

# The green spillover effect of the inward foreign direct investment: Market versus innovation

Mingrong Wang<sup>a</sup>, Xi Zhang<sup>b,\*</sup>, Yi Hu<sup>c,d</sup>

<sup>a</sup> School of Economics, Capital University of Economics and Business, Beijing, 100070, China

<sup>b</sup> School of Economics, Beijing Technology and Business University, Beijing, 100048, China

<sup>c</sup> School of Economics and Management, University of Chinese Academy of Sciences, Beijing, 100190, China

<sup>d</sup> Key Laboratory of Big Data Mining and Knowledge Management, Chinese Academy of Sciences, Beijing, 100190, China

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Little work has focused on whether or under which conditions foreign direct investment (FDI) can spill cleaner-production technologies. To explore the complicated effects of FDI's technical spillover on the green innovation effort of host countries, this paper develops a multi-stage decision-making model in which abatement treatments of firms are described. It is found that marketization level and innovation capacity of the host country are two key factors impacting FDI's green spillovers. The results show there are preconditions in terms of green spillovers, i.e., FDI can improve or has no impact on the environmental performance of local firms under different conditions. Moreover, there are double threshold effects: the degree of FDI's green spillover varies with the different levels of the two threshold variables of marketization and innovation capacity. An increase in innovation capacity always motivates cleaner-technology diffusion in host countries. In addition, a moderate tax system is conducive to the green spillovers of FDI. This paper provides a theoretical support for the pollution halo hypothesis that FDI can promote cleaner development of host countries. Finally, from a perspective of cleaner-production practice, the policy implications are discussed to make production cleaner and ensure environmental sustainability.

## 1. Introduction

Starting in the 1990s, FDI played an important role in economic growth through employment effects, technology-transfer effects, competition effects and balance-of-payment effects. With commonly well-known remarks, market- and efficiency-seeking FDI can create positive externalities in the form of technology transfer, knowledge diffusion and the availability of cheaper capital. Through horizontal and vertical economic linkages at the firm level, advanced technologies and management experience brought by FDI can generate green spillovers to a host economy (Pan et al., 2020; Liu et al., 2021). Therefore, in the renewable energy sector, many developing countries are seeking to attract FDI, accounting for over 10% of global FDI in 2015 (Keeley and Matsumoto, 2018). Typically, how to prevent environmental degradation and further improve environmental quality is now a central issue all over the world, so the positive diffusion of cleaner-production technologies brought by FDI is desired for a host country. By considering this scenario, globalization is promoting sustainability through FDI's market competition that impels economic agents in a host country to revise their

behavior towards a cleaner production. Such market interaction not only makes the host country be more convenient to absorb foreign cleaner technologies, but also boosts its independent green innovation activities, which is conducive to sustainable development. In view of this meaningful topic, this paper aims at examining the impact of FDI's cleaner technologies on green innovation efforts in a host economy. For this purpose, we need to discuss how FDI with clean technical advantages makes location decisions, and how the host country formulates policies to attract green FDI. Thus, a broader literature review on host nation institutions and FDI location decisions is necessary.

In the eclectic paradigm built upon transaction cost theories, it has shown that the determinants of FDI inflows depend on a series of characteristics of a host country, where two characteristics are paid much attention. The first characteristic concerns market entry or exit barriers. Entry barriers, which increase the cost of starting a business (e.g., transport and communication costs, foreign exchange costs and tariffs), prevent multinational enterprises (MNEs) from establishing new business in host markets (Alesina et al., 2005). Some exit barriers, such as the cost of withdrawal, the consequence of termination and the ease

\* Corresponding author.

E-mail address: [zhangxi@btbu.edu.cn](mailto:zhangxi@btbu.edu.cn) (X. Zhang).

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or difficulty of bankruptcy, are increasingly being factored into the initial investment decision of FDI (Besley, 2015). These costs are related to value-added activities and can, therefore, be identified and measured easily by MNEs (Calhoun, 2002). In contrast, the social content of costs consists primarily of culture-driven costs faced by MNEs (Eden and Miller, 2004). Due to measurement difficulties, the empirics of cultural variables have drawn considerable criticism (Shenkar, 2012; Konara and Mohr, 2019). Except for cultural distance, several studies (e.g., Kostova, 1999; Kostova and Zaheer, 1999; Schwens et al., 2011) have emphasized the importance of the institutional distance between the home and host countries to FDI inflows, which is referred to as the second characteristic.

The regulatory institution is drafted in rules, procedures and requirements imposed on business, such as a rule-of-law, property rights and tax regulations, determining the costs of investment enforcement and monitored to be high or low (e.g., Jandhyala, 2013; Gan and Qiu, 2019; Contractor et al., 2021). Although there are regulatory institution differences across countries, it may still be a more powerful determinant of FDI location decisions than macroeconomic or industrial factors (Hitt, 2016). As the cross-nation institutional distance increases, FDI's transaction costs and risks arising from operating in host markets are likely to increase, resulting that MNEs will face more challenges to sustain their competitive advantages (Kostova and Roth, 2002; Salomon and Wu, 2012). Consequently, Daude and Stein (2007) claim that "... significant effects on FDI, some institutional aspects matter more than others do ...". This is why prior literatures generally use institutional theories to explain the FDI behavior of multinational enterprises (Bajgar and Javorcik, 2020).

Going beyond the work of Daude and Stein (2007), a large body of literature have identified that the institutional quality is a critical factor driving MNEs' location decisions, and have concluded that friendly institutional environment at a host country can attract more FDI inflows, yet non-friendly institutions increase the costs of foreign investments (Casi and Resmini, 2017; McCloud et al., 2018; Comi et al., 2021). In empirical studies, non-friendly institutional environment plays a role as a tax on increasing the costs of doing business, whereas tax exemptions significantly attract FDI inflows (Oman, 2000; Daude and Stein, 2007). Indeed, an institution with high quality promotes the location and technical transfer of FDI by reducing market barriers and exerting technical advantages. While the former strengthens the incentives to invest by increasing MNEs' returns, the latter stimulates domestic agents to enter into related production activities by learning FDI's advanced technologies. This has a positive impact on cleaner production practices of a host country, thereby emitting less pollutant to air and mitigating environmental damages. Meanwhile, cleaner production technologies brought by FDI have been paid attention not only from environment science but also from economic researches. Cleaner production is empirically proved to be costlier than normal production process in coal-fired power generating sectors (Huang et al., 2019), so firms are usually reluctant to adopt the cleaner production to save the costs of reforming the production system. Thus, the incentives of this reform can only be from outside, such as the environmental tax. As in Henisz and Zelner (2004), OECD (2013) and Contractor et al. (2021), the quest of this paper is to trace the effects of regulatory policy changes on FDI inflows, employing the tax policy as an institutional quality dimension. We wonder how institutional quality affects the uneven distribution of FDI cross countries, and why host countries have different attitudes to FDI. In achieving our objectives, we exploit whether and to what extent the government tax policy attracts FDI, simultaneously shedding light on whether FDI tends to flow into the host country with tax exemptions. Investigating these issues will provide direct basis on how FDI influences the cleaner production and exerts impacts on pollution emissions in host countries. It has important implications for government policy reform in green innovation, as well as for MNEs to select investment locations.

In brief, these two streams of literature offer valuable insights into economic and institutional stimulants of FDI inflows. The recovery from

the 2008 financial crisis brought a change in FDI patterns. FDI from developing countries began to play a more important role on the world outward investment scene. The global share of South FDI outflows increased from 7.6% in 2000 to 41.2% in 2018, and the stock share rose from 9.3% to 24.3% (UNCTAD, 2020). Meanwhile, some studies began to focus on the internationalization of firms, strategic intent of FDI, and FDI entry mode from the standpoint of emerging countries (Ciravegna et al., 2013; Xie and Li, 2017; Li et al., 2021). Previous studies, which make use of business cycle theory to demonstrate the behavior of the North FDI outflows (e.g., Levy et al., 2007; Buch and Lipponer, 2005; Hsu et al., 2011), may not necessarily apply to the South FDI outflows, due to ownership differences. Moreover, relative to FDI from developed countries, outward FDI from emerging countries is more likely to concentrate in countries with similar institution environment, and is more beneficial for economic growth of the host country (Zhang, 2021). The reason is that it provides home firms with low-risk ways of entry by combining their technical advantages with local advantages. The host country can also benefit from increased employment rate and transfer of advanced skills. Can outward FDI of emerging countries improve environmental quality and promote sustainable development in a host country? Many studies show related empirical results, yet this does not mean that the impact of FDI on environment quality in host countries is conclusive due to unobserved heterogeneity and endogeneity (Jiao et al., 2020). Under this context, it is really valuable to provide some theoretical insights to uncover the complex impact of FDI on host countries' environment. Thus, we analyze the effect of FDI on environment quality in a host country from a green spillover perspective, including the involvement of the host tax exemption policy, by endogenizing the green innovation effort of the host country.

This work is strictly related to literatures on environmental Kuznets curve hypotheses between FDI and carbon emissions, involving in the inverted-U curve, the N-shaped curve, and the S-shaped curve (Shahbaz et al., 2019; Xie and Sun, 2020). There are two sets of contrasting views on the hypotheses. First, FDI, as a carrier of capital, technology and management, can bring advanced technology and management experience, and fill the funding gap to the host country, thereby contributing to a cleaner environment by abating pollution emissions, improving energy efficiency, and reducing effluent discharges. Therefore, it has become one of the important driving forces for economic structure transformation in the host country. In the scenario where labor-intensive manufacturing activities are less ecologically harmful than its capital-intensive counterparts, the spillover effect of FDI can aid developing countries in replacing their old pollution-causing technologies (Gallagher, 2009). This is supported by empirical results in Ouyang and Lin (2015), Shahbaz et al. (2015) and Zhang et al. (2020). Hence, Kahia et al. (2017), Liu et al. (2017) and Nepal et al. (2021) propose the utilization of FDI's cleaner technologies to reduce carbon emissions. Second, FDI is like a double-edged sword and has its own two-sidedness. FDI might damage the host country's ecological environment as well (e.g., Al-Mulali and Tang, 2013; Zhang and Zhou, 2016). The underlying reason is that FDI inflows damage the environment in locations where environmental regulations are more permissive. On that line of thought, FDI inflows may be encouraged at the cost of environment and contribute to an increase in pollution emissions, leading to pollution haven (Bakhsh et al., 2017; Solarin et al., 2017; Koçak and Sarkgünesi, 2017; Shahbaz et al., 2019). Although these studies present conflicting conclusions, FDI is still considered as a vital source of sustainable development (Melane-Lavado et al., 2018) and a fundamental source of external capital in the private sector (Aust et al., 2020). How can the host country select the essence and discard the dross of FDI simultaneously? We attempt to explore this problem by balancing the tradeoff between the domestic market share of FDI and the host green innovation effort. This study, to a certain extent, can help the host country not only acquire foreign cleaner technologies, but also improve its renewable energy ratio in energy supply by encouraging FDI to invest in renewable sectors. Furthermore, it is instructive for the host country to improve the

incentive system for promotion of renewable energy use, formulating regulatory and market incentives, like tax incentives. This has deeply meaningful implications for those countries with green technical bottleneck and lack of private investments.

When talking about cleaner production, it should be remembered that green innovation activities play a major role in shaping the future of cleaner production in a country. Especially, technological innovation, as a basic means of transforming economic growth mode, can reduce pollution emissions, invent new green products, and improve cleaner-production process. Consequently, the innovation-driven and green development approaches to coordinate economic, societal and environmental development are of broad interest to cleaner/sustainability community. Thus, at the ushering age of globally sustainable development goals, it becomes necessary to improve the green innovation capacity of a country, so that a country can fulfill its sustainable development objectives. Aust et al. (2020) puts forward the issue as to whether international business operation can help firms become greener. Since then, many studies start to focus on the sustainable business operation of MNEs. Amendolagine et al. (2021) presents a comprehensive review in the international business literature. Roughly speaking, it is widely supported that FDI flows strengthen the internationalization process of firms and promote the global innovation level (Cassiman and Golovko, 2018). This is also evidenced by empirical data. Green patents quantity and their business value show that green FDI significantly improves green productivity (Perri and Andersson, 2014; Chiarvesio et al., 2015; Noailly and Ryfisch, 2015; Stiebale, 2016; Melane-Lavado et al., 2018). Therefore, Maksimov et al. (2019) claims that MNEs can make the green transition more easily than other firms. However, there is empirically ambiguous in terms of FDI and technological innovation. One view believes that FDI plays an important role in improving the technological innovation capacity of the host country through spillover effect, and the other believes that FDI is not conducive to the improvement of its innovation capacity, since it crowds out the innovation space of the host firms. However, compared to the technological spillover effect of FDI, the study on the innovation spillover effect of FDI is few. The existence and direction of FDI's innovation spillovers on the host country still lack a unified understanding. Theoretical analysis is therefore very necessary to demonstrate the relationship between FDI and technological innovation capacity. It would provide the intrinsic support for how FDI affects the decision-making of firms' cleaner production, which serves as the theoretical foundation to empirically verify the relationship between FDI and green innovation. Also, it will have significant implications for policy-makers to formulate the environmental regulations and foreign investment policies. Motivated by numerous recent studies that focus on emissions reduction and green innovation (e.g., Wang et al., 2016; Melane-Lavado et al., 2018; Jiang et al., 2020; Amendolagine et al., 2021), we extend FDI literatures by analyzing the impact of FDI on the independent green innovation of the host country, and further, seek insights on sustainable development. We establish how FDI spills directly and indirectly to the host green innovation effort, which shows the connection between FDI's green spillovers and the host country's innovation capacity. Except the methodological aspect, this paper aims to look into policies for environmental sustainability in the host country, by means of focusing on cleaner production process. Consequently, the questions under consideration in this paper are: what government policies attract FDI to the host country? How do MNEs exploit the competitive advantage of abatement technologies through FDI? What are green spillovers derived from FDI? What factors can make the domestic firm prone to green innovation? To better answer these questions, it is extremely important to understand the complex interactions between FDI's spillover effect and innovation capacity.

In the course of reviewing literatures, we have not come across any study which has carried out the impact of FDI on host countries' green innovation at large. The study in this pursuit cannot therefore give a wholesome map about the green spillovers of FDI to the host country.

There exists a research gap in terms of policy prescription for foreign capital in order to stimulate the green innovation activities of the host country, and this paper addresses it by considering the cleaner-technology production as the major vehicle to reduce pollution emissions. With this in view, a linear market game model is established from the viewpoint of the host country. Such single-country pattern, despite of its deficiencies, may offer a more suitable setting to explore the complex nexus between FDI's green spillovers and the green innovation effort of the host country. Specifically, the potential contributions of this study are five-fold. First, it examines the green-spillover role of FDI through comparing FDI's abatement technology with the host country's. Second, emphasizing the importance of knowledge gained from experiential learning and innovation capacity, it identifies several key factors that affect FDI's green spillovers and host-country's green innovation effort. Third, it uses a fairly straightforward specification that describes the institutional quality to be friendly or not to FDI, and then yet grasps its major influence on market competition equilibrium and green innovation effort. Fourth, as some other researchers have done, it analyzes the reason for complementarities between FDI and the host innovation capacity, and further, examines some issues that needed to be taken into account when assessing the green spillover effects of FDI. Fifth, for the purpose of policy reform, it discusses possible channels of green spillovers, highlighting the different spillover degree of FDI among these channels. More importantly, we offer the explanation and sustainable implications for why FDI's green spillover degree varies under different conditions. This research can help the host country understand the complex interactions between FDI's entry mode, marketization level and technological innovation capacity, so as to provide fruitful grounds for the government to formulate reasonable and effective innovation activities and foreign investment policies, to improve cleaner production, and to realize economy sustainable development. Apart from the contextual and methodological aspects, this paper contributes towards the policy design, as we discuss the policy implications for implementation of sustainable development by focusing on the cleaner production practices. So this study is of broad interest to all areas of society.

The rest of this paper is organized as follows. The next section is the model. Section 3 examines the complex interactions among FDI's green spillovers, marketization level, and innovation capacity. Section 4 presents the policy implications of theoretical results. Section 5 concludes this paper. All proofs and technical details can be found in the Appendix.

## 2. The model

Logically, the host country formulates tax preference policies to attract FDI; FDI inflows with cleaner-production advantage enter into the host country and compete with local firms in terms of market share. In this process, the green spillovers occur by learning-by-doing of local firms. Along this line, we establish a game model to examine how FDI's green spillovers affect the host's innovation effort. To simplify notations, the host country, FDI and local firms are denoted by the government, firm  $F$  and firm  $D$ , respectively.

Here, we select the tax policy to address whether the host's institutional environment to FDI is friendly or not. Denote the profit tax rate to firms  $F$  and  $D$  by  $1-T_F$  and  $1-T_D$ , respectively, and then the tax preference policy requires  $1-T_F < 1-T_D$ . Equivalently,  $T_F > T_D$ . Further, we assume  $1 = T_F > T_D = T > 0$ . This assumption is not loss of generality, since it is just used to reflect the tax preference to FDI. To focus on the effect of FDI with cleaner-production advantage on the domestic green innovation effort, we assume that firms  $F$  and  $D$  produce homogeneous goods, and except for abatement cost, they have the same production technology. As in Markusen (1995), firm  $F$  is assumed to have advanced abatement technologies compared with firm  $D$ . Owing to the difference in clean technologies, firm  $D$ 's abatement cost is larger than that of firm  $F$ , and thereby, firm  $D$  will face competition, even substitute, from FDI. In order to keep market share, firm  $D$  will try its best to reduce abatement cost by

innovation effort. Thus, green spillovers occur. Let the abatement costs of firms  $F$  and  $D$  be  $c_F$  and  $c_D$ , respectively. The green spillover,  $e$ , is measured by the abatement cost reduction of firm  $D$ . Surely, innovation will accompany the associated disutility. According to Rogerson (2003) and Vita et al. (2021), the disutility can be addressed by  $e^2/(2\mu)$ , where  $\mu$  indicates the innovation capacity (or technological absorptive capacity) of firm  $D$ .

With the abatement cost after green spillovers, firm  $D$  competes with firm  $F$  in goods price. The Hotelling's line competition is adopted to describe the price competition between firms  $F$  and  $D$ . The motivation to employ the line competition for mathematical modelling is because, (a) it is easier for MNEs to measure the cost of starting a new business in host markets, (b) it better fits the pricing case of homogeneous goods, and (c) it is easier to discover policy implications from theoretical results. Let  $t$  be the transportation cost, and to some extent,  $t$  reflects the local marketization level.

In view of the above analysis, this study builds a three-stage game model where the decision-making sequence is plotted in Fig. 1. One country's marketization level is exogenous, being expressed by the transportation cost  $t$  at stage 0. Given  $t$ , the government's problem is to select profit tax  $1-T$  in order to stimulate firm  $D$ 's green innovation effort. Given  $t$  and  $1-T$ , at stage 2 firm  $D$  chooses its effort  $e$  to reduce its abatement cost  $c_D$  by innovation effort with disutility  $e^2/(2\mu)$ . So,  $c_D-e$  is firm  $D$ 's abatement cost after green spillovers, which can be handled in empirical work by the firm's investment saving in pollution control. Given  $t$ ,  $T$ ,  $c_D-e$  and  $c_F$ , at stage 3 firm  $F$  and  $D$  compete in a homogeneous goods market by setting their prices.

According to the backward induction method, we first consider stage 3 where the total market share is normalized as 1, and  $x_D$  (or  $x_F$ ) represents market share of firm  $D$  (or  $F$ ). Thus,  $x_D+x_F=1$ . Let  $p_D$  and  $p_F$  denote price charged by the two firms. The present problem is analogous to a model designed to determine optimal retail locations in a spatially defined duopoly. See Fig. 2, the two firms are located at two ends of the horizontal line of length 1. The transportation cost per unit of length is  $t$ . Total payment for goods is equal to goods price ( $p$ ) plus transportation cost ( $tx$ ). At equilibrium,

$$\begin{cases} p_D + tx_D = p_F + tx_F \\ x_D + x_F = 1 \end{cases} \quad (1)$$

The solution is  $x_D=(2t+p_F-p_D)/2t$  and  $x_F=(2t+p_D-p_F)/2t$ .

At stage 2, firm  $D$  makes a tradeoff between the abatement cost reduction and the effort disutility. Only if the former is larger than the latter, the profit impels firm  $D$  to try its best to absorb firm  $F$ 's advanced clean technologies. So, firm  $D$ 's problem is to select  $e$  in order to achieve net profit maximization, given by

$$\max_e T(p_D - c_D + e)x_D - \frac{1}{2\mu}e^2 \quad (2)$$

where  $p_D$  and  $x_D$  are the equilibrium levels at stage 3.

At stage 1, the government hopes to improve domestic green productivity by green spillovers of FDI. Introducing FDI implies that it must be at cost of market share. Therefore, the government's problem is how to draft preferential tax policy in order to balance the two conflicting objectives of green spillovers and market share. The green spillover is positively related to firm  $D$ 's net profit, so does the government's profit share from firm  $D$ . For measurement convenience, we use the government's profit share to index FDI's green spillovers. Then, the

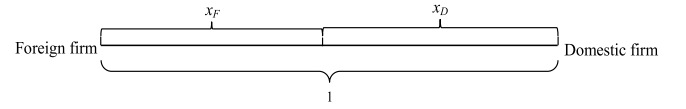


Fig. 2. The Hotelling's linear competition model.

government's problem is to maximize green spillovers by selecting the degree of tax preference to FDI. That is,

$$\max_T (1-T)(p_D - c_D + e)x_D \quad (3)$$

given  $e$  at stage 2.

For the host country as a whole, the socially optimal green innovation effort is determined by

$$\max_e e - \frac{1}{2\mu}e^2 \quad (4)$$

The unique optimal solution is

$$e^{so} = \mu. \quad (5)$$

In the short run, any abatement treatment accompanies some fixed inputs. Hence,  $e^{so} < c_D$ . In the long run, all production inputs are variable, and the ideal outcome will be carbon neutrality where abatement treatment is not needed, i.e.,  $e^{so} = c_D$ . It is natural to ask a series of questions. Does the case of  $e=0$  happen? Is the socially optimal equilibrium effort reached by firm  $D$  individually? How does the socially optimal equilibrium effort reach? What factors affect firm  $D$ 's green innovation effort? The answers to these questions are very important to those countries with clean technology bottlenecks. In the remainder of this paper, we attempt to explore them.

### 3. The green spillover effect: marketization vs. innovation

From (1), the profit functions,  $\pi_D$  and  $\pi_F$ , of firms  $D$  and  $F$  are given by the following two equations, respectively,

$$\begin{cases} \pi_D = (p_D - c_D)x_D = (p_D - c_D) \frac{t + p_F - p_D}{2t} \\ \pi_F = (p_F - c_F)x_F = (p_F - c_F) \frac{t + p_D - p_F}{2t} \end{cases}$$

At stage 3, the two firms compete with each other in terms of market share through setting prices. The best response functions satisfy the first-order conditions of  $p_D=(t+c_D+p_F)/2$  and  $p_F=(t+c_F+p_D)/2$ . At equilibrium, we have

$$\begin{cases} p_D = t + \frac{2}{3}c_D + \frac{1}{3}c_F, p_F = t + \frac{2}{3}c_F + \frac{1}{3}c_D \\ x_D = \frac{1}{2t} \left( t + \frac{1}{3}c_F - \frac{1}{3}c_D \right), x_F = \frac{1}{2t} \left( t + \frac{1}{3}c_D - \frac{1}{3}c_F \right) \\ \pi_D = \frac{1}{2t} \left( t + \frac{1}{3}c_F - \frac{1}{3}c_D \right)^2, \pi_F = \frac{1}{2t} \left( t + \frac{1}{3}c_D - \frac{1}{3}c_F \right)^2 \end{cases} \quad (6)$$

**Theorem 1.** Given  $t$ , if  $|c_D - c_F| \geq 3t$ , then  $x_D=0$  or  $x_F=0$ ; if  $|c_D - c_F| < 3t$ , both  $x_D$  and  $x_F$  are positive over  $(0, 1)$ . Therefore, the difference in cleaner technologies of foreign and domestic capital is an important prerequisite for



Fig. 1. The game sequence among the government, firms  $F$  and  $D$ .

green spillovers.

**Theorem 1** is similar to the “Environmental Kuznets Curve (EKC)” theory proposed by Kuznets in 1954. In the early phase of economic growth, many developing countries seek to attract FDI in order to make up for domestic private investment gaps and propel economic development. However, due to the upstream and downstream relationship among industries, the poor technical basis of the host country does not allow MNEs to sufficiently exert technical advantage in cleaner production, thereby accelerating the utilization of resources and producing many pollution-intensive products. The green spillovers of FDI are weak, and the host country may be pollution haven for resource-seeking FDI. Only if the technical basis of the host country reaches or exceeds a certain level, the technological levels of multinational and domestic firms match each other and further, FDI’s technology spillovers happen. This is because MNEs buy input factors (say raw materials, intermediate goods) from domestic firms, and conversely, domestic firms can provide reprocessing of intermediates for MNEs. To meet the strict environmental standards of input factors, MNEs will provide necessary technical guidance and training for domestic suppliers. FDI inflows bring opportunities for local firms to learn and adopt environment-friendly production technologies and advanced environmental management techniques. Then, FDI generates green spillovers to domestic firms and the pollution halo arises, resulting that the environmental quality of host countries is improved through introducing FDI’s cleaner production technologies. These results are consistent with previous literatures (see, e.g., Doytch and Uctum, 2016; Rafindadi et al., 2018; Pazienza, 2019; Zhao et al., 2019; Cheng et al., 2020; Wang and Luo, 2020). Thus, from the perspective of green spillovers, **Theorem 1** provides an alternative explanation for the question why host countries have different attitudes toward FDI.

Before the government introduces FDI, it should make a comparison of the cleaner-technology difference in the domestic and foreign firms. If the abatement cost difference of  $|c_D - c_F|$  is large enough, the price competition makes the entire market be owned by firm D or F. At the moment, the green spillover is close to zero. Only if  $|c_D - c_F| < 3t$ , firms F and D are co-existence at a market competition. In this setting, as advanced technologies and management experience brought by FDI flow into the host country, its cleaner production level will improve. The underlying reasons involve two aspects. On the one hand, the entry of MNEs will intensify the local market competition. This forces the domestic enterprise to adapt to new technologies, learn effective production organization mode, and imitate MNEs’ new products to survive in business, which accelerates the application of clean technologies. Through the forward and backward linkages within the industry, the entry of MNEs will drive the innovation activities of local firms and the diffusion of cleaner technologies among them. On the other hand, MNEs usually have environment-friendly production technologies, take strict environmental standards of input factors, master advanced environmental management system, and take more social responsibility. With FDI inflows into the host country, the usage of cleaner-production technologies increase gradually, which, as suggested by Huang et al. (2019), promotes the technological upgrading and helps curb pollution emissions in the host country. In addition, FDI inflows into the host country imply that the local production factors, such as capital and labor, will be reorganized, leading to a rise in energy efficiency, so that the trend of cleaner production is improved in the host country.

To explore FDI’s green spillovers, we focus on the case in which firm F has technical advantage in clean production and the government introduces FDI. That is,  $0 < c_D - c_F < 3t$ . Let  $c_D - c_F = \Delta c$ . Then,  $\Delta c \in (0, 3t)$ . By (6),  $\partial \pi_D / \partial (c_D - c_F) = -1 / \{3t[t - (c_D - c_F) / 3]\} < 0$ , which implies that firm D has motivation to reduce its abatement cost. Thus, at stage 2, firm D’s optimal problem is to choose its green innovation effort  $e$  in order to maximize its profit

$$\max_e T\pi_D - \frac{1}{2\mu}e^2 \quad (7)$$

where

$$\pi_D = \frac{1}{2t} \left[ t + \frac{1}{3}c_F - \frac{1}{3}(c_D - e) \right]^2 = \frac{1}{2t} \left[ t - \frac{1}{3}\Delta c + \frac{1}{3}e \right]^2 \quad (8)$$

Substituting (8) into (7) and rearranging yield

$$\max_e - \left( \frac{1}{2\mu} - \frac{T}{18t} \right) e^2 + \frac{T}{9t} (3t - \Delta c) e + \frac{T}{18t} (3t - \Delta c)^2 \quad (9)$$

In (9), the first term is referred as the disutility effect of firm D’s innovation effort, and the second term is the price effect of innovation effort. Then, we have the following **Theorem 2**.

**Theorem 2.** There exists a threshold value  $\Delta c^*$  such that: as  $\Delta c \in (0, \Delta c^*)$ , the price effect is larger than the disutility effect, and  $e > 0$ ; as  $\Delta c \in (\Delta c^*, 3t)$ ,  $e = 0$ , regardless of the relationship between the price effect and the disutility effect.

Roughly, with the increase in marketization level, the market competition between domestic and foreign enterprises intensifies gradually (Albornoz et al., 2009). The market competition makes MNEs sufficiently exhibit technical advantages in cleaner production, which conversely triggers competition feedback effect on the host enterprise (i.e., the price effect promotes the host enterprise to improve its technology level to survive in business). **Theorem 2** suggests that market-oriented reforms and fierce competition may drive FDI to spill cleaner technologies. Thus, the price effect plays an important role in determining the type of FDI’s spillovers. When the price effect is weak, FDI’s green spillovers are not sufficiently exhibited. This point allows us to understand why a country needs to make market-oriented reforms in terms of environmental protection, as the price decreased from innovation is surpassed by the disutility of innovation. When the price effect becomes stronger, advanced technologies and environment-friendly practices brought by FDI will motivate domestic enterprises to make more efficient use of resources or to adopt new technologies, which forces some “dirty” enterprises to close down while others are replaced by cleaner-tech and low-energy enterprises. Consequently, the production growth changes towards cleaner economic activities and undergoes a shift from pollution-intensive industries to cleaner ones. Finally, the environmental quality of the host country is improved. This finding confirms that FDI can exert the pollution halo effect on the host country, which is in line with the conclusion of Jiang et al. (2018), Xu et al. (2019) and Xie and Sun (2020). However, the stronger price effect makes enterprises be confronted with greater competition. It will make it difficult for enterprises to get a profit because of a large innovation investment in clean technologies. Thus, the pressure from market competition often forces enterprises to prefer over pollution-intensity technologies due to less cost and more profit compared with clean technologies. Consequently, in a free market, the usage of clean technologies is often insufficient. In order to improve the level of clean technologies, environmental policies, say R&D subsidies suggested by H. Wang et al. (2019), are necessary to stimulate clean R&D investment. This finding is similar to that of Dong et al. (2019). Therefore, we suggest that the host country should formulate differentiated foreign investment policies based on its actual conditions. For those countries with higher technology basis, the focus of introducing FDI should be shifted to environment-friendly foreign capital, extending the degree of green spillovers. For those countries whose initial technology level is lower, introducing foreign capital can improve their economic growth, while there are less green spillovers. As a remedy to this situation, the government should strengthen its independent innovation ability, since (9) shows that the innovation capacity parameter  $\mu$  is a key factor impacting the abatement effort of domestic firms.

From the proof of **Theorem 2** (see Appendix), it is found that as  $\mu > 9t/T$ ,  $e = c_D - c_F$ , and as  $\mu < 9t/T$ ,  $e = 0$  happens. Therefore, technological innovation capacity has a very important role in the improvement of environmental quality of the host country, because technological innovation can improve cleaner-production process, spread green environmental protection products, and optimize industrial structure. The improvement of cleaner-production process can effectively use resources and energy, and reduce the resource and energy consumption in unit output, thereby reducing pollution emissions and ultimately improving environmental quality. The spread of green

environment protection products is reflected in the production equipment, such as clean energy and pollution treatment equipment, which can promote the cleaner-production system. The optimization of industrial structure is manifested in eliminating pollution-intensive industries, and developing technology-intensive manufactures and modern services, which reduces industrial pollution emissions. Thus, FDI inflows into high innovation capacity industries/enterprises benefit the host environment. Generally, in manufacturing industries, R&D focuses on advanced technologies and requires higher innovation capacity; whereas, R&D innovation in service sectors centers at management techniques and needs stronger learning capacity. Maybe, FDI's spillover degree in service sectors is larger than that in manufacturing ones. [Theorem 2](#) implies that FDI has differential green spillovers on various industries according to their innovation capacity: as FDI flows into manufacturing industries with high innovation capacity (or service sectors with strong learning capacity), green spillovers may reduce pollution emissions (this supports the pollution halo hypothesis). While FDI inflows into manufacturing industries with low innovation capacity (or service sectors with weak learning capacity), it will increase pollution emissions (this supports the pollution paradise hypothesis). Furthermore, within an industry, the enterprise with more R&D capital and staff is easier to absorb clean technologies brought by MNEs, and vice versa. This finding is in similar line with the findings of [Dong et al. \(2019\)](#). Therefore, the government should guide FDI into clean industries and service sectors to promote the green transformation and upgrading of its industrial structure, which is supported by [Jiao et al. \(2019\)](#) and [Oliveira et al. \(2020\)](#).

Combining [Theorem 1](#) with [Theorem 2](#), we know the upper bound  $3t$  is the necessary condition under which firm  $D$  participates the market competition, but  $\Delta c^*$  is just the upper bound determining whether firm  $D$  makes an effort or not. It is a natural question whether the government policy affects firm  $D$ 's abatement effort. Setting  $\hat{T} = 9t/\mu$ . As  $T < \hat{T}$ , it implies from (9) that the best choice of  $e$  satisfies

$$e^* = \frac{\mu T}{9t - \mu T} (3t - \Delta c). \quad (10)$$

**Theorem 3.** (i) In the short run, if  $T < \hat{T}$  and  $\mu \leq \Delta c + 3t(3/T - 1)$ ,  $e^* \leq e^0$ ; if  $\mu > \Delta c + 3t(3/T - 1)$ , then  $e^* > e^0$ , regardless of  $T < \hat{T}$  or  $T > \hat{T}$ . That is, besides the innovation capacity, the government policy affects firm  $D$ 's green innovation effort. Moreover, the effort level is aggressive in the innovation capacity, even exceeds the socially optimal level.

(ii) In the long run, if  $9tc_D/[T(3t+c_F)] \leq \mu < 9t/T$ , then  $e=c_D$ . That is, as long as the innovation capacity reaches the critical value  $9tc_D/[T(3t+c_F)]$ , firm  $D$ 's abatement cost may disappear completely and the green spillover is the strongest.

As suggested by [Zhou et al. \(2019\)](#) and [Amendolagine et al. \(2021\)](#), it is generally believed that the stronger innovation capacity is more beneficial for domestic enterprises to imitate and learn advanced technologies in the short run, and to digest and absorb more advanced technologies in the long run. Our findings support this view. According to [Theorem 3](#), FDI has green spillovers for domestic firms with moderate innovation capacity, and the spillover degree is gradually deepened over time. One potential explanation is that those enterprises with low R&D ability have employees with less years of education. It is difficult for these employees to successfully learn and imitate advanced technologies brought by FDI in the short run. Conversely, the enterprise, that clusters employees of higher education, often owns higher R&D ability. By sending higher-education technicians to study in MNEs, the domestic enterprise can acquire advanced technologies and operating skills. Meanwhile, an enterprise with high R&D can match MNEs in terms of technologies and products, and can also absorb advanced management experience and operating skills by employing MNEs' staff. Thus, moderate labor mobility is helpful for FDI's spillovers through cooperating between MNEs and domestic enterprises. Saying this, the flow of production factors

brought by FDI plays an important role in green spillovers. Since FDI is a carrier of various production factors, it will bring production factors into a location from domestic enterprises and different regions. By short-term exchange and cooperation, the flow of factors will intensify FDI's spillover degree within the industry and expand FDI's spatial spillovers in the geographical space. As shown by [Zhao et al. \(2019\)](#), capital inflows brought by FDI alleviate the lack of funds for the host country, and more importantly, in the energy industry FDI inflows can promote some host energy-intensive enterprises to develop new technologies to improve energy efficiency.

[Theorem 3](#) implies that technological innovation plays an important role in green development, and then, the question that arises from this is how to improve the innovation capacity of the host country. There are two alternative ways. One is through employment. MNEs with advanced technologies are more likely to invest in high-tech industries of a host country, so that they often need skilled workers. For this reason, MNEs will train employees to enhance their technical strength. Free labor mobility will make domestic enterprises get advanced technical knowledge and further, improve the host innovation capacity. The other is the demonstration effect among enterprises. MNEs are often operated and managed in the face of international markets, leading to their production technology, production organization, quality management, financial operation, and product environment standard being carried out according to international practices. In terms of cleaner production and environmental sustainability, MNEs in cleaner production and environment protection will be brought into the host enterprise. Such demonstration effect diffuses among local enterprises, improving the technological progress of the host country. However, technological progress does not necessarily result in technological innovation. In fact, FDI's spillovers will raise the green technological level of the host country, but this is not the same as the improvement of the host innovation capacity. The enhancement of the innovation capacity of the host country depends on domestic enterprises, which is a long-term process.

[Theorem 3](#) also identifies that besides the innovation capacity, the government's tax preference policy affects FDI's green spillovers through firm  $D$ 's abatement effort. Therefore, it is necessary for us to examine how the tax rate  $1-T$  affects firm  $D$ 's abatement effort.

**Theorem 4.** Given  $T > 9t/(3t+c_F)$ , if  $\mu \leq 9tc_D/[T(3t+c_F)]$ ,  $e < \mu < c_D$ ; if  $\mu > 9tc_D/[T(3t+c_F)]$ ,  $e=c_D$ . Given  $T \leq 9t/(3t+c_F)$ , if  $\mu \leq \Delta c + 3t(3/T - 1)$ ,  $e < \mu < c_D$ ; if  $\mu > \Delta c + 3t(3/T - 1)$ ,  $e=c_D$ .

For  $T > 9t/(3t+c_F)$ , the profit share  $T$  limits the green innovation effort to be less than  $c_D$ . However, for  $T \leq 9t/(3t+c_F)$ , the profit share makes the effort reach the upper bound  $c_D$ . In short, the differential tax policy  $(1-T)$  has a negative influence on green innovation effort of domestic firms. It is necessary to provide moderate tax preferences for FDI to spill its cleaner-production technologies. As the different abatement tendencies in terms of FDI sources, the government should adjust its trade policies with diversified tax systems to seek cleaner FDI by a complex of economic, administrative, and legal instruments. The conclusions of [Sinha et al. \(2017\)](#) and [Xie et al. \(2020\)](#) are similar our findings, noting that trade openness has a different impacts on pollution emissions in different host countries.

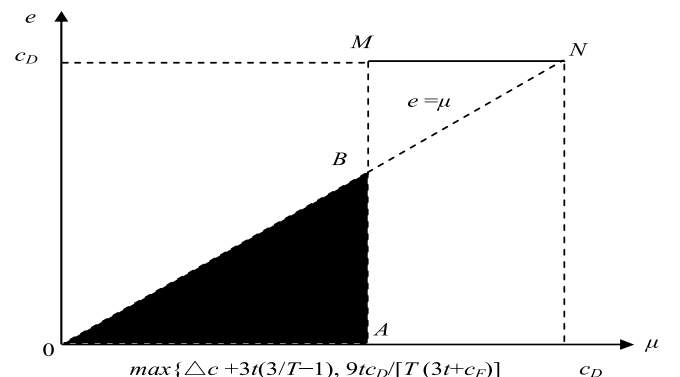


Fig. 3. The relationships between  $e$  and  $\mu$ .

See Fig. 3, the feasible set of firm D's abatement effort consists of triangle AOB and line segment MN. The green spillovers of FDI on the host country are non-linear. That is, they may change with the accumulation of some influencing factors (say innovation capacity). The threshold effect of FDI's green spillovers occurs. Given  $t$  and  $\mu$ , the tax policy  $(1-T)$  determines the extent of green spillover. If the tax preference to FDI is large, i.e.,  $T < \max\{9tc_D/(\mu(3t+c_F)), 1+9t/(\mu-\Delta c)\}$ , the profit share discourages the incentive in firm D's innovation effort so that it is strictly less than the socially desired level. Only if  $T \geq \max\{9tc_D/(\mu(3t+c_F)), 1+9t/(\mu-\Delta c)\}$ , the abatement effort is coincident with the socially optimal one. However, low tax preference harms the attraction for FDI. Therefore, it is a challenge to the government how to make a tradeoff between the tax preference and green spillovers. Substituting (10) into (8) yields

$$\pi_D = \frac{1}{18t} \left( 3t - \Delta c + \frac{\mu T}{9t - \mu T} (3t - \Delta c) \right)^2 = \frac{9}{2} t (3t - \Delta c)^2 \frac{1}{(9t - \mu T)^2}$$

The government's problem is to choose the tax rate  $1-T$  in order to maximize green spillovers as shown below

$$\max_T \frac{9}{2} t (3t - \Delta c)^2 \frac{1 - T}{(9t - \mu T)^2} \quad (11)$$

Obviously, the parameter  $t$  is a key factor impacting the green spillovers through firm D's abatement effort (see the kink point A in Fig. 3). For example, as  $t \rightarrow 0$ , the objective function in (11) is close to zero, and there is no green spillover. Besides, Theorems 3 and 4 both show that  $\mu$  is another critical parameter influencing the green spillovers. Thus, to obtain green spillovers as much as possible,  $t$  and  $\mu$  need to be simultaneously considered before the government formulates the tax preference policy.

**Theorem 5.** Only if  $t/\mu \in (1/9, 2/9)$ , the optimal tax preference policy of the government satisfies  $1-T = 9t/\mu - 1$ . Moreover, the parameter  $\mu$  is positively related with the maximum green spillover  $9t(3t - \Delta c)^2/[8\mu(9t - \mu)]$ , while the effect of the parameter  $t$  on the maximum green spillover is ambiguous.

Cleaner production usually saves energy and emits less pollutant to the air, thereby mitigating the damages to the environment. For achieving green transition of economy, firms can reduce pollution emissions by way of absorbing FDI's cleaner-production technologies or improving their cleaner-production system through green innovation activities. Alternatively, domestic firms may directly utilize cleaner-production equipments of FDI instead of dirty ones to pursue both economic growth and environmental sustainability. Meanwhile, the high innovation capacity, being measured by skilled workers and R&D staff, can accelerate the upgrading process of firms' cleaner-production equipments (Zhou and Zhao, 2016). Theorem 5 shows that with an improvement in innovation capacity, FDI's green spillovers are strengthened. But it is proved that poor technical basis would impede the implementation of cleaner production (Borges et al., 2021). Relative to pollution-intensive production, cleaner production implies higher equipment investments and higher wage workers. Under poor technical conditions, firms are usually not willing to upgrade to cleaner production for saving production cost. In this sense, the actual conditions of the host country may have the threshold effect on such upgrading transformation. Indeed, Liu et al. (2020) empirically identify the threshold effect of technical progress on environmental pollution.

When taking innovation capacity and marketization level as double thresholds, there is a complicated relationship between the government policy and FDI's spillovers. When the value of  $t/\mu$  is very large, the tax preference policy inhibits the green effort of domestic firms, but improves FDI's spillovers. However, with a further increase of the value of  $t/\mu$ , FDI's green spillovers may enhance innovation activities of domestic firms.

In addition, the relationship between innovation capacity and green spillover is not a simple one-way causal relationship, but a relationship of interaction. This theoretically proves that the relationship between innovation capacity and ecological environment is nonlinear, and may be affected by other variables such as marketization level and environmental regulation.

According to above discussion,  $t/\mu \in (1/9, 2/9)$  derives  $T < 9t/\mu$  and further, supports an interior solution of  $e$  at stage 2;  $0 < t/\mu \leq 1/9$  deduces

$T \geq 9t/\mu$  that does not support an interior solution of  $e$ , and there only exists a corner solution  $e = c_D$ ;  $t/\mu \geq 2/9$  implies  $T < 9t/\mu$ , and in which case there is also a corner solution of  $e = 0$ . Then, we can conclude the equilibrium outcome in Theorem 6.

**Theorem 6.** If  $1/9 < t/\mu < 2/9$ , the subgame Nash equilibrium is the tax preference policy  $1-T^* = 9t/\mu - 1$ , the innovation effort  $e^* = (2\mu - 9t)(3t - \Delta c)/[2(9t - \mu)]$ , and the green spillover  $9t(3t - \Delta c)^2/[8\mu(9t - \mu)]$ . If  $0 < t/\mu \leq 1/9$ , the subgame Nash equilibrium is the tax preference policy  $1-T^* = 0$ , the innovation effort  $e^* = c_D$ , and the green spillover  $9t(3t + c_F)^2/[8\mu(9t - \mu)]$ . If  $t/\mu \geq 2/9$ , the tax preference policy  $1-T^* = 1$ , the innovation effort  $e^* = 0$ , and zero green spillover.

Theorem 6 investigates the impact of FDI on green spillovers, but with mixed results. As in Antweiler et al. (2001) and Zhao et al. (2019), we decompose FDI's green spillover into scale, structure and technical effects. The scale effect refers the increase in the variety and quantity of green products when FDI with cleaner technologies flows into the host country. With the cross-industry, cross-region spread of new green products, the cleaner production level in the host country will be improved as a whole. The structural effect is the change in production factor structure by FDI, leading to the labor mobility between foreign-investing and domestic enterprises and the reallocation of capital and labor. The labor mobility accelerates the dissemination of energy-saving technologies, air pollution-reduction technologies, and effluent discharge-reduction technologies to local firms, thereby helping the host country to conserve much energy and resource, and reduce pollution emissions. With the increase of FDI inflows, the production factor structure will be optimized in terms of energy-saving and abatement technologies, pollution intensity will be gradually reduced and environmental quality will show an upward trend. The technical effect refers to the competition pressure from FDI such as the lower abatement cost, leading to a larger market share in green products, which compresses the business space of local enterprises and stimulates their innovation activities, resulting in improvement in FDI's spillovers. Specifically, the technical effect affects FDI's green spillovers in two ways: one is that domestic enterprises imitate the advanced production or environment-friendly products of FDI through introducing MNEs' equipments and employing MNEs' technicians; the other is that domestic enterprises invest in innovation activities to survive in fierce market competition. These three effects work together in transferring cleaner technologies, eco-friendly products, and high-tech industries from MNEs to local firms, leading toward a rise in green spillovers. These spillovers increase the green productivity and efficiency of domestic firms, which ensure sustainable development.

The above analysis shows that the parameters  $T$ ,  $t$  and  $\mu$  can be used to measure the scale, structural and technical effect of FDI's green spillovers, respectively. However, it is shown from Theorem 6 that these three effects are not isolated, but interdependent. Specifically, the scale effect sometimes inhibits the green spillovers of FDI, say  $1-T^* = 1$ , thus the structural and technical effects play an important role. In this sense, to meet the goal of sustainable growth, the government should not simply focus on FDI quantity, but maybe, FDI quality should be paid more attention. Otherwise, a lot of pollution-intensive MNEs enter the host country and environmental problems come into being. Therefore, reasonable FDI policy must focus on environment-friendly technologies, cleaner production and green products brought by FDI, which makes the host economy be sustainable growth. What's more, FDI quality, such as the structural and technical effect, cannot be ignored. The aim of attracting and utilizing FDI should be shifted to optimize the structure of foreign capital by reinforcing the environmental assessment of MNEs in investment process. The government should guide FDI into high-tech and efficient production. This makes it necessary for policy-makers to understand MNEs' cleaner production behaviors, distinguish different foreign investors, and implement differentiated innovation incentives for domestic firms.

The different equilibrium efforts can be interpreted by considering the government's attitude toward FDI. In the initial phase of introducing FDI, the government has a great desire for FDI scale due to promoting economic growth, thus providing much tax preference to foreign capital and lowering environmental standards. Under these circumstances, some pollution-intensive and energy-intensive MNEs will be transferred to the host country,

directly resulting in an increase in pollution emissions. Such FDI will just increase the production activities of the host economy by consuming a large amount of resources, while not spill the demonstration effect to the host enterprises. With the growth of FDI scale, the government will gradually pay more attention to the quality of FDI and provide priorities to those MNEs represented by advanced cleaner-production technologies. At this moment, the increase in FDI will improve energy efficiency and abate pollution emissions of the host country, directly urging the host enterprise to upgrade and optimize the production process towards cleaner tendency. The role of FDI in technological innovation will accelerate the green transformation of the industrial structure and build a cleaner production mode.

In addition, [Theorem 6](#) implies that foreign investment may not generate green spillovers, since the innovation effort happens only if the host innovation capacity reaches a certain level. It is therefore necessary for the government to provide additional subsidies via special funds for firms' innovation activities.

#### 4. Implications for practice and policy

So far, we have analyzed the threshold effects of marketization level, initial technology basis, innovation capacity and regulatory institution on green spillovers of FDI. The theoretical results have brought forth several insights regarding the cleaner production practices. These aspects have been seldom investigated from the perspective of sustainable development, and we will explain the practice and policy implications of the theoretical results in this section.

Broadly speaking, market competition is a shadow index of marketization level, and the host's technology basis determines the demonstration effect between MNEs and domestic firms through the upstream and downstream production relationships. [Theorems 1 and 2](#) imply that the marketization level plays an important role in determining whether the abatement effort occurs or not, whereas the initial technology basis of the host country affects the intensity of FDI's green spillovers. Some studies have suggested that FDI's spillover effects are weakened when the technological basis of the host country is too high or too low ([Zhang et al., 2020](#)). When the technology basis in the host country is low, the distance to the frontier technology of MNEs is long, resulting in the mismatching of production factors caused by technological gaps between MNEs and domestic firms, which affects the absorption and diffusion of advanced technologies. If it is high and close to frontier technology, the space of MNEs' demonstration effect becomes small. It should therefore be noted that there exists a threshold effect of domestic technology level on FDI's green spillovers. In view of these findings, it can be assumed that inward FDI pattern in developed or emerging countries could be environment-friendly and beneficial for sustainable development in those countries with higher technology basis and marketization level. In contrast, FDI that flows into those regions with low marketization level and poor technology basis may exhibit the pollution haven, being harmful for the local environment. These are consistent with empirical ones in [Adom and Amuakwa-Mensah \(2016\)](#) and [Dong et al. \(2019\)](#). To meet the 1.5 °C temperature limitation goal in the Paris Agreement, it is therefore imperative for high marketization country to attract the investment or the entry of environmental friendly and sustainable industrial MNEs, based on the comparative advantage in cleaner production. Yet, the policy-makers of low marketization country have to redesign foreign investment and trade policies. When the fossil fuel import is substituted by the cleaner-technology import, the efficiency of energy and material consumption will be improved, and the environmental standard of products will be raised, which in turn increases the host marketization level. This can be a first stepping stone towards the implementation of the carbon-peak objective, and the green innovation capacity plays an important role in this process.

Besides among similar industries, the green spillovers exist among different industries through the related production activities, such as buying raw materials, selling intermediate products, and reprocessing of intermediate goods. When various industries cluster in one location, the

forward and backward linkages between MNEs and domestic firms make knowledge diffusion/technology spillovers be easier. For example, FDI can promote energy intensity convergence and further, reduce regional energy efficiency differences ([Yu et al., 2018](#)). From this viewpoint, the industry agglomeration shortens the distance of neighboring firms and further strengthens the linkages among firms, so that it is beneficial for the host industry to absorb and digest cleaner technologies brought by FDI. Thus, the green spillovers of FDI inhibit the rise of energy/carbon intensity in the host country, which has important impact on globally environmental quality. However, along with the industry agglomeration, market competition becomes fierce and monopolistic competition appears among firms. As pointed out by [Dong et al. \(2019\)](#) and [Theorem 2](#), fierce market competition makes firms prefer to low-cost dirty technologies in order to get a profit, while monopolistic competition restrains the willingness of firms to pour money into R&D innovation. Overall, FDI's green spillovers caused by the industry agglomeration are ambiguous. On these grounds, the host country should make use of the positive effect of the industry agglomeration on FDI's technology spillovers to develop cleaner technologies and to promote green innovative activities of domestic firms. On the other hand, the host country should further optimize market competition mechanism to improve the green spillover conditions faced by MNEs. Meanwhile, to stimulate enterprises to spill or absorb advanced technologies, especially new renewable technologies, it is essential for the host country to implement environmental regulations and R&D subsidies.

Over the years, the researchers have identified the double-edged impact of FDI on environmental quality from several viewpoints, involving energy efficiency ([Dong et al., 2019; Zhao et al., 2019](#)), pollution emissions ([Shahbaz et al., 2019; Xie et al., 2020](#)), cleaner operation ([Huang et al., 2019; Jiao et al., 2020](#)). Beyond these, there is also a perspective of technological innovation capacity. It is well known that technological innovation can promote the R&D of cleaner products, reduce pollution emissions and improve green productivity. As a combination of capital, technology, management and marketing, FDI can bring cleaner-production technologies and pollution control experience to the host country through spillover effect. It is therefore believed that FDI can improve the technological innovation ability of the host country. Yet, the entry of FDI may crowd out the host's innovation space, which is detrimental to the improvement of its technological innovation capacity. As documented by [Wang and Luo \(2020\)](#), when FDI's scale or quality is low, the scientific and technical innovation capacity aggravates environmental pollution levels; with an increase in FDI scale or quality, however, the positive effects of technological innovation ability on environmental pollution are strengthened. Moreover, we find that FDI's positive spillover effect is not significant, when host's technological innovation capacity is low, while when it crosses a threshold, FDI's positive spillover degree increases with it. As the global economy is still at early green transformation phase, FDI inflows into low R&D capacity regions might prove to be harmful in aggregate for reducing global pollution emissions. Owing to these facts, accelerating global green transformation has to rely on both the host technical innovation ability and the environmental performance of FDI. Following the route of technology trade, high R&D capacity enterprises in the host country have access to cleaner production technologies brought by MNEs, which serves as a substitutable viable for independent R&D innovation. Nevertheless, some host enterprises, due to low R&D level, may not absorb advanced technologies and need to improve cleaner operations through a self-reliant way. In global trade, FDI inflows are an alternative instrument to solve the regional imbalanced development of energy intensity and renewable energy sources, as suggested by [Zhou et al. \(2019\)](#), [Feng et al. \(2019\)](#) and [N. Wang et al. \(2019\)](#).

FDI is a carrier of various production factors and brings different production factors to a region in the host country. The flow of production factors in geographical space will lead to FDI's spatial spillovers. The spatial spillover effect shows FDI's influence on local and surroundings, which makes lower energy efficiency regions catch up with

higher ones. FDI's green spillover will influence energy efficiency and industrial structure transformation in the host country. Typically, moderate labor mobility is beneficial for FDI's green spillovers. By cooperating with each other, the domestic enterprise can not only send employees to visit and study in MNEs, but also employ MNEs' staff. In this process, domestic enterprise acquires or absorbs advanced production technologies, operating skills, organizational ways, management experiences and sustainable development concepts like low-carbon economy, carbon peak and carbon neutralization. Besides promoting the host country to invest more resources in managing environmental pollution and reducing energy waste, cleaner technologies brought by FDI will reduce the use of non-clean energy and promote the use of renewable energy, which is a driving force to improve the green productivity and sustainable development capacity of the host country. In a word, the technical diffusion and flow of production factors play an important role in FDI's spillover effect on the economy, energy and environment of the host country. Therefore, in the process of regional economic integration, the policies of different regions should be coordinated between FDI sources and local firms to strengthen the spatial spillover of FDI. Local government can play a positive role in sustainable development by offering special funding (say subsidies, tax incentives) to encourage the adoption of cleaner technologies. Further, the spillover effect of FDI is also global: the production factors such as capital, management and technology brought by FDI in a country will gradually spread to the whole world (Zhao et al., 2019). This suggests policy makers to design comprehensive trade and investment policies by targeting the cleaner production practices, in order to ensure environmental sustainability.

What's more, the impact of FDI on green spillovers can be decomposed into scale, structural and technical effects. In terms of the scale effect, it is ambiguous whether the increase in FDI quantity is conducive to sustainable growth of the host country or not. Sometimes, when the scale effect is incompatible with the structural and technical effect, there is no green spillover of FDI. Only if the government policy, the enterprise innovation capacity and the flow of production factors brought by FDI are coordinated with each other, the competition pressure from foreign-investing enterprises can stimulate domestic enterprises to absorb advanced technologies and implement innovation activities. So, taking relevant policies and regulations of attracting FDI into the cleaner production framework will be an alternative way to explore the coordinated development of economic growth and environmental sustainability. This implies that when attracting foreign investment, the host country should pay more attention to its quality, such as environment-friendly technologies, cleaner production process and new green products.

## 5. Conclusion

The global economy today is at the nascent stage of green transformation. To accelerate the transformation, cleaner technologies need to be transferred properly, and associated financial investment also needs to be supported (Dechezleprêtre et al., 2011). In this regard, FDI has been recognized as an important channel for green spillovers. Surely, FDI inflows with cleaner technology can bring about positive technology transfer and spillovers, improve energy efficiency, reduce pollution emissions and prevent environmental degradation in the host country. Many empirical studies have analyzed FDI's spillovers. In contrast, little attention has been paid to the green spillovers of FDI. Moreover, there has been little theoretical analysis on the threshold effects of FDI's green spillovers. To explore the complex effects of FDI's technical spillovers on the green innovation effort of the host country, this paper develops a theoretical model. It is found that the marketization level and innovation capacity of the host country are two key factors impacting FDI's green spillovers. With low marketization level and weak innovation capacity, the green spillover is poor. Only if the ratio of marketization level to innovation capacity is equal to or larger than some threshold value, the green spillover occurs, even achieves the

socially optimal level. To seek the transmission channels of green spillovers, we formulate the competition between the foreign and domestic firms in a homogeneous goods market by Hotelling's linear model. At equilibrium, the government's policy has an essential influence on green spillovers, whereas once green spillovers happen, the innovation capacity of the domestic firm determines the spillover degree. More importantly, this paper presents the critical values of some key parameters. Typically, the explicit expressions for critical marketization level (it determines whether the green spillovers occur or not) and critical innovation capacity (it determines how much the green spillover degree is) are addressed and associated policy implications are provided in detail.

For easy understanding and application, this paper employs a linear price competition model to conduct the market share of homogeneous green goods. Such a theoretical frame provides a viewpoint to support the pollution halo hypothesis that FDI inflows can improve green innovation capacity of host countries and obtain cleaner development through cleaner technology dissemination and green spillover effects. Meanwhile, it describes a map to the host policymakers on how to improve the green spillovers of FDI and stimulate cleaner innovation activities of domestic firms. It clearly shows what the host government can do, how it can do, and whether it can do better to improve the green spillover effects of FDI at the firm level through an active and effective means such as cleaner production and energy conservation. Strengthening labor mobility and cooperation between MNEs and local firms can lead to the improvement of environmental performance, spillovers of cleaner technology to local firms. In addition, the regional economic integration is conducive to the spatial green spillovers of FDI by the upstream and downstream relationship in an industrial chain. Policy implications in Section 4 show that: (1) cleaner production and proactive green innovation of the host country can generate multiple effects on sustainable development; (2) improving the environmental performance of FDI not only prevents ecological environment damage of host countries, but also ensures the long-term operation of cleaner production and achieve common cleaner development.

The green spillovers of FDI not only effectively stimulate the green innovation capacity, but also reduce pollution emissions of the host country. Thus, the host country needs to implement more efficient openness policies in the context of sustainable development to attract cleaner FDI. This action should be linked with the actual conditions of the host country, such as marketization level, technical basis and initial innovation ability. The host government should improve them by subsidizing green innovation activities, introducing tax on polluting emissions and regulating environmental institutions. In doing so, local firms would be incited to facilitate green innovation and introduce cleaner-production technologies to improve environmental performance. This will ensure FDI's long-term interest in cleaner production to keep green competition advantage. In order to make this process be a smooth one, the host government should formulate some incentives and modify regulatory mechanisms that can promote cleaner production and protect the environment.

## CRedit authorship contribution statement

**Mingrong Wang:** Formal analysis, Writing – review & editing. **Xi Zhang:** Conceptualization, Supervision. **Yi Hu:** Methodology.

## Declaration of competing interest

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

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## Appendix

**The proof of Theorem 1:** If  $c_D - c_F \geq 3t$ , then  $x_D = 0$ , because

$$\begin{cases} p_D + tx_D \geq p_D = t + \frac{2}{3}c_D + \frac{1}{3}c_F \\ p_F + tx_F \leq p_F + t = 2t + \frac{2}{3}c_F + \frac{1}{3}c_D \end{cases}$$

Further,

The price disadvantage makes firm  $D$ 's market share be closed to zero. In the same manner, if  $c_F - c_D \geq 3t$ , then  $x_F = 0$ . Therefore, given  $t$ , if the difference in the abatement costs of firms  $F$  and  $D$  exceeds  $3t$ , the entire market is owned by firm  $D$  or  $F$ . In that case, the green spillover does not happen. Yet the condition of  $|c_D - c_F| < 3t$  makes the co-existence of firms  $F$  and  $D$  at a market competition. Hence,  $|c_D - c_F| < 3t$  is the prerequisite that the system of equation (6) has an interior solution.

**The proof of Theorem 2:** See Fig. A1.

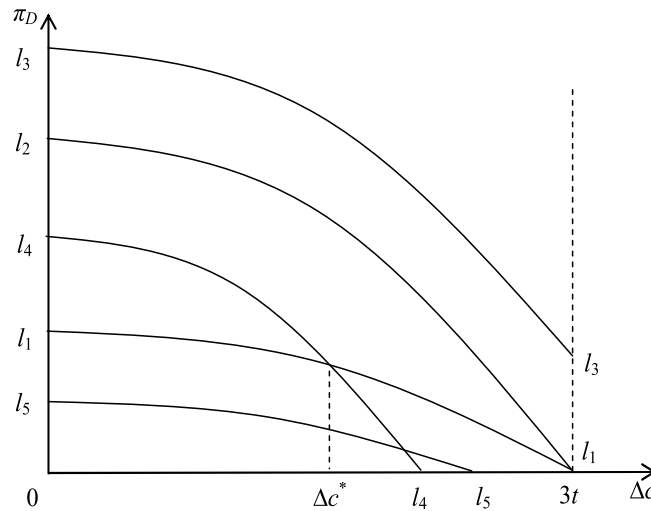


Fig. A1. Firm  $D$ 's profit changes with green innovation effort.

Firm  $D$ 's profit curve after tax  $l_1l_1$  is  $T(3t - \Delta c)^2/(18t)$ , which is decreasing at the decreasing rate in  $\Delta c$  over  $(0, 3t)$ . Due to the disutility effect, the abatement cost reduction of firm  $D$  is  $c_D - e$  and the associated equilibrium price equals  $T(3t - \Delta c)e/(9t)$ . The price effect of effort increases firm  $D$ 's profit, equaling  $T(3t - \Delta c)e/(9t)$ . Thus, the price effect of effort makes firm  $D$ 's profit curve  $l_1l_1$  move up to  $l_2l_1$ . The disutility effect of firm  $D$ 's effort,  $[T/(18t) - 1/(2\mu)]e^2$ , depends on the government's profit share and its own innovation capacity. If  $\mu > 9t/T$ , firm  $D$ 's profit curve  $l_2l_1$  shifts up to  $l_3l_1$  and certainly, it is willing to increase effort  $e$  until  $c_D$ . Therefore, if  $\mu > 9t/T$ , then  $0 < e < \Delta c$ . If  $0 < \mu < 9t/T$ , then  $[T/(18t) - 1/(2\mu)]e^2$  is negative, in which case effort  $e$  is determined by the relationship between the price effect and the disutility effect. As  $-[T/(18t) - 1/(2\mu)]e^2 < eT/3$ , the curve  $l_2l_1$  shifts down to  $l_4l_1$  and there exists  $\Delta c^*$  such that

$$\begin{cases} \Delta c \in (0, \Delta c^*), -\left(\frac{T}{18t} - \frac{1}{2\mu}\right)e^2 < \frac{T}{9t}(3t - \Delta c)e, e > 0; \\ \Delta c \in (\Delta c^*, 3t), -\left(\frac{T}{18t} - \frac{1}{2\mu}\right)e^2 \geq \frac{T}{9t}(3t - \Delta c)e, e = 0. \end{cases}$$

As  $-[T/(18t) - 1/(2\mu)]e^2 \geq eT/3$ ,  $-[T/(18t) - 1/(2\mu)]e^2 < eT(3t - \Delta c)/(9t)$ , and hence  $e = 0$ .

Considering the movement of  $l_2l_1$  to  $l_4l_1$ , though the disutility is less than the price effect, whether firm  $D$  goes to effort is determined by the difference of abatement cost  $\Delta c$ . Once  $\Delta c > \Delta c^*$ , the effort is equal to zero although there is a positive profit.

Therefore, as  $\Delta c \in (\Delta c^*, 3t)$ , the net profit with effort is less than that without effort and consequently, a rational firm will give its effort only if the cost difference is not too large.

**The proof of Theorem 3:** In the short run, it must be  $e^{s0} = \mu < c_D$  because of the existence of fixed costs. Given  $T < \hat{T}$ , to meet  $e \leq \mu < c_D$ , it must be

$$\frac{T(3t - \Delta c)}{9t - \mu T} \leq 1 \text{ or } \Delta c \geq 3t - \left(\frac{9t}{T} - \mu\right).$$

If  $9t/T - \mu \geq 3t$ , i.e.,  $\mu \leq 3t(3/T - 1)$ , then  $e \leq \mu < c_D$  or  $e^* \leq e^{s0}$ . If  $\mu \leq \Delta c + 3t(3/T - 1)$ ,  $e^* \leq e^{s0}$  still holds. But if  $\mu > \Delta c + 3t(3/T - 1)$ , then  $e > \mu = e^{s0}$ . Given  $T > \hat{T}$ , the objective function in (9) is strictly convex in  $e$ . Surely, the best choice of  $e$  is certain larger than  $e^{s0}$ .

In the long run, if  $\mu \geq 9tc_D/[T(3t + c_F)]$ , then  $e \geq c_D$  by (10). Namely, there is the critical innovation capacity  $9tc_D/[T(3t + c_F)]$ , determining whether  $e$  can reach  $c_D$  or not. Meantime, the proof of Theorem 2 shows that as  $\mu > 9t/T$ , the price effect of abatement effort is larger than the disutility effect. Then, Theorem 3 holds.

**The proof of Theorem 4:** By (10), the relationships between  $e$  and  $\mu$  follow that, as  $T > 9t/(3t+c_F)$ ,  $3t(3/T-1) < \Delta c + 3t(3/T-1) < 9tc_D/[T(3t+c_F)] < 9t/T$  and

$$\begin{cases} e < \mu \leq c_D, \mu \leq 3t\left(\frac{3}{T}-1\right), \\ e < \mu \leq c_D, 3t\left(\frac{3}{T}-1\right) < \mu \leq \Delta c + 3t\left(\frac{3}{T}-1\right), \\ e < \mu < c_D, \Delta c + 3t\left(\frac{3}{T}-1\right) < \mu \leq \frac{9tc_D}{T(3t+c_F)}, \\ e = c_D, \frac{9tc_D}{T(3t+c_F)} < \mu \leq \frac{9t}{T}, \\ e = c_D, \mu \geq \frac{9t}{T}; \end{cases}$$

as  $9t(3t-\Delta c)/[3t(3t+c_F)] \leq T \leq 9t/(3t+c_F)$ ,  $3t(3/T-1) < 9tc_D/[T(3t+c_F)] < \Delta c + 3t(3/T-1) < 9t/T$  and

$$\begin{cases} e < \mu, \mu \leq 3t\left(\frac{3}{T}-1\right), \\ e < \mu < c_D, 3t\left(\frac{3}{T}-1\right) < \mu \leq \frac{9tc_D}{T(3t+c_F)}, \\ e < \mu < c_D, \frac{9tc_D}{T(3t+c_F)} < \mu \leq \Delta c + 3t\left(\frac{3}{T}-1\right), \\ e = c_D, \Delta c + 3t\left(\frac{3}{T}-1\right) < \mu \leq \frac{9t}{T}, \\ e = c_D, \mu \geq \frac{9t}{T}; \end{cases}$$

as  $T \leq 9t(3t-\Delta c)/[3t(3t+c_F)]$ ,  $9tc_D/[T(3t+c_F)] < 3t(3/T-1) < \Delta c + 3t(3/T-1) < 9t/T$  and

$$\begin{cases} e < \mu < c_D, \mu \leq \frac{9tc_D}{T(3t+c_F)}, \\ e < \mu < c_D, \frac{9tc_D}{T(3t+c_F)} < \mu \leq 3t\left(\frac{3}{T}-1\right), \\ e < \mu < c_D, 3t\left(\frac{3}{T}-1\right) < \mu \leq \Delta c + 3t\left(\frac{3}{T}-1\right), \\ e = c_D, \Delta c + 3t\left(\frac{3}{T}-1\right) < \mu \leq \frac{9t}{T}, \\ e = c_D, \mu \geq \frac{9t}{T}. \end{cases}$$

**The proof of Theorem 5:** Excluding the common factor of  $9t(3t-\Delta c)^2/2$  in (11), we denote

$$R(T) = \frac{1-T}{(9t-\mu T)^2}.$$

So,

$$\frac{\partial R(T)}{\partial T} = (9t-\mu T)^{-3} [2\mu(1-T) - (9t-\mu T)].$$

As the government increases one unit of tax rate, the marginal effect consists of two components. One is the decrement in the marginal green spillover, measured by  $D = 2\mu(1-T)$ . The other is the increment in the marginal cost from absorbing green technology, which is  $E = \mu T - 9t$ . Setting a tax rate  $(1-T)$  implies that the government must make a balance between  $D$  and  $E$  to maximize the green spillover. The tradeoff outcome is the marginal revenue equaling the marginal cost, i.e.,

$$2\mu(1-T) = 9t - \mu T, \text{ or } 1-T = 9t/\mu - 1$$

To ensure the existence of the optimal tax preference, it must be true that  $T = 2-9t/\mu \in (0, 1)$ . Equivalently,  $t/\mu \in (1/9, 2/9)$ .

Plugging  $1-T = 9t/\mu - 1$  into  $R(T)$ , the maximum green spillover is given by

$$\frac{9}{2} t(3t - \Delta c)^2 \frac{1}{4\mu^2(1-T)} = \frac{9}{8} t(3t - \Delta c)^2 \frac{1}{\mu^2} \frac{\mu}{9t - \mu} = \frac{9}{8} \frac{t(3t - \Delta c)^2}{\mu(9t - \mu)} \triangleq \Gamma.$$

As  $t/\mu \in (1/9, 2/9)$ ,

$$\frac{\partial \Gamma}{\partial \mu} = \frac{9}{8} t(3t + c_F - c_D)^2 \frac{2\mu - 9t}{\mu^2(9t - \mu)^2} > 0,$$

$\Gamma$  is increasing in  $\mu$ . In addition,

$$\frac{\partial \Gamma}{\partial t} = \frac{9}{8\mu} \frac{3t + c_F - c_D}{(9t - \mu)^2} [54t^2\mu(9t + c_F - c_D)].$$

As  $t \rightarrow \mu/9$ ,  $\Gamma$  decreases; as  $t \rightarrow 2\mu/9$ ,  $\Gamma$  increases. So we have

$$\frac{\partial \Gamma}{\partial t} \begin{cases} < 0, t \rightarrow \frac{1}{9}\mu; \\ > 0, t \rightarrow \frac{2}{9}\mu. \end{cases}$$

**The proof of Theorem 6:** As  $t/\mu \in (1/9, 2/9)$ , by Theorem 5 there exists an interior optimal profit tax rate  $1-T^* = 9t/\mu - 1$  at stage 1. Substituting  $T^* = 2 - 9t/\mu$  into (10), we obtain the equilibrium innovation effort  $e^* = (2\mu - 9t)(3t - \Delta c)/[2(9t - \mu)]$  at stage 2. It implies from the proof of Theorem 5 that the green spillover is equal to  $\Gamma = 9t(3t - \Delta c)^2/[8\mu(9t - \mu)]$ .

As  $0 < t/\mu \leq 1/9$  (or  $t/\mu \geq 2/9$ ),  $1-T < 0$  (or  $1-T > 1$ ) by the proof of Theorem 5. That is,  $1-T$  has no solution over  $(0, 1)$ . Yet, as  $0 < t/\mu \leq 1/9$ ,

$$\lim_{1-T \rightarrow 0} D = 0 \text{ and } \lim_{1-T \rightarrow 0} E = \mu - 9t$$

then, we can find that as  $1-T \rightarrow 0$ ,  $D > E$ . At the moment, there exists a corner solution  $1-T^* = 0$  at stage 1. Because the objective function in (9) is strictly concave, the equilibrium effort is  $e^* = c_D$ . Further,  $\Delta c = c_D^* - c_F = c_D - e^* - c_F = -c_F$  at stage 2, and the green spillover  $\Gamma = 9t(3t + c_F)^2/[8\mu(9t - \mu)]$ .

As  $t/\mu \geq 2/9$ , since

$$\lim_{1-T \rightarrow 1} D = 2\mu \text{ and } \lim_{1-T \rightarrow 1} E = -9t,$$

$D = 2\mu < 9t = -E$ . There exists another corner solution  $1-T^* = 1$  at stage 1. In this case, the government extracts all revenue from abatement effort, thereby firm D has no motivation to reduce its abatement cost. At equilibrium,  $e^* = 0$  and further, the green spillover  $\Gamma = 0$ .

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