with foreign ownership larger than 50% are regarded as FDI in Columns (4)-(6) when constructing the knowledge stock of green FDI firms. CD Wald F-statistic denotes Cragg-Donald Wald F-Statistic, and KP Wald F-statistic denotes Kleibergen-Paap rk Wald F-statistic. Stock-Yogo critical values for weak identification test (Cragg-Donald and Kleibergen-Paap rk Wald F statistics) are 16.38 at 10% and 8.96 at 15% maximal IV size. All columns contain firm control variables, firm fixed effects, year fixed effects, industry fixed effects, and province fixed effects. Standard errors in the parentheses are clustered at the industry level. ***, **, *, indicate significance at 1% level, 5% level, and 10% level, respectively.

Table A11: Robustness Checks on Alternative Green FDI Definitions

Dependent Variable:	Green Patent Family Count		
Knowledge Stock of: *Second-stage Estimation*	Horizontal GrFDI (1)	Downstream GrFDI (2)	Upstream GrFDI (3)
GrFDI Know (GrPat)	-0.058	1.029**	2.251*
	(0.509)	(0.482)	(1.263)
GrFDI Know (GrPatOutCN)	-0.082	0.510*	1.296
	(0.264)	(0.285)	(0.866)
GrFDI Know (FIGrPatCN)	-0.112	0.496*	0.718
	(0.440)	(0.287)	(0.460)
GrFDI Know (Text&GrPat)	0.000	0.732***	2.512*
	(0.263)	(0.357)	(1.393)
Observations	51,296	51,296	51,296
Firm Controls	Y	Y	Y
Firm FE	Y	Y	Y
Year FE	Y	Y	Y
Industry FE	Y	Y	Y
Province FE	Y	Y	Y

Notes: The table shows the results for the second-stage estimation, which is Poisson regression. Dependent variable is firm green patent family count. $GrFDIKnow$ is classified into three types: the knowledge stock of green FDI firms in the same industry (Horizontal GrFDI), in downstream industries (Downstream GrFDI), and upstream industries (Upstream GrFDI). All knowledge stock indicators are in logarithms. The regressions for using alternative green FDI definitions are separately conducted: "GrPat" is the second green FDI definition: whether FDI firms' own green patents. "GrPatOutCN" stands for the third green FDI definition: whether FDI firms own green patents that cite prior arts from foreign countries. "FIGrPatCN" represents the fourth green FDI definition: whether FDI firms' foreign investors have filed green patents in China. "Text&GrPat" means the intersection of the first and second definitions of green FDI: whether the text description of FDI business scope includes keywords related to environmental governance, clean production, clean energy, or green technology, and owns green patents. The first-stage estimation results are not shown in the table for the sake of brevity. All columns contain firm control variables, firm fixed effects, year fixed effects, industry fixed effects, and province fixed effects. Standard errors in the parentheses are clustered at the industry level. ***, **, *, indicate significance at 1% level, 5% level, and 10% level, respectively.