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Learn to be green: FDI spillover effects on eco-innovation in China

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Global knowledge flows are not only important in promoting economic activities but also in addressing global environmental issues. In order to examine the mechanisms of how firms in emerging economies can learn from global partners in finding solutions to environmental challenges, we explore a rich data set covering nearly 190,595 Chinese firms and analyze the knowledge flows that local firms received from foreign firms in developing eco-innovations. We examine both knowledge flows in the same industry and those in the up- and down-stream industries, and, in particular, provide a nuanced consideration around the under-explored industrial conditions and regional institutions of technology spillovers and domestic eco-innovation. We find clear evidence that foreign green technology spillovers have a positive impact on the eco-innovation of domestic firms in China. This superior performance is particularly pronounced in certain industries (e.g., technology-intensive, pollution-intensive, and highly competitive) and cities with higher levels of environmental regulation stringency. Our results show that domestic firms differ significantly in the extent to which they benefit from global knowledge flows.

JEL classification: D21, F23, O32

1. Introduction

In addressing global environmental challenges, the development of eco-innovation depends not only on internal research and development (R&D) efforts but also on access to external sources of knowledge and technologies (Popp, 2011; Suresh, 2012; Li-Ying *et al*., 2018; Mothe *et al*., 2018; Fernández *et al*., 2021). Given the importance of collaboration with different technology sources (e.g., customers, suppliers, and competitors), knowledge flows from foreign partners play a crucial role in innovation for emerging economies (Gerschenkron, 1962; Breschi and Lissoni, 2001; Lee, 2006; Wang *et al*., 2020). In this vein, technologically backward economies could benefit from collaborating with advanced ones and receive positive green technology spillovers (Luo *et al*., 2021). Foreign direct investment (FDI), which contains advanced green technologies and management experience from developed countries, is an important source of global knowledge flows for developing countries and thereby an important channel for technology spillovers.

By engaging in cooperation with foreign firms, domestic firms are expected to absorb low-emissions technologies, better administration practice, and assistance in environmental product design (Ali *et al*., 2016; Luo *et al*., 2021). In the pursuit of staying competitive in global markets, foreign firms have strong incentives to transfer advanced green technologies and managerial knowledge to local suppliers (Alcacer and Oxley, 2014). Domestic firms without contractual relationship with foreign-invested-enterprises (FIEs) can also benefit from technology spillovers through their efforts to meet the strict environmental standards and to improve the environmental friendliness of their products (Newman *et al.*, 2015). With more and more firms incorporating sustainability issues in their strategies (Lozano *et al.*, 2014) and putting emphasis on sustainable sectoral chain governance to realize environmental goals (Vezzoli *et al.*, 2015), technology spillovers across the horizontal (in the same industry) and vertical (in the up- and down-stream industries) linkages can generate positive impact on firms' eco-innovation and even on total social welfare (Costantini *et al.*, 2017; Lin *et al.*, 2020).

The Pollution Halo Hypothesis argues that FDI transfers their greener technologies such as pollution abatement technologies, renewable energy-related technologies, and energy-conserving technologies to host countries (Cole *et al.*, 2008 for Ghana; Demena and Afesorgbor, 2020 for meta-analysis; Dong *et al.*, 2019 for China; Pao and Tsai, 2011 for BRIC countries; Pazienza, 2019 for Organization for Economic Cooperation and Development (OECD) economies; Zhang and Zhou, 2016 for China). However, another stream of research—known as the Pollution Haven Hypothesis—holds a different view. The argument is that foreign companies relocate their pollution-intensive activities to developing countries in order to escape the tighter environmental requirements at home country, which suggests a negative environmental impact from FDI inflow (e.g., Dietzenbacher and Mukhopadhyay, 2007; Rezza, 2013; Baek, 2016; López *et al.*, 2018). A recent research (Castellani *et al.*, 2022) points out that existing literature on the FIEs' effect on eco-innovation of indigenous firms is under researched and mainly based on case studies and national surveys, and the findings of those studies thus have limited generalizability.

Our empirical analysis is based on firms in China where significant environmental challenges are present and environmental stringency varies across its regions (Dean *et al.*, 2009; Marquis *et al.*, 2011; Bu and Wagner, 2016). Considering China's aim of reducing its CO_2 emission by 2030, its capability in technology learning and upgrading (Ivarsson and Alvstam, 2010; Lacasa *et al.*, 2019; Wang *et al.*, 2019), and the less stringent environmental regulations in China (Freitas *et al.*, 2023),[1] Chinese firms still have great opportunities to learn advanced green knowledge and technologies from FIEs. It is of great importance to investigate whether and to what extent FIEs have helped the development of eco-innovation in domestic firms through industrial linkages. From the perspective of industrial linkages, this paper will examine both the horizontal and vertical FDI spillovers, and explore whether and how the relationship between FDI spillovers and domestic eco-innovation is contingent on industrial conditions and regional institutions.

The contribution of this paper is twofold. First, global knowledge flows play a central role for innovation, social activities, and economic activities (Bathelt and Li, 2020; Wang *et al.*, 2020). A large amount of existing literature has investigated the effect of technology spillovers on total factor productivity (TFP) and gross domestic product (Bwalya, 2006; Lin *et al.*, 2009; Barrios *et al.*, 2011; Du *et al.*, 2012; Damijan *et al.*, 2013; Gorodnichenko *et al.*, 2014; Liang, 2017; Lu *et al.*, 2017), but the debate has so far overlooked FDI's link to environmental innovation (termed as eco-innovation or green innovation) and its knowledge flows (for reviews, see Demena and Afesorgbor, 2020; Wei *et al.*, 2022; Wang *et al.*, 2023). To address the research gap, based on the Pollution Halo Hypothesis and firm-level data of green patents, this paper examines the impact of FDI spillovers on eco-innovation of domestic firms in China at the horizontal and vertical levels. This provides micro evidence for the relationship between FDI spillovers and eco-innovation from the perspective of industrial linkages. As an emerging economy, China is undergoing a transition process in developing frontier technologies, changing patterns of global interaction in technology upgrading, and also contributing to technologies related to eco-innovation (Dai *et al.*, 2020), making it an ideal opportunity to explore the potential benefits of FDI relative to advanced economies (Findlay, 1978).

Secondly, to contribute to the Pollution Halo and Pollution Haven debate, our study adds to the literature by unfolding how the impact of FDI spillovers on eco-innovation is contingent on industrial conditions and regional institutions. More specifically, we analyze to what extent the benefits of green spillovers vary with regard to industrial conditions such as industrial technology intensity, pollution intensity, and competition intensity. We argue that industrial technology

[1] Due to the less stringent environmental regulations in China, firms are likely to be associated with energy-intensive production.

levels are associated with greater R&D efforts and absorptive capacity—a hardly imitable organizational learning capability—which help domestic firms in that industry recognize, absorb, and internalize the green technology spillovers (Cohen and Levinthal, 1990; Demirel and Kesidou, 2019). Meanwhile, in polluting and competitive industries, the spillover effects of FDI on eco-innovation of domestic firms are stronger. With regard to the industrial conditions of FDI spillover effects in China, Jiang *et al.* (2018) find that FDI impact on air quality demonstrates industry heterogeneity; however, this study is based on city-level data. There is a lack of firm-level studies on a large FDI recipient country in the developing world, such as China. Scant attention has so far been devoted to industry heterogeneity. Existing FDI spillovers literature has largely overlooked the institutional mechanisms underlying FDI spillovers (for systematic reviews and meta-analysis, see Spencer, 2008; Perri and Peruffo, 2016; Rojec and Knell, 2018). The portrayal of a more institutional account of FDI green spillover effects in the context of emerging markets offers a novel perspective for China, in particular. Lema *et al.* (2020) highlighted the salient role of institutional changes in creating new opportunities for latecomer development in the age of transformation toward sustainability. This study deepens our understanding of institutional forces that facilitate FDI green spillovers at home.

The remainder of this paper is organized as follows. Section 2 provides a review of the relevant literature and formulates the research hypotheses. Section 3 discusses data, variables measurements, and methodology. Section 4 presents the empirical results and robustness tests. Finally, Section 5 concludes the paper with a discussion on policy implications and limitations.

2. Background literature and research hypotheses

2.1 Green spillovers from foreign firms

As environmental issues have become a global grand challenge, eco-innovation is regarded as an important tool responding to this challenge and to achieve a green transition (Dangelico and Pujari, 2010; Ekins, 2010; Triguero *et al.*, 2013). Eco-innovation differs from general innovation in terms of its "double externality," that is, R&D and environmental externalities (Rennings, 2000). While all innovations are subject to the imperfect appropriability of returns (Cohen *et al.*, 2000), this issue is more salient for eco-innovations, as they carry a larger share of nonexcludable public benefits than do regular commercial-driven innovations (Cuerva *et al.*, 2014). FDI may positively impact domestic firms' eco-innovation through green technology spillovers, which can occur through demonstration effects, interfirm employee mobility effects, industrial linkage effects, and competition effects.

First, FIEs may demonstrate the feasibility of green technologies to domestic firms that provide technological resources, enhancing their learning and enabling them to improve their innovation capabilities (Piperopoulos *et al.*, 2018). Domestic firms observe globally competitive technologies and management practices of FIEs directly in the domestic market (Spencer, 2008; Perri and Peruffo, 2016). FIEs tend to have advanced green technologies, know-how, well-established distribution networks, and sophisticated research into international markets (Liao, 2015), which may spillover to domestic firms including suppliers, customers, and competitors (Vujanović *et al.*, 2022). Domestic firms with adequate absorptive capacity can recognize, utilize, and apply the acquired intangible resources to enhance internal green technology capabilities (Nair *et al.*, 2016; Bai *et al.*, 2020). As a result, domestic firms may become more active and effective in conducting their own eco-innovative activities.

Second, eco-innovation can be understood as an integrated process of technological and social change that involves changes in knowledge, practices, values, norms, aims, objectives, and governance systems (Bitencourt *et al.*, 2020). Not only is human capital needed as an important input for technological activities associated with eco-innovation development; it also plays an important role in sensing environmental issues, seizing the associated opportunities and reconfiguring their organizational resources for eco-innovation to capture these opportunities (Hart, 1995; Marzucchi and Montresor, 2017; Kiefer *et al.*, 2019). Green spillovers from FIEs may be realized through interfirm employee mobility, whereby trained managers and skilled workers who once worked for FIEs move to domestic firms or set up their own firms (Liu *et al.*, 2009; Braunerhjelm *et al.*, 2020). Such worker mobility serves as an important source of knowledge flows and spillovers, provides host country the labor force with sophistication in green technologies who can guide the eco-innovation activities of domestic firms and increase the awareness of environmental issues and practices (Li *et al.*, 2018). Green technologies, organization, green management and production skills, and international marketing techniques embedded in these former employees of FIEs may enhance their new organizations' eco-innovation performance. The more complex the new piece of knowledge, the more important the personal contact or mobility (Todo *et al.*, 2009; Gibson and McKenzie, 2014; Breschi *et al.*, 2020). Inter-personal communication and interaction can facilitate the green knowledge recipient's understanding of the new green knowledge and technologies.

Third, industrial linkages, including both backward linkages and forward linkages, are another channel of spillovers. Backward linkages exist when FIEs transact with suppliers in upstream industries, while forward linkages arise when FIEs provide advanced and high-quality green intermediate inputs and machinery equipment of high quality to domestic firms, or when FIEs do businesses with local customers and provide domestic customers with green technology support. Domestic firm can access and assimilate globally dispersed pools of green ideas and knowledge by collaborating with more advanced FIEs. FIEs send a clear signal of their endorsement of greener products and production processes, which incentivizes their suppliers to conduct eco-innovation so as to meet FIEs' requirements, as when failing to do so, FIEs may terminate the transactional relationships and seek alternative suppliers (Wu and Ma, 2016). Environmental requirements on the quality of inputs from FIEs may lead to eco-innovation and improve the efficiency of local collaborative firms. To benefit from the improved performance of intermediate input suppliers, FIEs may intentionally transfer knowledge to their suppliers to improve production efficiency in the value chain and make their products meet quality standards (Lin *et al.*, 2009). In order to reduce dependency on a single supplier, foreign customers such as FIEs tend to develop technical relationships with multiple suppliers, including diffusing technologies widely either by direct transfer to firms or by spillovers. These FIEs are mostly users of final products. This relationship contributes to the green knowledge flows to the supply sectors and the entry in the supplier market (Blalock and Gertler, 2008). As for forward spillovers, domestic customers could benefit from the environmental knowledge embodied in products, processes, and technologies through the deliberate transfer from foreign suppliers (Jindra *et al.*, 2009). Foreign upstream firms also provide advanced environmental friendly input and better quality of equipment with less energy consumption to domestic firms, which offer domestic firms the opportunities to learn about green product design and process eco-innovation.

Finally, spillovers may also occur through market competition. The entry of FIEs affects the existing equilibrium and imposes competitive threats to domestic firms. Market competition may be a two-edged sword in terms of its effect on eco-innovation. A market that lacks competition could lead to inefficiency and result in sluggish eco-innovative activities. On the other hand, foreign firms not only bring low-emission technologies and practice, but also increase the competition in the host country, which pushes domestic firms to adjust their production process, improve their technological levels, acquire advanced labor skills, and enhance eco-innovation capabilities (Zarsky, 1999). Hence, competition effects would also enhance domestic firms' eco-innovation performance. However, in some circumstances, the competition effects of FDI may negatively affect domestic firms' eco-innovation. The entry of FIEs may also make competing domestic firms worse off (Aitken and Harrison, 1999), as they will be competing for market share, human capital, and financial resources. When losing market share to FIEs, domestic firms may be forced to save costs by cutting down risky activities such as innovation. They may divert human capital and financial resources to production rather than innovation to remain in competition.

FDI is a vehicle for introducing advanced technologies and managerial knowledge to developing countries. It may indeed stimulate eco-innovation because it opens door for domestic firms to learn advanced green knowledge, resources, and learning opportunities and it exerts competitive pressures on domestic firms, forcing them to boost eco-innovation so as to remain competitive. Following these theoretical arguments, we hypothesize that:

Hypothesis 1a: FDI spillover effects are positively associated with eco-innovation of domestic firms in China through industrial horizontal linkage.

Hypothesis 1b: FDI spillover effects are positively associated with eco-innovation of domestic firms in China through industrial vertical linkage.

2.2 Development of contingent effect hypotheses

Sharing of knowledge and jointly developing solutions is essential to address climate change and global challenges (Popp, 2011; Suresh, 2012). FDI and its economic agent (FIEs) have been charged with both a "race to the top" and a "race to the bottom" in environmental performance (Dean *et al.*, 2009; Bu and Wagner, 2016; Rudolph and Figge, 2017; Cheng *et al.*, 2018).

The Pollution Halo Hypothesis proposes that tighter environmental requirements at home trigger FDI to develop innovation solutions. FDI transfers their greener technologies such as pollution abatement technologies, renewable energy-related technologies, and energy-conserving technologies to host countries. As a result, FDI reduces the emissions in host countries (Eskeland and Harrison, 2003). Numerous studies have clarified the positive "Halo" impact of FDI on the environment (see, e.g., Cole *et al.*, 2008 for Ghana; Demena and Afesorgbor, 2020 for meta-analysis; Dong *et al.*, 2019 for China; Pao and Tsai, 2011 for BRIC countries; Pazienza, 2019 for OECD economies; Zhang and Zhou, 2016 for China).

On the contrary, the Pollution Haven Hypothesis suggests that FDI relocates their pollution-intensive activities to developing countries so as to escape the tighter environmental requirements at home, leading to a positive relationship between FDI inflow and emissions (see, e.g., Javorcik and Wei, 2004; He, 2006; Dietzenbacher and Mukhopadhyay, 2007; Levinson and Taylor, 2008; Zeng and Zhao, 2009; Almulali and Foon Tang, 2013; Rezza, 2013; Baek, 2016; López *et al.*, 2018; Shahbaz *et al.*, 2018, 2019; Hanif *et al.*, 2019; Sarkodie and Strezov, 2019).

With regard to the evidence for studies in China, FDI impact on air quality demonstrates industry heterogeneity (Jiang *et al.*, 2018). Meanwhile, there also exists regional heterogeneity. For instance, Zhang and Zhou (2016) reveal that FDI reduces CO_2 emission in China, but there is evidence of regional variation due to different technology spillover effects and industrial structure. While Bao *et al.* (2011) emphasize the geographic agglomeration, Lan *et al.* (2012) stress human capital. This could inform selection of specific factors for the contingency analysis.

In the remainder of this section, we consider the contingency role of industrial and regional factors in the nexus of FDI green spillovers and eco-innovation. Section 2.2.1 explores the industry heterogeneity in terms of technology intensity, pollution intensity, and competition intensity. Subsequently, Section 2.2.2 explores the regional heterogeneity in terms of environmental regulation.

2.2.1 Industry heterogeneity

First, technology-intensive industry has a relatively high investment for R&D activities. Spillover effects greatly depend on local firms' R&D capabilities and firms in technology-intensive industries are likely able to absorb technology spillovers from foreign firms (Wang *et al.*, 2017). Compared with industries with low technology intensity, industries with high technology intensity could absorb and utilize green technologies from FDI spillovers more efficiently. Furthermore, the human capital in these firms is relatively high, with the long-term sustainable investment in fostering human capital and promoting new technologies, and thus such firms usually have higher possibility to gain higher absorptive capacity. Facing foreign capital inflows, firms with high technology intensity can absorb and learn the advanced green technologies and management experience of FIEs based on their better learning and absorptive capacity, and thereby these firms gain more from FDI spillovers (Blalock and Gertler, 2009; Liang, 2017).

Second, pollution-intensive industries refer to those industries that directly or indirectly produce numerous pollutants. Pollution intensity is another important factor to consider, as eco-innovation is more associated with pollution-intensive industries (Kunapatarawong and Martínez-Ros, 2016; García-Marco *et al.*, 2020). In the context of various policies and actions to protect the environment, such as "winning the battle against the blue sky" and achieving the goal of carbon neutrality, pollution-intensive industries are facing tremendous pressure on energy conservation and emissions reduction (Kunapatarawong and Martínez-Ros, 2016;

Zheng and Shi, 2017). This increases the incentive of these industries to engage in upgrading their environmental technologies, enhancing product and process innovation, and greening their supply chains and management practices (Krishnan *et al.*, 2000), as well as to reduce their environmental pollution by providing environmentally friendly products to meet environmental standards and gain competitiveness in the market. Therefore, pollution-intensive industries incentivize firms to devote more effort in acquiring valuable green technologies and management practices and learning more from FDI spillovers, which is a powerful driving force behind the improvement of eco-innovation in pollution-intensive industries.

Third, in competitive industries, the emergence of new competitors threatens the survival of incumbents and their temporary profit, which prompts firms to shorten the innovation cycle (Aghion *et al.*, 1999). Besides, to gain from the potential rents from success in industrial competition, innovation is spurred. This can also meet the need to maintain existing rents in the face of competitive threat (Carlin *et al.*, 2001). In terms of the competition intensity, the fierce competitive environment makes firms more active in learning foreign green technologies, and then conduct independent green R&D activities through intense cooperation with FIEs. Meanwhile, facing competition from other firms in the same industry, firms have more incentives to continuously increase their investments in innovation activities and in training of employees to improve their own innovation capabilities (Porter, 1990; Aghion *et al.*, 2005). In particular, with environmental standards becoming stricter, firms need to provide environmental-friendly differentiated products, set up a good image in the market, and strive for a favorable position in the fierce competition. Therefore, FDI green spillovers can be better utilized in highly competitive industries. Based on the above discussions that the spillover effects of FDI on eco-innovation of domestic firms are contingent on industry conditions, we propose the following hypotheses:

Hypothesis 2a: For firms in technology intensive industries, the spillover effects of FDI on eco-innovation of domestic firms are stronger.

Hypothesis 2b: For firms in polluting intensive industries, the spillover effects of FDI on eco-innovation of domestic firms are stronger.

Hypothesis 2c: For firms in competitive industries, the spillover effects of FDI on eco-innovation of domestic firms are stronger.

2.2.2 Regional heterogeneity

Different policy making, comparative advantages, and resource endowments across different regions in China lead to regional heterogeneity. Therefore, regional heterogeneity is also one of the important factors affecting FDI spillovers on eco-innovation. This section explores the regional heterogeneity in terms of environmental regulation.

Environmental regulation is an essential policy instrument for the government to promote technological innovation and improve firms' economic performance and reduction in pollution (Ambec and Lanoie, 2008; Dechezleprêtre and Sato, 2017; Ren *et al.*, 2018; Yang and Song, 2019; Chen *et al.*, 2021). Conventional wisdom assumes that environmental regulations adversely affect a firm's competitiveness by imposing additional financial burdens such as compliance costs and increasing opportunity costs through allocating scarce resources to comply with environmental regulations (Palmer *et al.*, 1995). On the other hand, the strong version of the "Porter Hypothesis" (Porter and Van der Linde, 1995) challenges the conventional wisdom by arguing that properly designed ecological regulations would lead to a "win-win" situation; that is, firms simultaneously achieve higher levels of profits and produce green products because environmental regulations often boost R&D and stimulate innovation and economic growth (D'Agostino, 2015; Xie *et al.*, 2017).

The "double externality" problem of eco-innovation, which refers to the fact that both technology and environmental externalities result in suboptimal investments and reduce incentives in eco-innovation, provides an important motive for environmental regulation (Beise and Rennings, 2005; Requate, 2005; Faber and Frenken, 2009; Prieger and Sanders, 2012;

Kesidou and Wu, 2020; Song *et al.*, 2020). As such, environmental regulation is an important policy instrument that encourages the adoption of an environmental strategy.

Environmental regulations also create normative consensus and a shared cognitive base between FIEs and domestic firms in the same geographical region or organizational field. This could contribute to facilitating more interactions between the two groups of firms and result in greater FDI spillovers to enhance domestic firms' eco-innovation activities (Child *et al.*, 2007; Zhou *et al.*, 2019). The heterogeneity in environmental regulations may affect the motivations of local firms to learn to be green(er). The actual stringency of environmental regulation varies across Chinese subnational regions (Shi and Xu, 2018). Some studies have provided evidence that home subnational environmental regulation stringency influences firms' behavior (Bu and Wagner, 2016). Therefore, firms in regions with stringent environmental regulations may have a higher propensity to find environmental-friendly solutions and conduct eco-innovation, and learn more advanced knowledge/technologies from foreign firms. Based on these arguments, we assume that spillover effects of FDI on eco-innovation of domestic firms are contingent on regional heterogeneity. Therefore, the following hypothesis is developed:

> *Hypothesis 3: In regions with more stringent environmental regulations, the spillover effects of FDI on eco-innovation are stronger.*

3. Data and methodology

3.1 Data

We use the number of green patents to measure eco-innovation. Patent data were collected from the database of China's National Intellectual Property Administration (CNIPA), formerly China's State Intellectual Property Office (SIPO).[2] The database contains detailed information on patents (Dang and Motohashi, 2015), including application number, application date, International Patent Classification (IPC), patent type (invention, utility model, or appearance design), applicants' names and addresses, inventors' names, and patent attorneys' names and addresses. To identify eco-innovation, we use a detailed patent search strategy developed by the OECD (Haščič and Migotto, 2015), combined with the "IPC Green Inventory" provided by the World Intellectual Property Organization.[3] Green patents refer to inventions, utility models, and appearance designs with environmental technologies that can improve energy efficiency, reduce pollution, and achieve sustainable development. They include alternative energy, environmental protection materials, pollution control and recycling technologies, energy conservation, and emission reduction technologies.

Our second database is obtained from the Annual Surveys of Industrial Enterprises in China (ASIEC) dataset from the National Bureau of Statistics (NBS). The dataset covers all Chinese firms with an annual turnover of more than RMB 5 million during the period 1998–2013. It contains detailed information about firms, including their name, ownership, location, industry, assets, revenue, investment, profit, export, employment, and cash flow. The data are cleaned via extensive checks for nonsense observations, outliers, coding mistakes, and the like. In particular, we dropped observations if they had missing values for key financial variables (such as total assets, fixed assets, and industrial output) or if the number of employees was reported to be less than 10.[4] We use the concordance table constructed by Brandt *et al.* (2012) and then link four-digit industries in the ASIEC data with input-output (IO) sectors following Brandt *et al.* (2017). Based on this concordance method, Lu *et al.* (2017) examine the FDI spillover effects on firm productivity. For the definition and descriptive statistics of main variables, please see Table 1.

[2] For the overall trends in eco-innovation by Chinese firms over time and across provinces, please see Figures A1 and A2 in the Appendix.

[3] http://www.wipo.int/classifications/ipc/en/green_inventory/

[4] The exact number of firms covered in this study is 190,595. In our regression analysis, we use an unbalanced panel dataset.

Table 1. Variable definition and summary statistics

Index code	Variables	Definition	Mean	Std. Dev.
Ecoinno	Eco-innovation (firm-level)	Green patents granted to each firm (take logarithm)	0.011	0.126
Horizontal	Horizontal FDI (industry-level)	The share of output of foreign-invested enterprises (FIEs) in total industrial output	0.204	0.160
Forward	Forward FDI (industry-level)	The forward FDI weighted average by the ratio of input purchased from upstream sectors	0.079	0.061
Backward	Backward FDI (industry-level)	The backward FDI is weighted average by the ratio of output supplied to downstream sectors	0.107	0.167
Capital	Firm capital (firm-level)	Firm capital input (measured by total assets, take logarithm)	10.045	1.493
Labor	Firm labor (firm-level)	Firm labor input (measured by total number of employees, take logarithm)	4.807	1.087
Wage	Human capital stock (firm-level)	Wage/total employee (take logarithm)	2.542	0.698
Patentstock	Patent stock (firm-level)	The patent stock of the firm in the previous years with 15 depreciation rate (take logarithm)	0.150	0.571

3.2 Methodology

Based on firm-level data from 75 IO manufacturing sectors during the period 1998–2013, following the previous literature to investigate the spillover effects of FDI on firm performance (e.g., Liu, 2007; Liang, 2017), spillover effects are measured by the impact of foreign presence on output level or labor productivity of domestic firm. Together with other factors that are supposed to influence performance of domestic firms, such as capital, labor, the stock of firm specific factors, we employ the following empirical models to investigate the industrial spillover effects of FDI on firm eco-innovation.

$$\mathrm{Ecoinno}_{\mathrm{ijt}} = \alpha_0 + \alpha_1 \mathrm{Horizontal}_{\mathrm{j,t-1}} + \alpha_2 \mathrm{X}_{\mathrm{j,t-1}} + \delta_{\mathrm{i}} + \delta_{\mathrm{p}} + \delta_{\mathrm{t}} + \varepsilon_{\mathrm{ijt}} \quad (1)$$

$$\mathrm{Ecoinno}_{\mathrm{ijt}} = \beta_0 + \beta_1 \mathrm{Forward}_{\mathrm{j,t-1}} + \beta_2 \mathrm{Backward}_{\mathrm{j,t-1}} + \beta_3 \mathrm{X}_{\mathrm{j,t-1}} + \delta_{\mathrm{i}} + \delta_{\mathrm{p}} + \delta_{\mathrm{t}} + \varepsilon_{\mathrm{ijt}} \quad (2)$$

where $Ecoinno_{ijt}$ is measured as the number of green patents granted to firm *i* in sector *j* and year *t*. X is a vector of control variables. We control for firm-level effects using firm capital input (*Capital*), labor input (*Labor*), human capital stock (*wage*), and patent stock (*patentstock*). Firms with more capital and labor input are more capable of benefiting from FDI spillovers (Driffield *et al.*, 2021); firm wage can reflect the human capital stock, as high wage indicates firms with high level of human capital (Wakelin, 1998; Sun, 2010); firm patent stock can measure firm accumulated effort in overall innovation (Czarnitzki and Toole, 2011; Dechezlepretre *et al.*, 2015). δ_i is firm-fixed-effects, δ_p is province-fixed-effects, δ_t is year-fixed-effects, and ε_{ijt} is error term. All independent variables are lagged by one year.

$Horizontal_{jt\text{-}1}$, $Backward_{jt\text{-}1}$, and $Forward_{jt\text{-}1}$ are the regressors of interest, capturing FDI in sector *j* and year *t-1*, backward FDI in sector *j* and year *t-1*, and forward FDI in sector *j* and year *t-1*, respectively. Consistent with previous studies, we measure FDI spillovers using the presence of FIEs which is a widely accepted measure (Xu and Sheng, 2012; Perri and Peruffo, 2016; Liang, 2017; Lu *et al.*, 2017; Rojec and Knell, 2018). The concept of FDI spillovers as used in this study mainly reflects the unintended or unanticipated diffusion of knowledge. $Horizontal_{jt}$ is measured by the share of output of FIEs in industrial total output, i.e.,

$$Horizontal_{jt} = \frac{\sum^{i} \in \Omega_{jt} FDI\_firm_{ijt} \times output_{ijt}}{\sum^{i} \in \Omega_{jt} output_{ijt}} \tag{3}$$

where $Output_{ijt}$ measures the output of firm i of sector j in year t; FDI_firm_{ijt} measures the foreign equity share of firm i of sector j in year t; and Ω_{jt} is the set of firms in sector j in year t.

Following Javorcik (2004), we construct the backward and forward industrial FDI index based on China's 2002 Input–Output Table. Specifically, for domestic firm i in sector j in year t, its backward FDI is

$$Backward_{jt} = \sum_{m\ if\ m \neq j} \alpha_{jm} \times Horizontal_{jt} \tag{4}$$

where α_{jm} is the ratio of sector j output supplied to sector m. Its forward FDI is

$$Forward_{jt} = \sum_{k\ if\ k \neq j} \beta_{jk} \times \frac{\sum^{i} \in \Omega_{jt} FDI\_firm_{ijt} \times \left(output_{ijt} - EX_{ijt}\right)}{\sum^{i} \in \Omega_{jt} \left(output_{ijt} - EX_{ijt}\right)} \tag{5}$$

where β_{jk} is the ratio of inputs purchased by sector j from sector k; EX_{ijt} the export value of firm i at time t; $output_{ijt}$–EX_{ijt} is the size of firm i's output for domestic market.

Furthermore, to test our second and third hypotheses, we introduce the interaction terms between the contingent factors and FDI spillover variables, respectively, to examine the contingency role of industrial and regional factors in nexus of FDI green spillovers and eco-innovation. We estimate the following regressions:

$$\begin{aligned} \text{Ecoinno}_{\text{ijt}} = {} & \alpha_0 + \alpha_1 \text{Horizontal}_{\text{j,t-1}} + \alpha_2 \text{Horizontal}_{\text{j,t-1}} \times \text{contingent factors} \\ & + \alpha_3 \text{contingent factors} + \alpha_4 \text{X}_{\text{j,t-1}} + \delta_{\text{i}} + \delta_{\text{p}} + \delta_{\text{t}} + \varepsilon_{\text{ijt}} \end{aligned} \tag{6}$$

$$\begin{aligned} \text{Ecoinno}_{\text{ijt}} = {} & \beta_0 + \beta_1 \text{Forward}_{\text{j,t-1}} + \beta_2 \text{Backward}_{\text{j,t-1}} + \beta_3 \text{Forward}_{\text{j,t-1}} \times \text{contingent factors} \\ & + \beta_4 \text{Bactward}_{\text{j,t-1}} \times \text{contingent factors} + \beta_5 \text{contingent factors} + \beta_6 \text{X}_{\text{j,t-1}} + \delta_{\text{i}} \\ & + \delta_{\text{p}} + \delta_{\text{t}} + \varepsilon_{\text{ijt}} \end{aligned} \tag{7}$$

where *contingent factors* include technology intensity, pollution intensity, competition intensity, and environmental regulation stringency.

Considering the potential endogeneity issue, we follow Park *et al.* (2010) and use exchange rate changes weighted by the 1995 share of FDI in sector j to construct the instrumental variable (IV) ($ERindex_{jt}$) based on the data from International Financial Statistics from International Monetary Fund and ACIE in 1995. To be more specific, let the set of all countries investing in China be indexed by n (from 1 to N). For each country n in year t, the change in the exchange rate is

$$ERchange_{nt} = [\ln(E_{nt}) - \ln(P_{nt})] - [\ln(E_{n,1995}) - \ln(P_{n,1995})] \tag{8}$$

where E_{nt} is the nominal exchange rate (currency units per SDR, periods of average) and P_{nt} is the price level (consumer price index) for country n in year t.

Then, for sector j in year t, the weighted average exchange rate changes across the FDI countries are

$$ERindex_{jt} = \sum_{n \in [1,N]} s_{jn} ERchange_{nt} \tag{9}$$

where s_{jn} is the share of FDI in sector j in 1995 accounted for country n with $\sum_{n \in [1,N]} s_{jn} = 1$. Therefore, $Erindex_{jt}$ is the IV for horizontal FDI in sector j in year t. The instruments for backward and forward FDI presence (indexed as *Erindex_back* and *Erindex_for*, respectively) are constructed based on I-O coefficients, as mentioned above.

The exchange rate index (*Erindex*) is based solely on the FDI countries prior to our sample period (1998–2013), and the exchange rate change across foreign countries can be regarded as exogenous to the performance of domestic firms. In addition, the more the currency of foreign countries depreciates, the more they tend to invest abroad, indicating that the exchange rate change across foreign countries is directly correlated with the presence of FDI. Therefore, we can use this shock as the IVs for FDI presence.

4. Empirical results

4.1 Basic results

The benchmark results are reported in Table 2, indicating that both horizontal and vertical FDI spillovers have significant positive impact on firm eco-innovation. As shown in columns (3) and (4), the coefficients are 0.011 for horizontal FDI spillovers, 0.062 and 0.014 for forward and backward FDI spillovers, respectively, which are all significant at 5% level. A one percent point increase in the share of foreign firms in an industry leads to, on average, a 1.1% increase in eco-innovation of domestic firms in the same industry, a 6.2% increase in the downstream industry, and a 1.4% increase in the upstream industry. Hypotheses 1a and 1b are verified. In the industrial linkages, FDI spillovers are embodied in the advanced technologies and organizational management practice, as well as the communication and interaction among upstream and downstream FIEs. FIEs may intentionally transfer green knowledge, green intermediate inputs, and machinery equipment of high quality to their suppliers to improve production efficiency in the value chain and ensure that products meet quality standards, or they may unintentionally impart their technical knowledge and practical experience to local upstream and downstream partners. The advanced green technologies and management experience from upstream industries can enhance domestic firms' eco-innovation and the stringent environmental standards from downstream

Table 2. The spillover effects of industrial FDI on eco-innovation of domestic firms

Dependent variable *Ecoinno*	(1)	(2)	(3)	(4)
Horizontal	0.055***		0.011**	
	(0.005)		(0.005)	
Forward		0.134***		0.062***
		(0.016)		(0.017)
Backward		0.013***		0.014***
		(0.003)		(0.003)
Capital			0.003***	0.003***
			(0.000)	(0.000)
Labor			0.003***	0.003***
			(0.001)	(0.001)
Wage			0.005***	0.004***
			(0.000)	(0.000)
Patentstock			0.021***	0.021***
			(0.001)	(0.001)
Constant	0.009***	0.007***	−0.054***	−0.056***
	(0.001)	(0.001)	(0.004)	(0.004)
Firm FE	Yes	Yes	Yes	Yes
Year FE	Yes	Yes	Yes	Yes
Province FE	Yes	Yes	Yes	Yes
Observations	613,310	613,310	411,348	411,348
Adjusted R^2	0.232	0.232	0.291	0.291
Method	Panel FE	Panel FE	Panel FE	Panel FE

The standard error is in parentheses.
*** and ** represent the significance levels of 1% and 5% respectively.
FE, fixed effect.

Table 3. The spillover effects of industrial FDI on eco-innovation of domestic firms (IV estimates)

Dependent variable *Ecoinno*	(1)	(2)	(3)	(4)
Horizontal	0.243***		0.157*	
	(0.088)		(0.085)	
Forward		0.981***		0.235*
		(0.093)		(0.131)
Backward		0.069***		0.026*
		(0.015)		(0.014)
Capital			0.001	0.001***
			(0.001)	(0.000)
Labor			0.003***	0.002***
			(0.001)	(0.000)
Wage			0.002***	0.001***
			(0.001)	(0.000)
Patentstock			0.019***	0.004***
			(0.001)	(0.000)
Firm FE	Yes	Yes	Yes	Yes
Year FE	Yes	Yes	Yes	Yes
Province FE	Yes	Yes	Yes	Yes
Observations	613,310	613,310	411,348	411,348
Weak identification test (F statistics)	1413.89	2127.13	1014.97	894.00

The standard error is in parentheses.
*** and *represent the significance levels of 1% and 5%, respectively.

industries, and consumer preferences for environmental-friendly products also push firms to put efforts into green innovative activities.

Given the concerns over the potential endogeneity,[5] we further employ the IV[6] strategy. Table 3 presents the results of IV estimates. The IV is a strong predictor of FDI with F statistics of 1413.89 and 1016.26 for columns (1) and (3), which are greater than 16.38, the critical value based on two stage least squares (TSLS) size with the desired maximal size 10%, and with F statistics of 2127.13 and 894.91 for columns (2) and (4), which are greater than 7.03, the critical value based on TSLS size with the desired maximal size 10% (Stock and Yogo, 2005). We still find significant positive effect of FDI spillovers in horizontal, forward, and backward linkages on firm eco-innovation, with the coefficient of 0.157, 0.234, and 0.025, respectively.

4.2 Results on the contingent effects

4.2.1 Industry heterogeneity

As technology intensity would affect the FDI spillover effects on firm eco-innovation, we employ two indicators to measure technology intensity. As shown in Table 4, columns (1) and (2) are empirical results based on the classification of high-tech industries by the NBS[7] (*hightech*, a dummy variable equals 1 if firms are in high-tech industries and 0 otherwise), and columns (3) and (4) are based on R&D measure, which is firm R&D intensity weighted by an average R&D intensity of the respective industry (*R&D*). The interaction terms of FDI spillovers through horizontal linkage and the technology intensity (0.024 for *Horizontal* × *hightech,* 0.001 for *Horizontal* × *R&D*), FDI spillovers through vertical linkage and the technology intensity (0.257 for *Forward* × *hightech,* 0.048 for *Backward* × *hightech;* 0.005 for *Forward* × *R&D,* 0.001 for *Backward* × *R&D*) all show statistically significant positive effects, indicating that the spillover effects

[5] Such as, potential omitted variables. FIEs may be more willing to invest in industries characterized by distinctive domestic technological capabilities and more successful innovative performance, justifying concerns of reverse causality (Crescenzi *et al.*, 2015).

[6] The instrumental variable is explained in Section 3.2. We also employ system Generalized Method of Moments (GMM); please see Appendix A2.

[7] http://www.stats.gov.cn/tjsj/tjbz/201812/t20181218_1640081.html

Table 4. Testing for industry heterogeneity (technology intensity)

Dependent variable *Ecoinno*	(1)	(2)	(3)	(4)
Horizontal	0.006**		0.052***	
	(0.003)		(0.012)	
Forward		0.049***		0.295***
		(0.017)		(0.041)
Backward		0.012***		0.014*
		(0.003)		(0.008)
Horizontal × *hightech*	0.024***			
	(0.008)			
Forward × *hightech*		0.257***		
		(0.039)		
Backward × *hightech*		0.048***		
		(0.010)		
hightech	−0.008***	−0.038***		
	(0.002)	(0.005)		
Horizontal × *R&D*			0.001***	
			(0.000)	
Forward × *R&D*				0.005***
				(0.001)
Backward × *R&D*				0.001***
				(0.000)
R&D			−0.0002***	−0.001***
			(0.00005)	(0.00006)
Controls	Yes	Yes	Yes	Yes
Firm FE	Yes	Yes	Yes	Yes
Year FE	Yes	Yes	Yes	Yes
Province FE	Yes	Yes	Yes	Yes
Observations	411,348	411,348	207,813	207,813
Adjusted R^2	0.181	0.291	0.395	0.395

The standard error is in parentheses.
***, **, and * represent the significance levels of 1%, 5%, and 10%, respectively.

of FDI on eco-innovation are more pronounced in the industries with higher technology intensity. Hypothesis 2a is confirmed. With higher technology intensity, firms have more advantages in advanced equipment and cutting-edge technologies, and can better learn and absorb advanced green knowledge and technologies from FIEs. The coefficients of the interaction terms of forward FDI and technology intensity (*Forward* × *hightech, Forward* × *R&D*) are consistently larger than those of the interactions between backward FDI and technology intensity (*Backward* × *hightech, Backward* × *R&D*), showing that technology-intensive firms can absorb advanced green technologies and production experience from upstream FDI, and the size of this effect is greater than the benefits based on the environmental standards and requirements from downstream FDI.

We assume that the pollution intensity of the industry will affect the spillover effects of FDI. Following Duque and Gilraine (2022), we use coal consumption divided by total sales value (*coalpro*) to measure the pollution intensity across industries. As presented in columns (1) and (2) of Table 5, firms in industries with high pollution intensity can generate more significantly positive green spillover effects compared to those in industries with low pollution intensity, with the coefficients of 0.119 for *Horizontal* × *coalpro*, 1.485 and 0.458 for *Forward* × *coalpro* and *Backward* × *coalpro*, respectively, which supports Hypothesis 2b. With the responsibility for cleaning production, firms in pollution-intensive industries face more pressure on improving the cleanliness of technology. Therefore, firms in pollution-intensive industries have a greater incentive to engage in upgrading their environmental technologies, improving the products and processes for environmental benefits, and greening their supply chains and management practices. These firms would invest more in green innovative activities and develop their green technologies.

In terms of competition intensity, a highly competitive industry may push firms to innovate. We use the Herfindahl Hirschman Index (*HHI*) to reflect the degree of market concentration.

Table 5. Testing for industry heterogeneity (pollution intensity and competition intensity)

Dependent variable *Ecoinno*	(1)	(2)	(3)	(4)
	Pollution intensity		Competition intensity	
Horizontal	0.013***		0.010*	
	(0.002)		(0.005)	
Forward		0.078***		0.047***
		(0.021)		(0.017)
Backward		0.006*		0.011***
		(0.004)		(0.004)
Horizontal × *coalpro*	0.119**			
	(0.050)			
Forward × *coalpro*		1.485**		
		(0.688)		
Backward × *coalpro*		0.458***		
		(0.073)		
coalpro	−0.0005***	−0.147***		
	(0.0002)	(0.042)		
Horizontal × *HHI*			−0.017***	
			(0.004)	
Forward × *HHI*				−0.057***
				(0.014)
Backward × *HHI*				−0.001
				(0.003)
HHI			0.0004	0.001
			(0.001)	(0.001)
Controls	Yes	Yes	Yes	Yes
Firm FE	Yes	Yes	Yes	Yes
Year FE	Yes	Yes	Yes	Yes
Province FE	Yes	Yes	Yes	Yes
Observations	361,358	361,358	373,335	373,335
Adjusted R^2	0.076	0.311	0.293	0.293

The standard error is in parentheses.
***, **, and * represent the significance levels of 1%, 5%, and 10%, respectively.

The lower value of the *HHI* reflects the fiercer market competition in the respective industry. As reported in Table 5 columns (3) and (4), both the horizontal and forward FDI inflows have more significant positive effect on stimulating eco-innovation of domestic firms in industries with fiercer competition, with the coefficients of −0.017 and −0.057 for *Horizontal* × *HHI* and *Forward* × *HHI*, respectively, which support Hypothesis 2c. Compared with firms in low-competitive industries, those in high-competitive industries can obtain significant FDI green technology spillover effects, which reveals that the fierce competition will encourage firms to learn advanced green technologies from FDI and strengthen the cooperation with FIEs through the forward industrial linkages.

4.2.2 Regional heterogeneity

We further examine whether regional heterogeneity in environmental regulations would lead to a difference in the spillover effects of FDI on firm eco-innovation. We employ environmental pollution abatement and control investment (*envinvest*) (Zhang *et al.*, 2011) and the decontamination rate of urban refuse (*decontamination*) to measure the stringency of environmental regulations. The actual stringency of environmental regulation varies across Chinese subnational regions (Shi and Xu, 2018). As shown in Table 6, the green spillover effects of FDI on firm eco-innovation are more significant in the regions with more stringent environmental regulations, with the coefficients of 0.012 for *Horizontal* × *envinvest,* 0.020 for *Horizontal* × *decontamination*, 0.049 for *Forward* × *envinvest,* 0.008 for *Backward* × *envinvest*, 0.029 for *Forward* × *decontamination*,

Table 6. Testing for regional heterogeneity (environmental regulation stringency)

Dependent variable *Ecoinno*	(1)	(2)	(3)	(4)
Horizontal	0.011*		0.014*	
	(0.006)		(0.008)	
Forward		0.089***		0.114***
		(0.023)		(0.026)
Backward		0.010**		0.012***
		(0.004)		(0.004)
Horizontal × *envinvest*	0.012*			
	(0.006)			
Forward × *envinvest*		0.049***		
		(0.019)		
Backward × *envinvest*		0.008**		
		(0.003)		
envinvest	0.001	−0.003*		
	(0.002)	(0.002)		
Horizontal × *decontamination*			0.020***	
			(0.005)	
Forward × *decontamination*				0.029*
				(0.016)
Backward × *decontamination*				0.005*
				(0.003)
decontamination			−0.003***	−0.003**
			(0.001)	(0.001)
Controls	Yes	Yes	Yes	Yes
Firm FE	Yes	Yes	Yes	Yes
Year FE	Yes	Yes	Yes	Yes
Province FE	Yes	Yes	Yes	Yes
Observations	302,467	302,467	225,661	225,661
Adjusted R^2	0.333	0.333	0.310	0.310

The standard error is in parentheses.
***, **, and * represent the significance levels of 1%, 5%, and 10%, respectively.

and 0.005 for *Backward* × *decontamination*, which are all significant at the 10% level. Hypothesis 3 is verified. Firms in regions with properly stringent environmental regulations may have a higher propensity to find environmentally friendly solutions and conduct eco-innovation and learn more advanced knowledge/technologies from foreign firms. The coefficients of the interaction terms of forward FDI and environmental regulation stringency (*Forward* × *envinvest*) are consistently larger than those of the interactions between backward FDI and environmental regulation stringency (*Backward* × *envinvest*), showing that when the environmental regulation stringency increases, the extent to which firms benefit from the advanced green technologies of upstream FDI and then engage in eco-innovation is greater than the extent to which they benefit from downstream FDI.

4.3 Robustness checks

In the basic regression analysis, we use the number of green patents granted to measure eco-innovation, since patent counts measure the quantity but not the quality of innovation (Li, 2012; Dang and Motohashi, 2015). The CNIPA grants three types of patents, including invention patents, utility model patents, and appearance design patents, among which the invention patents are considered to be of the highest novelty and technological inventiveness. Therefore, we rerun equation (1) using the number of green invention patents (logarithm) (*Ecoinno_invention*) as alternative dependent variable. The results shown in Table 7 columns (1) and (2) remain robust, indicating that FDI spillovers can also significantly promote firm eco-innovation quality, with the

Table 7. Robustness checks: alternative measures

Dependent variable	(1)	(2)	(3)	(4)
	Ecoinno_invention		*Ecoinno*	
	Alternative dependent variable: green invention patents		Alternative FDI spillover indicators: based on patent data	
Horizontal	0.002** (0.001)			
Forward		0.028*** (0.011)		
Backward		0.004* (0.002)		
Horizontal_pat			0.111*** (0.033)	
Forward_pat				0.288** (0.114)
Backward_pat				0.367*** (0.071)
Controls	Yes	Yes	Yes	Yes
Firm FE	Yes	Yes	Yes	Yes
Year FE	Yes	Yes	Yes	Yes
Province FE	Yes	Yes	Yes	Yes
Observations	411,348	411,348	410,820	410,820
Adjusted R^2	0.048	0.260	0.292	0.292

The standard error is in parentheses.
***, **, and * represent the significance levels of 1%, 5%, and 10%, respectively.

Table 8. Robustness checks: adding more controls

Dependent variable *Ecoinno*	(1)	(2)	(3)	(4)
Horizontal	0.010** (0.005)		0.048*** (0.012)	
Forward		0.061*** (0.017)		0.203*** (0.044)
Backward		0.013*** (0.003)		0.015* (0.008)
greenindustry	−0.002 (0.001)	−0.001 (0.001)		
rad			0.001* (0.001)	0.001* (0.001)
Controls	Yes	Yes	Yes	Yes
Firm FE	Yes	Yes	Yes	Yes
Year FE	Yes	Yes	Yes	Yes
Province FE	Yes	Yes	Yes	Yes
Observations	411,348	411,348	207,813	207,813
Adjusted R^2	0.291	0.291	0.395	0.395

The standard error is in parentheses.
***, **, and * represent the significance levels of 1%, 5%, and 10%, respectively.

coefficient of 0.002, 0.028, and 0.004 for FDI spillovers in horizontal, forward, and backward linkages, respectively.

Different measures can capture different channels or aspects of spillovers from foreign presence (Wei and Liu, 2006). We then construct FDI spillover indicators using the share of patents of FIEs (based on Section 3.2 equations [3]–[5]) to be an alternative measure of the technology spillovers from foreign invested firms The results shown in columns (3) and (4) of Table 7 are consistent with our main results. Notably, different from the basic results, the coefficient of forward linkage effects based on patents is smaller than that of backward linkages as shown in column (4) of Table 7. The possible explanation is that the measure of FDI spillovers using output data (as in our main regressions) captures the spillover from whole production process, including production experience and equipment investment, while the measure using patent data captures the spillover of technology embedded in the contacts between domestic firms and the foreign partners in vertical linkages. Upstream FIEs provide technology experience of more varieties and higher quality at lower costs, which may reduce the pressure for downstream firms to conduct eco-innovation (Chen *et al.*, 2022) and thereby generate a smaller effect of forward FDI spillovers than that of backward spillovers.

We further control whether firms are in green industries[8] (*greenindustry*) and firm R&D investment (*rad*) to see if they influence the FDI spillover effects on firm eco-innovation. As shown in Table 8, the basic regression result still holds when the potential selection bias of green industries or high involvement in R&D activities are controlled.

5. Conclusion

This paper examined the impact of green spillovers from foreign firms on eco-innovation of domestic firms in China, and further explored whether (and how) the relationship between green spillovers and domestic eco-innovation is contingent on industrial conditions and regional institutions.

5.1 Concluding remarks

Firstly, we examined both knowledge flows in the same industry as well as knowledge exchanges in the up- and down-stream industries. The results indicate that FDI green spillovers positively impact the eco-innovation of domestic firms through horizontal and vertical linkages. The study also suggests that industry technology intensity will affect the green spillover effects. High-tech industries have a higher intensity of investment in technology, and have more advantages in technical equipment and R&D experience. As a result, technology-intensive firms have better absorptive capacity, and thereby can make better use of the green spillovers from foreign firms and absorb advanced green technologies and production management experience.

Secondly, evidence indicates that knowledge flows on eco-innovation are better received by domestic firms in pollution-intensive industries. Industries with high pollution intensity face more pressure and responsibilities for eco-innovation. Therefore, firms in pollution-intensive industries can directly learn advanced green technologies and management experience from foreign firms in the same industry, and also benefit from the FDI inflows among industries through the interaction with upstream and downstream FIEs.

Thirdly, FDI spillovers have more significant effects on eco-innovation of firms in highly competitive industries. The highly competitive environment stimulates firms to learn from foreign advanced technologies and management practice, and improves their own capabilities in conducting eco-innovation. In order to survive and maintain market share, firms in highly competitive industries have greater incentives to learn and absorb foreign advanced green knowledge and technologies effectively.

Fourthly, our results also suggest that foreign firms have a positive and significant impact on eco-innovation of domestic firms in regions with more stringent environmental regulations. Proper environmental laws and regulations can promote green spillovers from foreign firms to improve the eco-products or production processes, and enhance eco-innovation capabilities in local firms. The inducement effect of environmental regulation could lead to more significant green spillover effects.

[8] The classification of green industry is based on the "Green Industry Guidance Catalog" issued by the China National Development and Reform Commission. The full list of the green industries can be found at: https://www.amac.org.cn/businessservices_2025/ywfw_esg/esgzc/zczgsc/202007/t20200714_9848.html or https://www.amac.org.cn/businessservices_2025/ywfw_esg/esgzc/zczgsc/202007/P020200805692422001669.pdf.

5.2 Practical implications and limitations

China is regarded as the world factory in the global value chain, but it still faces many difficulties, such as low-added-value products and insufficient independent innovation capabilities. Aiming at making transitions from imitation to innovation, and from manufacturing to creation, China's transition to a green economy is a key concern around the world (Marquis *et al.*, 2011). With eco-innovation becoming an efficient way to protect the ecological environment and achieve sustainable development, green spillovers from foreign firms to domestic firms through industrial horizontal and vertical linkages play an important role in the development of eco-innovations in developing countries. Emerging economies have given eco-innovation an important place in their policy agendas and set up various incentive plans to attract green FDI in the hope of technology spillovers from FIEs to indigenous firm (Noailly and Ryfisch, 2015; Johnson, 2017). China pledged to achieve carbon neutrality before 2060 at the virtual UN General Assembly meeting. This raises a big question about how China can reach this goal. Given that China is a leading recipient of FDI inflows and that it aims to enhance its international competitiveness through innovation, our study provides insightful evidence and a way forward on how to stimulate eco-innovation to protect environment and achieve green development.

Policies could be designed to attract more FDI and encourage their eco-innovation activities in China through national economic diplomacy. Policy makers should reduce restrictions on FDI to encourage inflow of advanced green production technology and input brought by foreign firms. Foreign firms' activities should be reasonably regulated to promote domestic firms to improve the eco-innovation performance through the technology spillovers. Domestic firms should be encouraged to actively foster the absorptive capacity and learn foreign advanced green technologies to benefit from FDI inflows in the industry. Meanwhile, the relationship between domestic and foreign firms in the upstream and downstream linkages should also be strengthened. For managers of domestic firms, there should be more collaboration with foreign firms. In the process of interaction and communication with foreign firms in the forward and backward industrial linkages, domestic firms gain opportunities to learn advanced green environmental standards and technologies and draw on the experience of foreign green production processes and organizational management practice.

In addition, a targeted policy mix should be developed for different industries. Policy makers should efficiently introduce FDI and fully utilize the advanced green technologies as they conduct corresponding investment policies by combining sectoral characteristics with the degree of FDI spillovers (Liu *et al.*, 2017; Hansen and Hansen, 2020). Appropriate funds and policy support for industries with high technology intensity are of great significance as these firms could play leading roles in conducting eco-innovation and stimulating the green transition (Wei *et al.*, 2020). Under the guidance of technology-intensive industries, firms with relatively low technology intensity can be incentivized to catch up with high-tech firms. For pollution-intensive industries, advanced technologies and management experience in clean production, energy conservation, emissions reduction, pollution management, and other green R&D activities from foreign firms should be fully utilized. The advanced knowledge and management practice can help pollution-intensive firms reduce path dependence and improve the cleanliness technologies. A competitive environment is also of great importance to strengthen the green spillover effects from FDI. Appropriate competition can make effective allocation of innovative resources and simulate firms to develop green technologies. For managers of domestic firms, their aim should be to co-locate with foreign firms to gain access to technology spillovers from industry leaders and to take advantage of any "windows of opportunity" (Lema *et al.*, 2020).

Furthermore, regional heterogeneity in environmental regulation stringency should be considered in fostering the green spillovers from foreign firms to local firms. The evidence on environmental regulations confirms the crucial role of such regulations in steering eco-innovation of foreign firms and domestic firms. However, Liao (2018) points out that China's environmental instruments for promoting firm eco-innovation "lacked authority" and were missing "comprehensive application of different environmental policy instruments." Our study suggests that China needs to further formulate and implement various environmental policy instruments. Filling institutional voids in government environmental regulations will stimulate more eco-innovation through enhancing the effects of FDI eco-innovation spillovers. Lema *et al*. (2020) highlighted the salient role of institutional changes in creating new opportunities for latecomer development in the age of transformation toward sustainability. The formulation and implementation of environmental laws and regulations generate inducement effect of efficient energy use and reduction in pollution (Ambec and Lanoie, 2008; Dechezleprêtre and Sato, 2017; Ren *et al.*, 2018; Yang and Song, 2019; Chen *et al.*, 2021), which would incentivize firms to utilize FDI spillovers and conduct more eco-innovation. Cities are the center of innovation because they bring together economic agents and assets. Government should coordinate urbanization strategies in order to take advantage of FDI spillovers. In the process of environmental governance, the investments in environmental protection and environmental awareness of firms can be increased. It is essential to improve the institutional environment and foster the capacity of regions in implementing environmental regulations and better utilizing foreign investment to promote eco-innovation of domestic firms.

The first limitation of this paper is that it tests hypotheses based on only one emerging economy—China, which may not be representative of all emerging economies given its large size and its rapid development toward frontier technology and changing patterns of global interaction in technology upgrading over time (Lacasa *et al.*, 2019). Although China shares similar characteristics to other emerging economies, e.g., imperfect factor markets and institutional voids, future research examining other countries would help to verify our hypotheses.

Second, although the use of green patent to measure eco-innovation has the advantage of being a continuous and relatively objective measure, the literature has noted various issues including not all eco-innovation outcomes being patented, and patented eco-innovation of different nature (radical vs. incremental) and of different quality (e.g., Dziallas and Blind, 2019; Taques *et al.*, 2021). However, data for alternative eco-innovation measures such as green R&D investment and forward citation are unavailable in our dataset. Future studies, therefore, should test the validity of our findings using alternative measures of eco-innovation.

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References

Aghion, P., M. Dewatripont and P. Rey (1999), 'Competition, financial discipline and growth,' *The Review of Economic Studies*, **66**(4), 825–852.

Aghion, N., B. Richard, G. Rachel and H. Peter (2005), 'Competition and innovation: an inverted-U relationship,' *The Quarterly Journal of Economics*, **120**(2), 701–728.

Aitken, B. J. and A. E. Harrison (1999), 'Do domestic firms benefit from direct foreign investment? Evidence from Venezuela,' *American Economic Review*, **89**(3), 605–618.

Alcacer, J. and J. Oxley (2014), 'Learning by supplying,' *Strategic Management Journal*, **35**(2), 204–223.

Ali, M., U. Cantner and I. Roy (2016), 'Knowledge spillovers through FDI and trade: the moderating role of quality-adjusted human capital,' *Journal of Evolutionary Economics*, **26**(4), 837–868.

Almulali, U. and C. Foon Tang (2013) 'Investigating the validity of pollution haven hypothesis in the gulf cooperation council (GCC) countries', *Energy Policy*, **60**, 813–819.

Ambec, S. and P. Lanoie (2008), 'Does it pay to be green? A systematic overview,' *Academy of Management Perspectives*, **22**(4), 45–62.

Arellano, M. and O. Bover (1995), 'Another look at the instrumental variable estimation of error-components models,' *Journal of Econometrics*, **68**(1), 29–51.

Baek, J. (2016), 'A new look at the FDI–income–energy–environment nexus: dynamic panel data analysis of ASEAN,' *Energy Policy*, **91**(4), 22–27.

Bai, Y., Q. Qian, J. Jiao, L. Li, F. Li and R. Yang (2020), 'Can environmental innovation benefit from outward foreign direct investment to developed countries? Evidence from Chinese manufacturing enterprises,' *Environmental Science and Pollution Research*, **27**(12), 13790–13808.

Bao, Q., Y. Chen and L. Song (2011), 'Foreign direct investment and environmental pollution in China: a simultaneous equations estimation,' *Environment and Development Economics*, **16**(1), 71–92.

Barrios, S., H. Görg and E. Strobl (2011), 'Spillovers through backward linkages from multinationals: measurement matters!,' *European Economic Review*, **55**(6), 862–875.

Bathelt, H. and P. Li (2020), 'Processes of building cross-border knowledge pipelines,' *Research Policy*, **49**(3), 103928.

Beise, M. and K. Rennings (2005), 'Lead markets and regulation: a framework for analyzing the international diffusion of environmental innovations,' *Ecological Economics*, **52**(1), 5–17.

Bitencourt, C. C., F. de Oliveira Santini, G. Zanandrea, C. Froehlich and W. J. Ladeira (2020) 'Empirical generalizations in eco-innovation: a meta-analytic approach,' *Journal of Cleaner Production*, **245**, 118721.

Blalock, G. and P. J. Gertler (2008), 'Welfare gains from foreign direct investment through technology transfer to local suppliers,' *Journal of International Economics*, **74**(2), 402–421.

Blalock, G. and P. J. Gertler (2009), 'How firm capabilities affect who benefits from foreign technology,' *Journal of Development Economics*, **90**(2), 192–199.

Blundell, R. and S. Bond (1998), 'Initial conditions and moment restrictions in dynamic panel data models,' *Journal of Econometrics*, **87**(1), 115–143.

Brandt, L., J. V. Biesebroeck, L. Wang and Y. Zhang (2017), 'WTO accession and performance of Chinese manufacturing firms,' *American Economic Review*, **107**(9), 2784–2820.

Brandt, L., J. V. Biesebroeck and Y. Zhang (2012), 'Creative accounting or creative destruction? Firm-level productivity growth in Chinese manufacturing,' *Journal of Development Economics*, **97**(2), 339–351.

Braunerhjelm, P., D. Ding and P. Thulin (2020) 'Labour market mobility, knowledge diffusion and innovation,' *European Economic Review*, **123**, 103386.

Breschi, S., C. Lawson, F. Lissoni, A. Morrison and A. Salter (2020), 'STEM migration, research, and innovation,' *Research Policy*, **49**(9), 104070.

Breschi, S. and F. Lissoni (2001), Knowledge spillovers and local innovation systems: a critical survey,' *Industrial and Corporate Change*, **10**(4), 975–1005.

Bu, M. L. and M. Wagner (2016), Racing to the bottom and racing to the top: the crucial role of firm characteristics in foreign direct investment choices,' *Journal of International Business Studies*, **47**(9), 1032–1057.

Bwalya, S. M. (2006), Foreign direct investment and technology spillovers: evidence from panel data analysis of manufacturing firms in Zambia,' *Journal of Development Economics*, **81**(2), 514–526.

Carlin, W., J. Haskel and P. Seabright (2001), Understanding 'the essential fact about capitalism': markets, competition and creative destruction,' *National Institute Economic Review*, **175**(1), 67–84.

Castellani, D., G. Marin, S. Montresor and A. Zanfei (2022), Greenfield foreign direct investments and regional environmental technologies,' *Research Policy*, **51**(1), 104405.

Cheng, Z., L. Li and J. Liu (2018), The spatial correlation and interaction between environmental regulation and foreign direct investment,' *Journal of Regulatory Economics*, **54**(2), 124–146.

Chen, Y., H. Jiang, Y. Liang and S. Pan (2022), The impact of foreign direct investment on innovation: evidence from patent filings and citations in China,' *Journal of Comparative Economics*, **50**(4), 917–945.

Chen, M., A. Sinha, K. Hu and M. I. Shah (2021) 'Impact of technological innovation on energy efficiency in industry 4.0 era: moderation of shadow economy in sustainable development,' *Technological Forecasting and Social Change*, **164**, 120521.

Child, J., Y. Lu and T. Tsai (2007), Institutional entrepreneurship in building an environmental protection system for the People's Republic of China,' *Organization Studies*, **28**(7), 1013–1034.

Cohen, W. M. and D. A. Levinthal (1990) 'Absorptive capacity: a new perspective on learning and innovation,' *Administrative Science Quarterly - Special Issue: Technology, Organizations, and Innovation*, **35**, 128–152.

Cohen, W. M., R. Nelson and J. P. Walsh (2000), 'Protecting Their Intellectual Assets: Appropriability Conditions and Why US Manufacturing Firms Patent (Or Not),' National Bureau of Economic Research Cambridge, Mass: USA.

Cole, M. A., R. Elliot and E. Strobl (2008), 'The environmental performance of firms: the role of foreign ownership, training and experience,' *Ecological Economics*, **65**(3), 538–546.

Costantini, V., F. Crespi, G. Marin and E. Paglialunga (2017), Eco-innovation, sustainable supply chains and environmental performance in European industries,' *Journal of Cleaner Production*, **155**(2), 141–154.

Crescenzi, R., L. Gagliardi and S. Iammarino (2015), 'Foreign multinationals and domestic innovation: intra-industry effects and firm heterogeneity,' *Research Policy*, **44**(3), 596–609.

Cuerva, M. C., Á. Triguero-Cano and D. Córcoles (2014) 'Drivers of green and non-green innovation: empirical evidence in low-tech SMEs,' *Journal of Cleaner Production*, **68**, 104–113.

Czarnitzki, D. and A. A. Toole (2011), 'Patent protection, market uncertainty, and R&D investment,' *The Review of Economics and Statistics*, **93**(1), 147–159.

D'Agostino, L. M. (2015), 'How MNEs respond to environmental regulation: integrating the Porter hypothesis and the pollution haven hypothesis,' *Economia Politica*, **32**(2), 245–269.

Dai, Y., S. Haakonsson and L. Oehler (2020), 'Catching up through green windows of opportunity in an era of technological transformation: empirical evidence from the Chinese wind energy sector,' *Industrial and Corporate Change*, **29**(5), 1277–1295.

Damijan, J. P., M. Rojec, B. Majcen and M. Knell (2013), 'Impact of firm heterogeneity on direct and spillover effects of FDI: micro-evidence from ten transition countries,' *Journal of Comparative Economics*, **41**(3), 895–922.
Dangelico, R. M. and D. Pujari (2010), 'Mainstreaming green product innovation: why and how companies integrate environmental sustainability,' *Journal of Business Ethics*, **95**(3), 471–486.
Dang, J. and K. Motohashi (2015) 'Patent statistics: a good indicator for innovation in China? Patent subsidy program impacts on patent quality,' *China Economic Review*, **35**, 137–155.
Dean, J. M., M. E. Lovely and H. Wang (2009), 'Are foreign investors attracted to weak environmental regulations? Evaluating the evidence from China,' *Journal of Development Economics*, **90**(1), 1–13.
Dechezlepretre, A., E. Neumayer and R. Perkins (2015), 'Environmental regulation and the cross-border diffusion of new technology: evidence from automobile patents,' *Research Policy*, **44**(1), 244–257.
Dechezleprêtre, A. and M. Sato (2017), 'The impacts of environmental regulations on competitiveness,' *Review of Environmental Economics and Policy*, **11**(2), 183–206.
Demena, B. A. and S. K. Afesorgbor (2020) 'The effect of FDI on environmental emissions: evidence from a meta-analysis,' *Energy Policy*, **138**, 111192.
Demirel, P. and E. Kesidou (2019), 'Sustainability-oriented capabilities for eco-innovation: meeting the regulatory, technology and market demands,' *Business Strategy and the Environment*, **28**(5), 847–857.
Dietzenbacher, E. and K. Mukhopadhyay (2007), 'An empirical examination of the pollution haven hypothesis for India: towards a green Leontief paradox?' *Environmental & Resource Economics*, **36**(4), 427–449.
Dong, Y., S. Shao and Y. Zhang (2019) 'Does FDI have energy-saving spillover effect in China? A perspective of energy-biased technical change,' *Journal of Cleaner Production*, **234**, 436–450.
Driffield, N., J. Du and M. Song (2021), 'Internationalization pathways of Chinese private firms: a closer look at firm-specific advantages,' *Journal of International Management*, **27**(3), 100835.
Du, L., A. Harrison and G. H. Jefferson (2012), 'Testing for horizontal and vertical foreign investment spillovers in China: 1998–2007,' *Journal of Asian Economics*, **23**(3), 234–243.
Duque, V. and M. Gilraine (2022) 'Coal use, air pollution and student performance,' *Journal of Public Economics*, **213**, 104712.
Dziallas, M. and K. Blind (2019) 'Innovation indicators throughout the innovation process: an extensive literature analysis,' *Technovation*, **80-81**, 3–19.
Ekins, P. (2010), 'Eco-innovation for environmental sustainability: concepts, progress and policies,' *International Economics and Economic Policy*, **7**(2-3), 267–290.
Eskeland, G. S. and A. E. Harrison (2003), 'Moving to greener pastures? Multinationals and the pollution haven hypothesis,' *Journal of Development Economics*, **70**(1), 1–23.
Faber, A. and K. Frenken (2009), 'Models in evolutionary economics and environmental policy: towards an evolutionary environmental economics,' *Technological Forecasting and Social Change*, **76**(4), 462–470.
Fernández, S., C. Torrecillas and E. Romilio (2021), 'Drivers of eco-innovation in developing countries: the case of Chilean firms,' *Technological Forecasting and Social Change*, **170**(1), 120902.
Findlay, R. (1978), 'Relative backwardness, direct foreign investment, and the transfer of technology: a simple dynamic model,' *Quarterly Journal of Economics*, **92**(1), 1–16.
Freitas, I. M. B., J. Jacob, L. Wang and Z. Li (2023) 'Energy use and exporting: an analysis of Chinese firms,' *Journal of Evolutionary Economics*, **33**, 179–207.
García-Marco, T., F. Zouaghi and M. Sánchez (2020), 'Do firms with different levels of environmental regulatory pressure behave differently regarding complementarity among innovation practices?' *Business Strategy and the Environment*, **29**(4), 1684–1694.
Gerschenkron, A. (1962), *Economic Backwardness in Historical Perspective*. Harvard University Press: Cambridge.
Gibson, J. and D. McKenzie (2014), 'Scientific mobility and knowledge networks in high emigration countries: evidence from the Pacific,' *Research Policy*, **43**(9), 1486–1495.
Gorodnichenko, Y., J. Svejnar and K. Terrell (2014) 'When does FDI have positive spillovers? Evidence from 17 transition market economies,' *Journal of Comparative Economics*, **42**, 954–969.
Hanif, I., S. M. F. Raza, P. Gago-de-santos and Q. Abbas (2019), 'Fossil fuels, foreign direct investment, and economic growth have triggered CO_2 emissions in emerging Asian economies: some empirical evidence,' *Energy*, **171**(6), 493–501.
Hansen, T. and U. E. Hansen (2020), 'How many firms benefit from a window of opportunity? Knowledge spillovers, industry characteristics, and catching up in the Chinese biomass power plant industry,' *Industrial and Corporate Change*, **29**(5), 1211–1232.
Hart, S. L. (1995), 'A natural-resource-based view of the firm,' *Academy of Management Review*, **20**(4), 986–1014.
Haščič, I. and M. Migotto (2015), 'Measuring environmental innovation using patent data,' *OECD Environment Working Papers, No. 89*, OECD Publishing, Paris.

He, J. (2006), 'Pollution haven hypothesis and environmental impacts of foreign direct investment: the case of industrial emission of sulfur dioxide (SO_2) in Chinese provinces,' *Ecological Economics*, **60**(1), 228–245.

Ivarsson, I. and C. G. Alvstam (2010), 'Upgrading in global value-chains: a case study of technology-learning among IKEA-suppliers in China and Southeast Asia,' *Journal of Economic Geography*, **11**(4), 731–752.

Javorcik, B. S. (2004), 'Dose foreign direct investment increase the productivity of domestic firms? In search of spillovers through backward linkages,' *American Economic Review*, **94**(3), 605–627.

Javorcik, B. S. and S. J. Wei (2004), 'Pollution havens and foreign direct investment: dirty secretor popular myth?' *Contributions in Economic Analysis & Policy*, **3**(2), 1244.

Jiang, L., H. F. Zhou, L. Bai and P. Zhou (2018) 'Does foreign direct investment drive environmental degradation in China? An empirical study based on air quality index from a spatial perspective,' *Journal of Cleaner Production*, **176**, 864–872.

Jindra, B., A. Giroud and J. Scott-Kennel (2009), 'Subsidiary roles, vertical linkages and economic development: lessons from transition economies,' *Journal of World Business*, **44**(2), 167–179.

Johnson, L. (2017) *Green Foreign Direct Investment in Developing Countries*. United Nations Environment Programme: Geneva.

Kesidou, E. and L. Wu (2020) 'Stringency of environmental regulation and eco-innovation: evidence from the eleventh Five-Year Plan and green patents,' *Economics Letters*, **190**, 109090.

Kiefer, C. P., P. Del Río González and J. Carrillo-Hermosilla (2019), 'Drivers and barriers of eco-innovation types for sustainable transitions: a quantitative perspective,' *Business Strategy and the Environment*, **28**(1), 155–172.

Krishnan, M. S., C. H. Kriebel, S. Kekre and T. Mukhopadhyay (2000), 'An empirical analysis of productivity and quality in software products,' *Management Science*, **46**(6), 745–759.

Kunapatarawong, R. and E. Martínez-Ros (2016), 'Towards green growth: how does green innovation affect employment?' *Research Policy*, **45**(6), 1218–1232.

Lacasa, I. D., B. Jindra, S. Radosevic and M. Shubbak (2019), 'Paths of technology upgrading in the BRICS economies,' *Research Policy*, **48**(1), 262–280.

Lan, J., M. Kakinaka and X. Huang (2012), 'Foreign direct investment, human capital and environmental pollution in China,' *Environmental and Resource Economics*, **51**(2), 255–275.

Lee, G. (2006), 'The effectiveness of international knowledge spillover channels,' *European Economic Review*, **50**(8), 2075–2088.

Lema, R., X. Fu and R. Rabellotti (2020), 'Green windows of opportunity: latecomer development in the age of transformation toward sustainability,' *Industrial and Corporate Change*, **29**(5), 1193–1209.

Levinson, A. and M. S. Taylor (2008), 'Unmasking the pollution haven effect,' *International Economic Review*, **49**(1), 223–254.

Li, X. (2012), 'Behind the recent surge of Chinese patenting,' *Research Policy*, **41**(1), 236–249.

Liang, F. H. (2017), 'Does foreign direct investment improve the productivity of domestic firms? Technology spillovers, industry linkages, and firm capabilities,' *Research Policy*, **46**(1), 138–159.

Liao, T. (2015), 'Local clusters of SOEs, POEs, and FIEs, international experience, and the performance of foreign firms operating in emerging economies,' *International Business Review*, **24**(1), 66–76.

Liao, Z. (2018) 'Content analysis of China's environmental policy instruments on promoting firms' environmental innovation,' *Environmental Science & Policy*, **88**, 46–51.

Lin, P., Z. Liu and Y. Zhang (2009), 'Do Chinese domestic firms benefit from FDI inflow? Evidence of horizontal and vertical spillovers,' *China Economic Review*, **20**(4), 677–691.

Lin, Z., S. Wang and L. Yang (2020), 'Motivating innovation alliance's environmental performance through eco-innovation investment in a supply chain,' *Journal of Cleaner Production*, **269**(2), 122361.

Liu, Z. (2007), 'Foreign direct investment and technology spillovers: theory and evidence,' *Journal of Development Economics*, **85**(1), 176–193.

Liu, Y., Y. Hao and Y. Gao (2017), 'The environmental consequences of domestic and foreign investment: evidence from China,' *Energy Policy*, **108**(9), 271–280.

Liu, X., C. Wang and Y. Wei (2009), 'Do local manufacturing firms benefit from transactional linkages with multinational enterprises in China?' *Journal of International Business Studies*, **40**(7), 1113–1130.

Li, J., J. Xia and E. J. Zajac (2018), 'On the duality of political and economic stakeholder influence on firm innovation performance: theory and evidence from Chinese firms,' *Strategic Management Journal*, **39**(1), 193–216.

Li-Ying, J., C. Mothe and T. T. U. Nguyen (2018) 'Linking forms of inbound open innovation to a driver-based typology of environmental innovation: evidence from French manufacturing firms,' *Technological Forecasting and Social Change*, **135**, 51–63.

López, L. A., A. Guadalupe, T. Kronenberg and J. F. D. Rodrigues (2018) 'Trade from resource-rich countries avoids the existence of a global pollution haven hypothesis,' *Journal of Cleaner Production*, **175**, 599–611.

Lozano, R., A. Carpenter and D. Huisingh (2014) 'A review of 'theories of the firm' and their contributions to corporate sustainability,' *Journal of Cleaner Production*, **106**, 430–442.

Luo, Y., M. Salman and Z. Lu (2021) 'Heterogeneous impacts of environmental regulations and foreign direct investment on green innovation across different regions in China,' *Science of the Total Environment*, **759**, 143744.

Lu, Y., Z. Tao and L. Zhu (2017), 'Identifying FDI spillovers,' *Journal of International Economics*, **107**(6), 75–90.

Marquis, C., J. J. Zhang and Y. H. Zhou (2011), 'Regulatory uncertainty and corporate responses to environmental protection in China,' *California Management Review*, **54**(1), 39–63.

Marzucchi, A. and S. Montresor (2017) 'Forms of knowledge and eco-innovation modes: evidence from Spanish manufacturing firms,' *Ecological Economics*, **131**, 208–221.

Mothe, C., U. T. Nguyenthi, D. N. Powe, D. K. Willis and G. B. Page (2018), Innovative products and services with environmental benefits: design of search strategies for external knowledge and absorptive capacity, *Journal of Environmental Planning and Management*, **61**(11), 1934–1954.

Nair, S. R., M. Demirbag and K. Mellahi (2016), 'Reverse knowledge transfer in emerging market multinationals: the Indian context,' *International Business Review*, **25**(1), 152–164.

Newman, C., J. Rand, T. Talbot and F. Trap (2015) 'Technology transfers, foreign investment and productivity spillovers,' *European Economic Review*, **76**, 168–187.

Noailly, J. and D. Ryfisch (2015) 'Multinational firms and the internationalization of green R&D: a review of the evidence and policy implications,' *Energy Policy*, **83**, 218–228.

Palmer, K., W. E. Oates and P. R. Portney (1995), 'Tightening environmental standards: the benefit-cost or the no-cost paradigm?' *Journal of Economic Perspectives*, **9**(4), 119–132.

Pao, H. T. and C. M. Tsai (2011), 'Multivariate Granger causality between CO_2 emissions, energy consumption, FDI (foreign direct investment) and GDP (gross domestic product): evidence from a panel of BRIC (Brazil, Russian Federation, India, and China) countries,' *Energy*, **36**(1), 685–693.

Park, A., D. Yang, X. Shi and Y. Jiang (2010), 'Exporting and firm performance: Chinese exporters and the Asian financial crisis,' *The Review of Economics and Statistics*, **92**(4), 822–842.

Pazienza, P. (2019), 'The impact of FDI in the OECD manufacturing sector on CO_2 emission: evidence and policy issues,' *Environmental Impact Assessment Review*, **77**(7), 60–68.

Perri, A. and E. Peruffo (2016), 'Knowledge spillovers from FDI: a critical review from the international business perspective,' *International Journal of Management Reviews*, **18**(1), 3–27.

Piperopoulos, P., J. Wu and C. Wang (2018), 'Outward FDI, location choices and innovation performance of emerging market enterprises,' *Research Policy*, **47**(1), 232–240.

Popp, D. (2011), 'International technology transfer, climate change, and the clean development mechanism,' *Review of Environmental Economics and Policy*, **5**(1), 131–152.

Porter, M. E. (1990) *The Competitive Advantage of Nations and Their Firms*. Macmillan: London.

Porter, M. E. and C. Van der Linde (1995), 'Toward a new conception of the environment-competitiveness relationship,' *Journal of Economic Perspectives*, **9**(4), 97–118.

Prieger, J. E. and N. J. Sanders (2012), 'Verifiable and non-verifiable anonymous mechanisms for regulating a polluting monopolist,' *Journal of Environmental Economics and Management*, **64**(3), 410–426.

Ren, S., X. Li, B. Yuan, D. Li and X. Chen (2018) 'The effects of three types of environmental regulation on eco-efficiency: a cross-region analysis in China,' *Journal of Cleaner Production*, **173**, 245–255.

Rennings, K. (2000), 'Redefining innovation—eco-innovation research and the contribution from ecological economics,' *Ecological Economics*, **32**(2), 319–332.

Requate, T. (2005), 'Dynamic incentives by environmental policy instruments—a survey,' *Ecological Economics*, **54**(2-3), 175–195.

Rezza, A. A. (2013) 'FDI and pollution havens: evidence from the Norwegian manufacturing sector,' *Ecological Economics*, **90**, 140–149.

Rojec, M. and M. Knell (2018), 'Why is there a lack of evidence on knowledge spillovers from foreign direct investment?' *Journal of Economic Surveys*, **32**(3), 579–612.

Rudolph, A. and L. Figge (2017), 'Determinants of ecological footprints: what is the role of globalization?,' *Ecological Indicators*, **81**(10), 348–361.

Sarkodie, S. A. and V. Strezov (2019) 'Effect of foreign direct investments, economic development and energy consumption on greenhouse gas emissions in developing countries,' *Science of the Total Environment*, **646**, 862–871.

Shahbaz, M., D. Balsalobre-Lorente and A. Sinha (2019), 'Foreign direct investment–CO_2 emissions nexus in Middle East and North African countries: importance of biomass energy consumption,' *Journal of Cleaner Production*, **217**(11), 603–614.

Shahbaz, M., M. A. Nasir and D. Roubaud (2018) 'Environmental degradation in France: the effects of FDI, financial development, and energy innovations', *Energy Economics*, **74**, 843–857.

Shi, X. and Z. Xu (2018), 'Environmental regulation and firm exports: evidence from the eleventh Five-Year Plan in China,' *Journal of Environmental Economics and Management*, **89**(5), 187–200.

Song, M., S. Wang and H. Zhang (2020) 'Could environmental regulation and R&D tax incentives affect green product innovation?,' *Journal of Cleaner Production*, **258**, 120849.

Spencer, J. W. (2008), 'The impact of multinational enterprise strategy on indigenous enterprises: horizontal spillovers and crowding out in developing countries,' *Academy of Management Review*, **33**(2), 341–361.

Stock, J. H. and M. Yogo (2005) 'Identification and inference for econometric models: asymptotic distributions of industrial variables statistics with many instruments,' *Journal of the American Statistics Association*, **89**, 1319–1320.

Sun, S. (2010), 'How does FDI affect domestic firms' exports? Industrial evidence,' *World Economy*, **32**(8), 1203–1222.

Suresh, S. (2012), 'Global challenges need global solutions,' *Nature*, **490**(7420), 337–338.

Taques, F. H., M. G. López, L. F. Basso and N. Areal (2021), 'Indicators used to measure service innovation and manufacturing innovation,' *Journal of Innovation and Knowledge*, **6**(1), 11–26.

Todo, Y., W. Zhang and L. Zhou (2009), 'Knowledge spillovers from FDI in China: the role of educated labor in multinational enterprises,' *Journal of Asian Economics*, **20**(6), 626–639.

Triguero, A., L. Moreno-Mondéjar and M. A. Davia (2013) 'Drivers of different types of eco-innovation in European SMEs,' *Ecological Economics*, **92**, 25–33.

Vezzoli, C., F. Ceschin, J. C. Diehl and C. Kohtala (2015), 'New design challenges to widely implement 'sustainable product-service systems,' *Journal of Cleaner Production*, **97**(6), 1–12.

Vujanović, N., S. Radošević, N. Stojčić, M. Hisarciklilar and I. Hashi (2022) 'FDI spillover effects on innovation activities of knowledge using and knowledge creating firms: evidence from an emerging economy,' *Technovation*, **118**, 102512.

Wakelin, K. (1998), 'Innovation and export behaviour at the firm level,' *Research Policy*, **26**(7), 829–841.

Wang, L., F. Chen and M. Knell (2019), 'Patterns of technology upgrading – the case of biotechnology in China,' *Asian Journal of Technology Innovation*, **27**(2), 152–171.

Wang, L., S. Jiang and S. Zhang (2020) 'Mapping technological trajectories and exploring knowledge sources: a case study of 3D printing technologies,' *Technological Forecasting and Social Change*, **161**, 120251.

Wang, L., H. H. M. Meijers and A. Szirmai (2017), 'Technological spillovers and industrial growth in Chinese regions,' *Industrial and Corporate Change*, **26**(2), 233–257.

Wang, C., Y. Wei and L. Wu (2023) 'Global eco-innovation and its local impact in emerging economies: boundary conditions of environmental regulations and pollution intensity,' *Journal of Product Innovation Management*, **5**, 1–33.

Wei, Y., S. Ding and Z. Konwar (2022), 'The two faces of FDI in environmental performance: a meta-analysis of empirical evidence in China,' *Journal of Chinese Economic and Business Studies*, **20**(1), 65–94.

Wei, Z., B. Han, X. Pan, M. Shahbaz and M. W. Zafar (2020) 'Effects of diversified openness channels on the total-factor energy efficiency in China's manufacturing sub-sectors: evidence from trade and FDI spillovers,' *Energy Economics*, **90**, 104836.

Wei, Y. and X. Liu (2006), 'Productivity spillovers from R&D, exports and FDI in China's manufacturing sector,' *Journal of International Business Studies*, **37**(4), 544–557.

Wu, J. and Z. Z. Ma (2016), 'Export intensity and MNE customers' environmental requirements: effects on local Chinese suppliers' environment strategies,' *Journal of Business Ethics*, **135**(2), 327–339.

Xie, R. H., Y. J. Yuan and J. J. Huang (2017) 'Different types of environmental regulations and heterogeneous influence on "green" productivity: evidence from China,' *Ecological Economics*, **132**, 104–112.

Xu, X. and Y. Sheng (2012), 'Productivity spillovers from foreign direct investment: firm-level evidence from China,' *World Development*, **40**(1), 62–74.

Yang, Q. and D. Song (2019) 'How does environmental regulation break the resource curse: theoretical and empirical study on China,' *Resources Policy*, **64**, 101480.

Zarsky, L. (1999), 'Havens, halos and spaghetti: untangling the evidence about foreign direct investment and the environment,' *Foreign Direct Investment and the Environment*, **13**(8), 47–74.

Zeng, D. and L. Zhao (2009), 'Pollution havens and industrial agglomeration,' *Journal of Environmental Economics and Management*, **58**(2), 141–153.

Zhang, C., Y. Lu, L. Guo and T. Yu (2011), 'The intensity of environmental regulation and technological progress of production,' *Economic Research Journal*, **46**(2), 113–124.

Zhang, C. and X. Zhou (2016) 'Does foreign direct investment lead to lower CO2 emissions? Evidence from a regional analysis in China,' *Renewable and Sustainable Energy Reviews*, **58**, 943–951.

Zheng, D. and M. Shi (2017), 'Multiple environmental policies and pollution haven hypothesis: evidence from China's polluting industries,' *Journal of Cleaner Production*, **141**(1), 295–304.

Zhou, Y., S. J. Zhu and C. He (2019), 'Learning from yourself or learning from neighbours: knowledge spillovers, institutional context and firm upgrading,' *Regional Studies*, **53**(10), 1397–1409.

Appendix

A1. The overall trends in eco-innovation by Chinese firms over time and across provinces

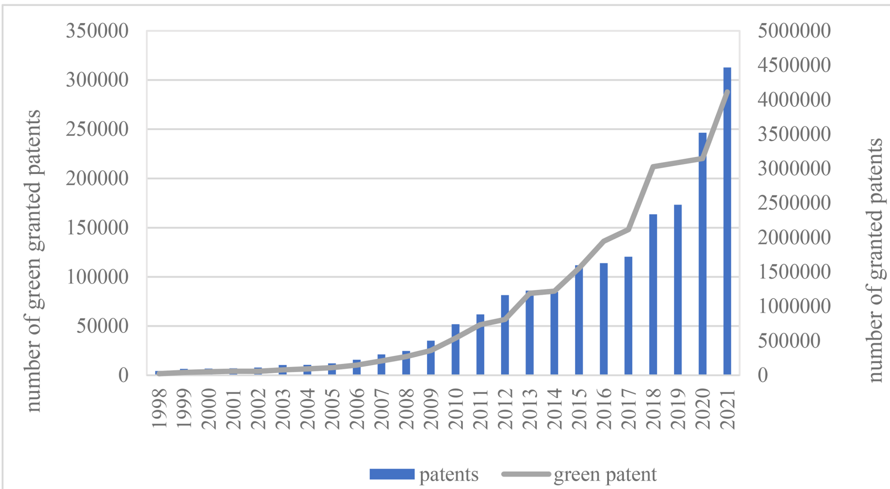

Figure A1. The number of patents and green patents in China from 1998 to 2021 *Note*: Green patents refer to inventions, utility models, and appearance designs with environmental technologies that can improve energy efficiency, reduce pollution, and achieve sustainable development. They include alternative energy, environmental protection materials, pollution control and recycling technologies, energy conservation, and emission reduction technologies. For more detailed description of green patents, please see Section 3.1. Data source: CNIPA.

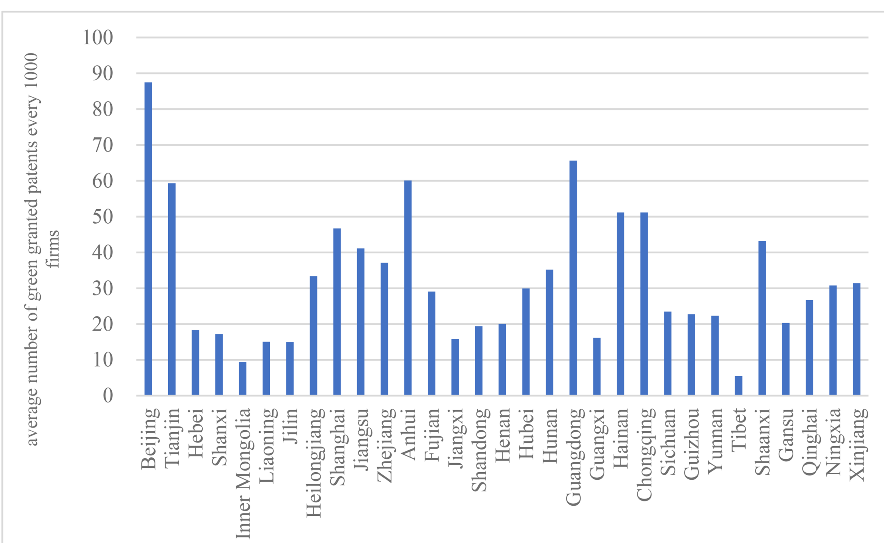

Figure A2. Average green patents granted to Chinese firms across provinces Data source: ASIEC and CNIPA (1998–2013).

A2. System GMM method

Table A1. The spillover effects of industrial FDI on eco-innovation of domestic firms (system GMM estimates)

Dependent variable *Ecoinno*	(1)	(2)	(3)	(4)
Horizontal	0.082***		0.026**	
	(0.011)		(0.011)	
Forward		0.040*		0.132***
		(0.023)		(0.037)
Backward		0.036***		0.026***
		(0.005)		(0.010)
Capital			0.004***	0.004***
			(0.001)	(0.001)
Labor			0.002**	0.002*
			(0.001)	(0.001)
Wage			0.002***	0.002***
			(0.001)	(0.001)
Patentstock			0.023***	0.022***
			(0.005)	(0.005)
constant	0.008	0.004**	−0.048***	−0.084***
	(0.034)	(0.002)	(0.019)	(0.016)
Firm FE	Yes	Yes	Yes	Yes
Year FE	Yes	Yes	Yes	Yes
Province FE	Yes	Yes	Yes	Yes
Observations	590,555	590,555	422,644	422,644
AR(1) test	0.000	0.000	0.000	0.000
AR(2) test	0.545	0.438	0.136	0.137
Sargan test	0.669	0.332	0.930	0.121

The standard error is in parentheses.
***, **, and * represent the significance levels of 1%, 5%, and 10%, respectively. *P*-values are reported in the AR (1) test, AR (2) test, and Sargan test.

We also employ the system GMM method (Arellano and Bover, 1995; Blundell and Bond, 1998)[9] to alleviate the potential endogeneity. Table A1 reports the empirical results of system GMM method and our main results remain robust, indicating the positive effect of FDI spillovers on firm eco-innovation.

[9] System GMM uses two equations, with one first-differenced where the explanatory variables are instrumented by their lagged levels and another one in levels where variables are instrumented by their own lagged first-differences. To solve the system estimator, variables in differences are instrumented with the lags of their own levels, while variables in levels are instrumented with the lags of their own differences. In our study, since all independent variables are lagged for one year, the independent variables in differences are instrumented with the own levels with two-year lags, and independent variables in levels are instrumented with the two-year lags of the own differences.