Responses of China's Cross-border Investors to Domestic Environmental Regulations

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Abstract: Environmental regulations have been widely imposed to foster the development of a green and sustainable economy. However, how cross-border investors respond to domestic environmental regulations (DERs) has not been well studied. This paper examines how firms respond to DERs by focusing on the effects on outward direct investment (ODI) and productivity, using the data of Chinese listed companies during 2012-2018. The regression results support that DERs significantly boost ODI through encouraging firms to transfer production to countries with less stringent environmental regulations, acquiring advanced technologies from developed economies, and increasing research and development (R&D) expenditures. The latter two responses also contribute significantly to firms' productivity improvement while the first cannot. We conduct a series of heterogeneity analyses and find that firms with high financing constraints, non-state-owned firms and high-polluting firms facing stringent DERs tend to opt for the first response. Our study sheds light on how Chinese firms navigate DERs and the diverse strategies they employ to respond to these regulatory pressures.

Key Words: domestic environmental regulations, outward direct investment, productivity

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1. Introduction

Environmental degradation and pollution issues have attracted increasing global attention. In 2017, environment ministers from across the world issued a declaration at the United Nations (UN) Environment Assembly, promising to prevent, mitigate, and manage pollution of the air, land and soil, freshwater, and oceans. They committed to creating a pollution-free planet. As a result, most countries have been strengthening their domestic environmental regulations (DERs) (Gao et al., 2022). According to the first global assessment of air pollution legislation conducted by the UN in 2021, the majority of countries have incorporated ambient air quality standards into their legislation. For example, China, as one of the world's largest emitters, plays a pivotal role in addressing global environmental issues and has pledged to reach its peak CO_2 emissions before 2030 and achieve carbon neutrality before 2060 (Tian et al., 2022). To meet these ambitious targets, China has enacted a series of environmental regulations, including the revised Environmental Protection Law of the People's Republic of China.

Stringent DERs have a significant impact on businesses, increasing their production and operational costs as these regulations limit pollution discharge. This, in turn, affects firms' decisions regarding domestic production and overseas investment. On one hand, firms may opt to relocate their production abroad to mitigate the environmental costs. On the other hand, they may strive to comply with DERs by upgrading their production technologies. To give a concrete example, the State Council of China issued the "Opinions on Strengthening Key Environmental Protection Work" in 2011. In response, Baosteel Group, one of China's leading steel corporations, which ranked as 72^{nd} in the Fortune Global 500 in 2021, actively expanded its overseas manufacturing and processing capabilities. They established several wholly-owned or joint venture companies abroad, including Baoli steel pipe (Thailand) co. LTD and Bao Steel India. Meanwhile, Baosteel Group has intensified its efforts towards the innovation of low-carbon technologies across six key areas, one of which involves the deployment of hydrogen-based vertical furnaces. In 2022, the company invested 1.89 billion yuan in the construction of a million-ton hydrogen-based vertical furnace.

Consequently, a critical follow-up question is how firms respond to more stringent environmental regulations. Existing literature suggests three primary channels through which firms reduce their emissions to comply with domestic regulations, namely, relocating polluting production activities abroad; acquiring effective pollution abatement technologies and implementing relevant equipment (Shapiro and Walker, 2018). These channels cannot be easily captured, while their effects manifest as heterogenous changes in firms' outward direct investment (ODI) and productivity. Therefore, this paper studies the responses of China's cross-border investors to DERs by investigating how these regulations influence their ODI and productivity. Through a comprehensive examination of firms' responses, we aim to provide valuable insights into the role of DERs in striking a balance between economic development and environmental conservation. This research holds significant implications, not only for China but for other countries as well, in promoting a mutually beneficial scenario for investment and the environmental preservation.

A large body of literature has investigated the effects of environmental regulations on either ODI or productivity (please refer to Section 2 for a more detailed literature review). However, neither theoretical nor empirical studies have reached a consensus on this matter. Regarding the effects on ODI, the Pollution Haven Hypothesis has been extensively debated. One strand of literature supports this hypothesis by arguing that stringent DERs increase compliance costs, compelling firms to shift production to foreign locations with less stringent environmental regulations, consequently boosting their ODI (e.g. Copeland and Taylor, 1994; Chung, 2014; Li et al., 2022a; Dong et al., 2022). Some other studies question the hypothesis as they find a negative impact of DERs on ODI (Naughton, 2014) or an ambiguous effect (Eskeland and Harrison, 2003). A similar situation applies to the effects on productivity. One strand of research argues that environmental regulations result in additional abatement costs and resource misallocation, which in turn reduce firms' profits, crowd out R&D expenditures, and ultimately inhibit productivity improvement (He et al., 2020a; Petitjean, 2019; Wang et al., 2023; Wang et al., 2018). Contrastingly, a second strand of perspective contends that environmental regulations can stimulate corporate R&D investment and technological innovation, subsequently leading to concurrent improvements in environmental performance and productivity through innovation compensation effects (Bai et al., 2023; Cheng et al., 2023; Dagestani et al., 2023; Liu et al., 2023). This perspective aligns with the so-called Porter Hypothesis (Li et al., 2022b; Li et al., 2023).

The aforementioned discrepancies in previous studies might stem from the fact that existing literature usually conducts an isolated analysis of the effects of DERs on either ODI or productivity, without considering the different responses adopted by different firms and their heterogenous impacts. As a result, the responses of cross-border investors to DERs call for more solid empirical investigations.

This paper aims to add contribution to relevant literature by bridging environmental regulations, ODI, and productivity in a cohesive framework. The first aim is to empirically analyze firms' responses to more stringent DERs by investigating how firms' ODI and productivity adapt to these regulations using comprehensive firm-level data from A-share listed companies. We conclude three responses. The first is relocating production to countries with less stringent environmental regulations; the second is acquiring advanced technologies from developed countries; and the third is increasing their own R&D expenditures to promote technological innovation. Notably, our results reveal that all three responses increase firms' ODI, but only the latter two strategies improve productivity.

The second aim is to investigate the diverse responses from the perspective of firms' heterogeneities. We categorize firms into high versus low financing constraint enterprises (hereafter HCEs versus LCEs), state-owned versus non-state-owned enterprises (hereafter SOEs versus non-SOEs), high-polluting versus low-polluting enterprises (hereafter HPEs versus LPEs) in terms of their considerable heterogeneities in financial capacity, social responsibility, and technological upgrading level. Our results demonstrate that LCEs, SOEs and LPEs are more inclined to comply with DERs by acquiring advanced technologies from developed countries or by increasing their own R&D expenditures to foster technological innovation. In contrast, HCEs, non-SOEs and HPEs are more prone to transferring their production to countries with lax environmental regulations.

The marginal contributions of the paper are concluded in three key aspects. First, this paper bridges environmental regulations, ODI, and productivity in a unified framework, which is different from the previous literature focused on the effects of DERs on either ODI or productivity. By adopting this framework, we have been able to investigate the mediating effect of ODI on productivity and conclude more insightful findings. For instance, we find that firms under stringent DERs do relocate production to foreign countries with more lenient environmental regulations by increasing their overseas investment (ODI). However, this response does not contribute to productivity improvement. Such critical insights would be elusive without the integrated analytical framework introduced in this paper. Second, we provide micro-level evidence on the responses of cross-border investors to DERs by using firm-level data. This complements the predominate regional or industrial-level studies (Dong et al., 2022; Gong et al., 2020; Liu et al., 2021a). The utilization of micro-level data not only mitigates potential endogeneity issues stemming from data aggregation (Guhl, 2019), but also suggests some important policy implications for achieving a delicate balance between environmental protection and economic development. For example, by demonstrating the varied responses of different firms and the diverse impacts they generate, we emphasize that targeted measures should be adopted for different firms based on their specific characteristics, including financing constraints, ownership structures, and pollution intensities.

The remainder of the paper is structured as follows. Section 2 provides our theoretical analysis. Section 3 introduces the empirical strategy and data. Section 4 presents the empirical results. Section 5 is the heterogeneity analysis, and Section 6 concludes.

2. Theoretical analysis

In response to increasingly stringent DERs, firms generally may adopt three approaches[1]. The first response involves relocating production to countries with lax environmental regulations to minimize environmental costs (referred to as the production relocation response). The second approach entails acquiring effective pollution abatement technologies from developed countries and applying relevant skills domestically (referred to as the technology acquisition response). The third strategy involves increasing their own R&D expenditures to promote technological innovation, ultimately reducing pollution emissions (referred to as the R&D expenditure response).

[1] There may be a fourth approach for firms, namely not taking any measures and paying the corresponding environmental costs. However, this paper argues that this response is unsustainable and will force the firms to quit the market. Thus, this response is not within the scope of this article.

In this section, we elaborate on the distinct theoretical impacts of DERs on firms' ODI and productivity through these three responses.

One direct response to stringent DERs is the relocation of production operations to locations with less stringent environmental regulations, thus lowering environmental costs. Copeland and Taylor (1994) propose a theoretical model where pollution is considered a byproduct of production, motivating firms to change their production location to maximize profits. Stringent DERs incentivize firms to meet environmental standards, for example, by investing in advanced pollution abatement equipment to deal with pollutant emissions. Failing to do so would result in high emissions costs, such as pollution emission taxes and permit fees. All the above increases firms' production and operational expenses. Consequently, environmental regulations are considered a source of comparative disadvantage, significantly influencing international specialization. In practical terms, the additional costs arising from stringent DERs prompt firms to contemplate shifting production to locations with less stringent regulations, commonly known as the Pollution Haven Hypothesis (Dong et al., 2022; Peng and Zhang, 2022; Wu et al., 2023).

It is worth noting that most countries with lenient environmental regulations tend to be low-income nations. Investments in these regions are typically driven by two main factors. Firstly, they seek to exploit the natural resources there. Secondly, they aim to establish avenues for expanding their market presence in these host countries, creating robust marketing networks, and making use of local resources to enable the localization of corporate product manufacturing and sales. Consequently, foreign investments in countries with lax environmental regulations are primarily guided by a resource-seeking and market-seeking approach (Chen et al., 2020). Moreover, it is important to recognize that countries with lax environmental regulations tend to lag behind in terms of technologies (Qiu et al., 2021). As a result, investments in these regions face significant challenges when it comes to accessing cutting-edge technologies and advanced managerial expertise. This impedes the effective utilization of valuable research resources and facilities, ultimately resulting in limited opportunities for the productivity enhancement of the parent company. In summary, we propose the first hypothesis.

H1: if firms opt for production relocation in response to tightened DERs, their ODI will increase, but their productivity may not necessarily improve.

Compared to the production relocation response, which can provide short-term compliance with DERs, technological innovation offers a fundamental way to meet DERs, albeit with a higher time cost. Neoclassical economic theory suggests that environmental regulations raise the unit emission costs for firms, compelling them to allocate resources towards environmental management, depleting their resources and discouraging investments in production technology improvement (Albrizio et al., 2017; Li et al., 2022b). However, Porter and Van der Linde (1995) argue that the tradeoff between environmental protection and technological advancement is flawed. They assert that technological progress is a dynamic process, and traditional static models neglect the possibility of technological improvement. In essence, if the benefits of technology improvement outweigh the costs, firms will opt for technological advancement to maximize long-term profits. Therefore, in the long run, firms facing regulatory pressure may find it desirable to improve their production technology.

One common means of improving production technology is through increased R&D expenditures. Porter and Van der Linde (1995), through a large number of case studies, observe that firms facing increasingly stringent environmental regulations desire to offset the costs of compliance through the compensation effect of technological innovation, leading to greater investments in R&D. Scholars have also found positive effects of environmental regulations on R&D spending (Huang et al., 2021; Jaffe and Palmer, 1997; Zheng et al., 2022). They argue that the shock of environmental regulations encourages firms to broaden their horizons and boost R&D expenditures, in their quest to discover processes or products that increase profits while complying with regulations (Franco and Marin, 2017).

With the increase in R&D expenditures, firms' productivity can be significantly enhanced. According to the theory of endogenous growth, R&D activities aimed at reducing production costs, improving product quality, or creating new products are considered primary drivers of technological progress and long-term economic growth (Aghion and Howitt, 1992). Schumpeter (2021)'s innovation theory posits that innovation can introduce novel production functions and previously untapped production factors, which can ultimately benefit overall production. Moreover, corporate innovation has the potential to lead to a reallocation of production factors from low-productivity to high-productivity sectors, compelling less productive production processes to exit the market (known as "creative destruction"). This, in turn, enhances the overall productivity of firms (Sengupta, 2014; Carayannis, 2020). Based on these theories, it is evident that an increase in R&D expenditures can stimulate improvements in firms' productivity.

The improvements in firms' productivity further play a pivotal role in driving their ODI. In the multi-country, multi-sector model developed by Helpman et al. (2004) and Melitz (2003), firms make critical decisions regarding entering foreign markets through ODI, assuming that ODI involves higher fixed costs but lower variable costs compared to other market access modes. Lower variable costs result in higher profits per unit of marginal production, but the higher fixed costs pose a significant threshold for ODI adoption. The boost in productivity contributes to a reduction in a firm's marginal costs, consequently bolstering its overall profitability. This enables firms to accumulate the necessary earnings to overcome the fixed costs associated with ODI, ultimately meeting the cost threshold required for ODI (Tian and Yu, 2022). Moreover, firms inevitably encounter obstacles when investing abroad, including entry requirements, regulations, and competition. The productivity enhancement equips firms to navigate these challenges more effectively, granting them a competitive advantage in international markets and enabling them to meet the demands of host country more efficiently. Consequently, host countries are more likely to welcome investments from such firms. In summary, we put forth our second hypothesis.

H2: if firms increase their R&D expenditure in response to tightened DERs, they will experience enhanced productivity, subsequently leading to an increase in their ODI.

R&D efforts come with the drawback of demanding substantial capital and time investments (Cheng et al., 2023). Therefore, in pursuit of expediting technological innovation, firms may opt for technology acquisition response. It is well understood that advanced technologies have the potential to traverse borders and yield positive externalities. Coe and Helpman (1995) pioneer the model of international technology spillover, which validates the presence of international technology spillover effects. They emphasize that the level of technological advancement is shaped not only by domestic research and development resources but also by the international technology spillover effects generated through international trade and investment. Cross-border investments, especially those in developed economies, have emerged as a pivotal avenue for firms to access cutting-edge international technology (Smarzynska Javorcik, 2004).

Advanced technology from foreign sources can be transposed to the home country through the reverse spillover effect of ODI (Liu et al., 2021b; Liu et al., 2021c). For instance, in the framework of Aitken and Harrison (1999), firms in technologically advanced countries possess valuable assets such as technological expertise, effective management and marketing practices, established export networks, collaborative ties with customers and suppliers, and a sterling reputation. Acquiring these assets is challenging for firms in technologically underdeveloped countries. Nonetheless, these assets can be reasonably transferred to the parent firms in technologically underdeveloped nations via their multinational subsidiaries located in technologically advanced host countries. This transfer can take various forms. On one hand, multinational subsidiaries can directly transfer advanced technology, processes, patents, and other research and development outcomes acquired in the host country to the parent company through technology licensing agreements (Li et al., 2017; Piperopoulos et al., 2018). On the other hand, employees working in multinational subsidiaries can accumulate advanced knowledge. As these experienced workers return from their tenure in multinational subsidiaries to contribute to the parent company by sharing their acquired expertise, the parent company can effectively harness this knowledge (Gao et al., 2013). This, in turn, elevates the parent company's technological capabilities and productivity. In summary, we propose the third hypothesis.

H3: if firms facing tightened DERs opt for technology acquisition response to acquire advanced technologies, they can expect a boost in their ODI, which, in turn, leads to improvements in productivity.

In summary, stringent DERs increase firms' ODI no matter which of the three aforementioned responses they take. Nonetheless, with regard to the effects on productivity, the technology acquisition response and improving R&D expenditure can enhance productivity while the production relocation response may not. Therefore, we conclude the following general hypothesis.

H0: tightened DERs increase firms' ODI and are very likely to improve their overall productivity.

3. Research design

3.1 Empirical model

3.1.1 Benchmark model

First, we estimate the effect of DERs on ODI and productivity, using the dynamic panel model as follows:

$$ODI_{ijt} = \alpha + \delta \cdot ODI_{ijt-1} + \beta_1 \cdot DER_{jt-1} + \gamma \cdot Z + \mu_i + \lambda_t + \varepsilon_{it} \quad (1)$$

$$TFP_{ijt} = \alpha + \delta \cdot TFP_{ijt-1} + \beta_2 \cdot DER_{jt-1} + \gamma \cdot Z + \mu_i + \lambda_t + \varepsilon_{it} \quad (2)$$

where subscripts i, j, and *t* stand for firm, province (where the firm located), and year respectively; μ_i and λ_t refer to fixed individual effect and fixed time effect; Z denotes control variables. ODI_{ijt} is the dependent variable, which is given by the logarithm of the number of firm *i*'s (located in province *j*) overseas affiliates in year *t*. TFP_{ijt} denotes the logarithm of firm *i*'s (located in province *j*) total factor productivity (TFP) in year *t*. DER_{jt-1} is the explanatory variable, denoting the environmental regulation intensity of province j in year *t-1*. We estimate models (1) and (2) using a SYS-GMM estimator, which takes the one period lagged term of the dependent variable as one explanatory variable, and takes the lag of the explanatory variable and measurement error into account as well. The dynamic panel model, estimated by the SYS-GMM estimator, can partially solve the endogeneity problem caused by mutual causality or omission of some explanatory variables (Xu et al., 2022). If β_1 and β_2 are significantly positive, we can conclude that DERs increase firms' ODI and productivity on average.

Next, we investigate whether firms would choose production relocation response to comply with more stringent DERs. Following Gao et al. (2018) and Li (2021), we group the host countries into different sets and construct new dependent variables to run the following models:

$$ODI_{ijt}^{LOW-ER} = \alpha + \delta \cdot ODI_{ijt-1}^{LOW-ER} + \beta_3 \cdot DER_{jt-1} + \gamma \cdot Z + \mu_i + \lambda_t + \varepsilon_{it} \quad (3)$$

$$ODI_{ijt}^{HIGH-ER} = \alpha + \delta \cdot ODI_{ijt-1}^{HIGH-ER} + \beta_4 \cdot DER_{jt-1} + \gamma \cdot Z + \mu_i + \lambda_t + \varepsilon_{it} \quad (4)$$

where ODI^{LOW-ER} ($ODI^{HIGH-ER}$) denotes the logarithm of the number of firms' overseas affiliates in countries with lax (strict) environmental regulations. If β_3 is significantly positive but β_4 is not, it indicates that firms are willing to increase investment in countries with lax environmental regulations rather than in those with strict regulations when DERs are tightened. We use the Environmental Performance Index (EPI)[2], published by Yale University and World Economic Forum, to evaluate the

[2] The EPI, which tracks many indicators related to the environment and sustainable development, is a

intensity of host countries' environmental regulation. An EPI above (below) average indicates the country imposes strict (lax) environmental regulations.

Similarly, in order to investigate whether firms would choose technology acquisition response to cope with DERs, we replace ODI^{LOW-ER} and $ODI^{HIGH-ER}$ in equations (3) and (4) by $ODI^{ADV-TEC}$ and $ODI^{BACK-TEC}$, which denotes the logarithm of the number of firms' overseas affiliates in technologically advanced countries or others, respectively. Again, if β_3 is significantly positive but β_4 is not, it indicates that firms are willing to increase investment in countries with advanced technology. That is, firms seek to acquire advanced technologies abroad for mitigating emissions when DERs are tightened. We use the Global Innovation Index (GII)[3], published by Cornell University and World Intellectual Property Organization, to evaluate each host country's technology level. A GII above (below) average indicates the country owns higher (lower) technology level.

We also examine whether firms would choose R&D expenditure response. Referring to Qi et al. (2023) and Zhao et al. (2020), we employ the following model:

$$RD_{ijt} = \alpha + \delta \cdot RD_{ijt-1} + \beta_5 \cdot DER_{jt-1} + \gamma \cdot Z + \mu_i + \lambda_t + \varepsilon_{it}. \tag{5}$$

Model (5) uses R&D expenditure (RD) as the dependent variable and the intensity of DERs as the explanatory variable. If β_5 is significant positive, it indicates that more stringent DERs prompt firms to increase R&D expenditures.

3.1.2 Mechanism examination through three responses

We use the following mediating effect model to examine whether and how DERs alter ODI and productivity through the three responses above (Lee et al., 2022; Xu et al., 2022).

$$ODI_{ijt} = \alpha + \delta \cdot ODI_{ijt-1} + \beta_6 \cdot DER_{jt-1} + \theta_1 \cdot M_{ijt} + \gamma \cdot Z + \mu_i + \lambda_t + \varepsilon_{it} \tag{6}$$

$$TFP_{ijt} = \alpha + \delta \cdot TFP_{ijt-1} + \beta_7 \cdot DER_{jt-1} + \theta_2 \cdot M_{ijt} + \gamma \cdot Z + \mu_i + \lambda_t + \varepsilon_{it} \tag{7}$$

We use model (6) to examine the mediating effects on ODI. Model (3) and (4) have already enabled us to test whether DERs alter ODI through production relocation and technology acquisition response, respectively. We thus employ model (6) to test the R&D expenditure response by letting the mediating variable M be RD. If β_6 in model (6) would decrease in the significance level and absolute value compared to β_1 in model (1), we can infer that ODI will increase if firms take R&D expenditure response to cope with DERs.

We employ model (7) to examine the mediating effects of DERs on productivity through the three responses. We thus let the mediating variable M in model (7) be

comprehensive index reflecting the environmental protection and sustainable development of each country around the world. It can better reflect the stringency of environmental regulation of a country than one or several pollutant emission indicators used in the existing literature. Moreover, another important advantage is that it's comparable across countries. For more details, please refer to https://epi.yale.edu/

[3] The GII ranks the innovation performance of most economies in the world using around 80 indicators. . For details, please refer to https://www.wipo.int/global_innovation_index/en/index.html

ODI^{LOW-ER}, $ODI^{ADV-TEC}$, and RD, respectively, to test whether the production relocation response, technology acquisition response, and R&D expenditure response triggered by tightened DERs can improve firms' productivity. If β_7 would decrease in the significance level and absolute value compared to β_2 in model (2), we can infer that the corresponding response can improve firms' productivity.

3.2 Variables and data sources

The explanatory variable (DER): We construct an index to measure the intensity of environmental regulations in each province. There are different measurements of environmental regulations, which can be summarized into two categories. The first category is using a single indicator as a proxy of environmental regulations. For example, some researchers use the fine of pollution or their proportion to the total output to measure the intensity of environmental regulations and some others use the number of environment-related laws and regulations to measure the intensity of environmental regulations (Liao, 2018; Wu and Lin, 2022). The second category is constructing a comprehensive index of environmental regulations by using multiple indicators (Zhao et al., 2020; Zhou et al., 2017). In this paper, we adopt the second method as it captures the multidimensions of DERs. We calculate the index of province-level environmental regulations using five indicators: the proportion of sulfur dioxide removed, the proportion of smoke (dust) removed, the proportion of wastewater that meets discharge standards, the ratio of solid wastes utilized, and the ratio of household wastes harmlessly treated. The weight of each indicator is determined by information entropy. The data sources are WIND Database and CEInet Statistics Database.

The dependent variable (ODI and TFP): In this paper, we mainly use the increment of overseas affiliated subsidiaries as a proxy for the ODI of a listed company (Koch and Basse Mama, 2019; Yu et al., 2021). This is due to data restrictions since the Annual Reports of China's listed companies do not disclose the monetary value of their overseas investment. Nevertheless, we also conduct robustness checks below using an alternative proxy. TFP is estimated using Levinsohn-Petrin method (LP method, refer to Cai and Ye (2020) for its advantages). The data source is China Stock Market & Accounting Research Database (CSMAR Database). Considering data validity and general practice (Hu et al., 2021; Zhang and Kong, 2021), we process the original sample data as follows: (1) only keep A-share listed companies; (2) only use the data from firms' Annual Report; (3) exclude the companies that are ST or *ST during the study period; (4) exclude the companies of which host countries are tax havens.

The control variables (Z)： Referring to existing literature (Liu et al., 2022; Wang et al., 2018; Zhang and Kong, 2021; Zheng et al., 2022), we add control variables at both province-level and firm-level. We include province-level control variables to capture effects due to province-specific differences. For example, enterprises located in a province with a higher level of economic development and opening degree have more frequent and better access to foreign markets and are more likely to invest abroad. Our province-level variables include economic scale (*gdp*), measured by the province's GDP per capita; degree of openness (*fdi*), measured by the province's FDI; economic structure (*strcu*), measured by the proportion of the added value of the secondary industry in GDP. We consider typical firm-level control variables that affect corporate investment and productivity. For example, it is widely known that a firm's scale and asset-liability ratio matter to its investment. The larger the enterprise is, the better the operation condition, and the availability of funds is higher than that of a small enterprise. So large-scale enterprises have stronger capability to invest abroad and improve productivity. The higher the asset-liability ratio is, the higher the business risk is, and the weaker capability to invest or increase productivity. Firm-level variables include the firm's scale (*size*), measured by the logarithm of firm's total assets; asset-liability ratio (*leverage*), measured by the ratio of total liabilities to total assets; current ratio (*liquidity*), measured by the ratio of current assets to current liabilities; the proportion of fixed assets (*fix_ast*), measured by the proportion of the net fixed assets to the total assets; return on assets (*roa*), measured by the ratio of net profit to total assets; Tobin's Q (*tobin_q*), measured by the ratio of the market capitalization to total assets; concentration of ownership (*top_ten_holders_rate*), measured by the sum of the holdings of the top 10 shareholders; firm's age (*age*), measured by the current year subtract the year of establishment and then plus one; firm's ownership (*state*), and it equals to 1 if the firm is state-owned, otherwise, equals to 0. The data comes from the CSMAR Database, WIND Database, and CEInet Statistics Database.

Our data consists of a panel from 30 provinces in mainland China from 2012 to 2018. Tibet is not included due to data unavailability. Table 1 presents the descriptive statistics of the key variables in this study.

Table 1: Descriptive statistics of variables.

Variable	Obs	Mean	Std. Dev.	Min	Median	Max
ODI	8634	0.178	0.566	-3.178	0.000	3.784
TFP	8395	7.879	1.052	3.116	7.768	12.175
DER	7104	-1.606	0.576	-2.914	-1.598	-0.028
RD	7604	0.174	0.314	0.000	0.073	4.315
gdp	8634	7.604	3.073	1.939	7.273	15.310
fdi	8634	0.046	0.045	0.000	0.032	0.192
strcu	8634	0.410	0.123	0.115	0.438	1.411
size	8633	22.514	1.540	16.757	22.249	30.952
leverage	8633	0.445	0.255	0.011	0.435	8.256
liquidity	8525	2.428	3.535	0.030	1.615	144.000
fix_ast	8525	0.204	0.148	0.000	0.177	0.880
roa	8633	0.036	0.107	-3.911	0.037	1.271
tobin_q	8339	2.062	2.758	0.684	1.606	192.705
top_ten_holders_rate	8634	59.077	15.669	8.810	60.460	101.160
age	8634	2.811	0.368	1.386	2.833	7.610
state	8634	0.313	0.464	0.000	0.000	1.000

4. Empirical results

4.1 Benchmark results

Table 2 provides the benchmark results with regard to the effects of DERs on ODI and productivity. Columns (1) and (4) report the average effect without the inclusion of control variables. The regression coefficient of *L.DER* is positive at the significance level of 5%. This indicates that more stringent DERs generally have a positive impact on firms' ODI and productivity. To mitigate the potential influence of omitted variables, we gradually introduce control variables that might affect firms' ODI and productivity. The regression coefficient of *L.DER* are still significantly positive and the magnitude remains stable after controlling provincial and firm characteristics in columns (2-3) and (5-6). After introducing all control variables above, the regression coefficient of *L.DER* to *ODI* (column (3)) is 0.2105 and significant at the level of 1%, which implies that a 1% increase in the DERs is associated with a 0.2105% increase in firms' ODI in the following year on average, ceteris paribus. Similarly, the results imply that a 1% increase in the DERs is associated with a 0.1175% increase in firms' productivity in the following year on average, ceteris paribus. In summary, stricter DERs are observed to have an overall positive effect on both firms' ODI and productivity. The benchmark results confirm hypothesis H0 proposed in section 2. When DERs are strengthened, Chinese firms will make responses that ultimately lead to an increase in their ODI and productivity. Detailed information on the responses firms may undertake and how these actions impact ODI and productivity will be provided in the following sections.

The bottom of Table 2 reports the relevant diagnostics of SYS-GMM method. AR (1) and AR (2) are the first-order and second-order test for residual autocorrelation, respectively. The results show that all p-values for AR (1) are below 0.01 and p-values for AR (2) are above 0.1, indicating that there is no autocorrelation for the random disturbance term. The overidentification test checks the validity of selected instrument variables. All p-values for overidentification test exceed 0.1. Therefore, we accept the null hypothesis that the selected instrument variables are valid.

Table 2: Effects of DERs on firms' ODI and productivity.

	(1)	(2)	(3)	(4)	(5)	(6)
	ODI	*ODI*	*ODI*	*TFP*	*TFP*	*TFP*
L.dep	-0.0178	-0.0465*	-0.0465*	0.9645***	0.7691***	0.7971***
	(-0.7297)	(-1.8592)	(-1.8332)	(58.8907)	(14.5812)	(15.2118)
L.DER	0.1586**	0.2087***	0.2105***	0.1168**	0.1157*	0.1175*
	(2.4722)	(2.5918)	(2.6087)	(2.5257)	(1.6758)	(1.6962)
gdp		-0.0417	-0.0386		-0.0148	-0.0160
		(-1.2631)	(-1.1522)		(-1.4479)	(-1.5665)
fdi		-0.4999	-0.4947		-0.2722*	-0.3050*
		(-0.8498)	(-0.8432)		(-1.6568)	(-1.8570)
strcu		0.2707	0.3178		0.0627	0.0369

		(0.3566)	(0.4276)		(1.0025)	(0.5820)
size		0.1795***	0.1623***		0.1325***	0.1216***
		(3.9294)	(3.4662)		(4.2440)	(4.0402)
leverage		0.2580*	0.2859**		0.2708***	0.2418**
		(1.9263)	(1.9637)		(2.8175)	(2.4521)
liquidity		0.0031	0.0028		-0.0073***	-0.0083***
		(0.5749)	(0.5011)		(-3.2107)	(-3.4321)
fix_ast		-0.4269**	-0.3992**		-0.4826***	-0.4554***
		(-2.1711)	(-2.0105)		(-9.1122)	(-8.5273)
roa		0.0485	0.0539		1.0083***	0.9063***
		(0.4846)	(0.5231)		(5.2701)	(4.8723)
tobin_q		0.0031	0.0035		-0.0061	-0.0033
		(0.3984)	(0.4461)		(-1.2005)	(-0.6605)
top_ten_holders_rate			0.0031			0.0014***
			(1.4417)			(4.1869)
age			-0.3090***			-0.0002
			(-8.9017)			(-0.0175)
state			-0.1292			-0.0469***
			(-1.1839)			(-3.5941)
Constant	0.4129***	-3.2998***	-2.2414*	0.5349***	-0.7965**	-0.8038**
	(3.4732)	(-2.8211)	(-1.9112)	(3.5472)	(-2.0395)	(-2.0782)
AR (1)	[0.000]	[0.000]	[0.000]	[0.000]	[0.000]	[0.000]
AR (2)	[0.382]	[0.862]	[0.907]	[0.989]	[0.688]	[0.705]
Overidentification test	[0.202]	[0.486]	[0.490]	[0.107]	[0.372]	[0.362]
Firm Fixed Effects	YES	YES	YES	YES	YES	YES
Year Fixed Effects	YES	YES	YES	YES	YES	YES

*Notes: ***, **, and * represent significance levels of 1%, 5%, and 10%, respectively. The value in parenthesis represents t-statistics, and the value in square bracket represents p-value. L.dep represents the lag term of dependent variable.*

4.2 Robustness checks

In this section, a series of robustness checks are conducted, which include employing alternative measurements for the explanatory variable and the dependent variable, as well as using an instrument variable to address potential endogeneity issues.

As mentioned in section 3.2, there are alternative measurements of environmental regulations. In the benchmark regression, we use a comprehensive index to evaluate each province's environmental regulation intensity. One may concern the potential measurement errors of DERs due to its measurement complexity and multidimensional characteristics. We thus conduct the first robustness check by employing an alternative measurement of DERs. We rerun the regressions by employing the number of each province's environmental penalties, drawing from the Administrative Punishment

Database of Peking University[4], as an alternative proxy variable of DERs. The results in column (1) and column (2) of Table 3 show that the regression coefficients of the explanatory variable *L.PENALTY* are significantly positive. This aligns with the benchmark results.

Second, we deal with the alternative proxies for ODI. We estimate the overseas investment value of a listed company (*ODI_ZK*) by multiplying the registered capital of its overseas subsidiaries by its shareholding[5]. We rerun the regressions using *ODI_ZK* as the dependent variable. The results in column (3) of Table 3 show that the regression coefficient of explanatory variable *L.DER* is significantly positive. It suggests that the positive effect of DERs on ODI turns out to be robust. We also conduct a robustness check by re-estimating the firm-level TFP (*TFP_OP*) using the OP method (Olley and Pakes, 1996) instead of the LP method before. The results in column (4) of Table 3 show that the findings are robust and not largely dependent on the chosen method of estimating TFP.

Table 3: Results of robustness checks (1).

	(1)	(2)	(3)	(4)
	ODI	*TFP*	*ODI_ZK*	*TFP_OP*
L.dep	-0.0250	0.8182***	0.6340***	0.7209***
	(-1.0082)	(14.7609)	(8.7801)	(7.8960)
L.PENALTY	0.0421*	0.0254*		
	(1.8186)	(1.9407)		
L.DER			3.3152*	0.0516**
			(1.8668)	(2.3125)
Constant	-1.1267***	-1.2916***	8.6138	0.2709***
	(-4.4900)	(-3.5006)	(1.4300)	(3.6442)
AR (1)	[0.000]	[0.000]	[0.000]	[0.000]
AR (2)	[0.997]	[0.673]	[0.756]	[0.764]
Overidentification test	[0.481]	[0.269]	[0.367]	[0.801]
Controls	YES	YES	YES	YES
Firm Fixed Effects	YES	YES	YES	YES
Year Fixed Effects	YES	YES	YES	YES

*Notes: ***, **, and * represent significance levels of 1%, 5%, and 10%, respectively. The value in parenthesis represents t-statistics, and the value in square bracket represents p-value. L.dep represents the lag term of dependent variable.*

We also introduce dummy variables for provinces to mitigate potential endogeneity stemming from the fact that a small number of firms changed their

[4] For details, please refer to https://www.pkulaw.com/penalty?way=topGuid

[5] These data are collected from the table of Overseas Affiliated Firms in the CSMAR database. However, only a few listed companies disclose the registered capital of their overseas subsidiaries and their shareholding, resulting in a limited sample for regression. As a result, we decide to use this limited sample to conduct a robustness check instead of the benchmark regression or the following heterogeneity analysis.

registered province during the sample period. The results are displayed in column (1) and column (2) of Table 4, where the coefficient of DERs remains significantly positive. This confirms the robustness of our results.

Next, we use an instrumental variable technique to address the endogeneity problem. We adopt the precipitation in each province as the instrument (He et al., 2020b; Li and Du, 2021; Wang et al., 2018). The idea is rooted in the following considerations. On the one hand, there exists a notable negative correlation between precipitation and air and water pollution, which reduces the pressure for pollution control (Lin, 2013). Consequently, precipitation is expected to have a negative impact on the implementation of local environmental regulations. This fulfills the requirement for a correlation between the instrument variable and the endogenous variable. On the other hand, precipitation is a natural phenomenon that is exogenous to firms' activities, which means its effect on ODI or productivity can only be realized through environmental regulation (Li and Du, 2021). Therefore, precipitation satisfies the exogeneity condition as an instrument variable for environmental regulation. The data of precipitation is sourced from China Water Statistical Yearbook.

The statistical results of first stage are presented in column (3) of Table 4. The F-statistics significantly surpass the conventional critical value of 10 (Li and Du, 2021; Seyoum et al., 2015), thereby rejecting the null hypothesis of weak instrumental variable. The coefficient exhibits a negative and statistically significant relationship, supporting the hypothesis that provinces with lower precipitation levels are inclined to enforce stricter environmental regulations. These results provide substantial evidence for the credibility of precipitation as an instrumental variable for environmental regulations. The new results in columns (4) and (5) of Table 4 suggest that our results remain robust.

In the regression above, we use the sample from 2012 to 2018 because some data are not available anymore after 2018. The proportion of smoke (dust) removed is a necessary indicator in calculating the comprehensive index of province-level environmental regulations. But it is no longer published after 2018. Therefore, we conduct a robustness check by extending the sample period to the latest 2021. But we exclude the proportion of smoke (dust) removed and use the remaining four indicators to calculate the index of province-level environmental regulations. The results in columns (6) and (7) of Table 4 show that the new coefficients are in line with the benchmark estimates.

Table 4: Results of robustness checks (2).

	(1)	(2)	(3)	(4)	(5)	(6)	(7)
	ODI	*TFP*	*DER*	*ODI*	*TFP*	*ODI*	*TFP*
L.dep	-0.0228	0.7976***		-0.0581**	0.7912***	-0.0660***	0.5040***
	(-0.9032)	(11.6038)		(-2.4873)	(15.9811)	(-3.6019)	(11.7251)
L.DER	0.1928*	0.1648**		0.1814***	0.0961***	0.1505**	0.0677**
	(1.6853)	(1.9639)		(2.7520)	(3.0506)	(2.0139)	(2.5557)
Precipitation			-0.0700***				

			(-5.6359)				
Constant	0.2507	-0.9410*	-3.0674***	-1.8569*	-0.8915***	-3.9000***	-2.9030***
	(0.5815)	(-1.7769)	(-33.9339)	(-1.9186)	(-3.0711)	(-3.5454)	(-9.4927)
AR (1)	[0.000]	[0.000]		[0.000]	[0.000]	[0.000]	[0.000]
AR (2)	[0.576]	[0.626]		[0.920]	[0.709]	[0.603]	[0.477]
Overidentification Test	[0.327]	[0.192]		[0.497]	[0.406]	[0.160]	[0.000]
Controls	YES	YES	YES	YES	YES	YES	YES
Firm Fixed Effects	YES	YES	YES	YES	YES	YES	YES
Year Fixed Effects	YES	YES	YES	YES	YES	YES	YES
Province Fixed Effects	YES	YES					
F of first stage			3762.65				

*Notes: ***, **, and * represent significance levels of 1%, 5%, and 10%, respectively. The value in parenthesis represents t-statistics, and the value in square bracket represents p-value. L.dep represents the lag term of dependent variable.*

4.3 Distinguish different responses

The aforementioned findings suggest that DERs play a role in boosting firms' ODI and productivity. This might be attributed to the three potential responses that we concluded in section 2. In this section, we test these responses in turn.

First, we test whether tightened DERs force firms to choose production relocation response. The significant positive results of model (3) shown in column (1) of Table 5 suggest that tightened DERs significantly force firms to invest in countries with less stringent environmental regulations and relocate dirty production to those countries to reduce domestic environmental costs. It might be confusing that the coefficient of $ODI^{HIGH-ER}$ in column (2) is significantly positive at a lower significance level of 10%, which means that stricter DERs also improve firms' investment in countries with more stringent environmental regulations. We speculate this may be due to the fact that countries with strict environmental regulations usually owns advanced technologies (in our sample, there are 54 countries with stringent environmental regulations, of which 41 are technologically advanced countries). Therefore, the existence of technology acquisition response may interfere the results for countries with strict environmental regulations. In order to test our speculation, we identify countries that have stringent environmental regulations but with less-advanced technologies, and use each firm's ODI in these countries ($ODI^{HIGH-ER\,\&\,BACK-TEC}$) as the dependent variable to re-estimate model (1). The results are displayed in column (5), where the coefficient of DERs becomes insignificant. Combined with the results in column (1), it is reasonable to conclude that firms have the incentive to choose production relocation response when DERs are strengthened. Stringent environmental regulations are linked to the adoption of sophisticated pollution abatement technologies, the imposition of pollution emission levies, and the requirement to procure emission permits. These regulatory measures result in a notable increase in firms' production and operational costs. Consequently, these augmented financial burdens induce firms to relocate their production activities to countries characterized by more lenient environmental regulations. The results also confirm hypothesis H1 that production relocation response can improve firms' ODI.

Second, we test whether the stricter DERs would incentivize firms to adopt technology acquisition response. We re-estimate models (3) and (4) after replacing ODI^{LOW-ER} and $ODI^{HIGH-ER}$ with $ODI^{ADV-TEC}$ and $ODI^{BACK-TEC}$, respectively. The results are displayed in columns (3) and (4) of Table 5 respectively. The regression coefficient of $ODI^{ADV-TEC}$ in column (3) is significantly positive, which indicates that stricter DERs significantly inspire firms to invest in technologically advanced countries and acquire the advanced technologies. Note that in column (4), where the dependent variable is $ODI^{BACK-TEC}$, the regression coefficient of the explanatory variable is also significantly positive. Again, this may due to the overlap between the countries with lax environmental regulations and that with less-advanced technologies (in our sample, there are 66 countries with less-advanced technologies, among which 53 have lax environmental regulations). Similarly, after excluding the overlapped sample, the regression coefficient of DERs in column (5), where the dependent variable denotes firms' ODI in countries with less advanced technologies but stricter environmental regulations, becomes insignificant. Combined with the result in column (3), it is reasonable to conclude that firms have the incentive to invest and acquire advanced technologies in technologically advanced countries when DERs are strengthened. The advanced technology can be transferred to the home country through the reverse spillover effect of ODI, such as intra-firm labor dispatch and experience sharing (Gao et al., 2013). Consequently, there exists an incentive for firms to invest in developed countries as a strategy to acquire advanced technologies, particularly when DERs become more stringent. The findings also confirm hypothesis H3 that technology acquisition response increases firms' ODI.

Finally, apart from learning advanced technologies from other countries, firms may increase their own R&D expenditures to cope with stricter DERs. We estimate model (5) to test it, and find that DERs have a significantly positive impact on R&D expenditures, as shown in column (6) of Table 5. In order to remain competitive and avoid becoming obsolete in the market, firms are compelled to upgrade their production technologies when DERs become more stringent. While investing in developed countries offers a channel for technological improvements, many firms face constraints related to necessary investment thresholds when attempting to enhance their technology through this avenue. Consequently, increasing their own R&D expenditures emerges as the most viable approach for firms to improve their cleaner production technology.

Table 5: Results of the channel analysis.

	(1)	(2)	(3)	(4)	(5)	(6)
	ODI^{LOW-ER}	$ODI^{HIGH-ER}$	$ODI^{ADV-TEC}$	$ODI^{BACK-TEC}$	$ODI^{HIGH-ER\ \&\ BACK-TEC}$	RD
L.dep	-0.0277	-0.0548**	-0.0536**	-0.0030	-0.0217	0.4614***
	(-0.7744)	(-2.1356)	(-2.0353)	(-0.0909)	(-0.5354)	(13.9122)
L.DER	0.0994***	0.1406*	0.1215*	0.1213***	0.0267	0.7754***

	(2.6513)	(1.8850)	(1.6484)	(2.8950)	(1.4096)	(5.2114)
Constant	-1.0605*	-2.1803**	-2.0016*	-1.3389**	-0.3501	0.6093
	(-1.8516)	(-2.0689)	(-1.9381)	(-2.1411)	(-1.5183)	(1.2273)
AR (1)	[0.000]	[0.000]	[0.000]	[0.000]	[0.000]	[0.035]
AR (2)	[0.987]	[0.877]	[0.811]	[0.817]	[0.652]	[0.193]
Overidentification Test	[0.317]	[0.288]	[0.269]	[0.316]	[0.411]	[0.140]
Controls	YES	YES	YES	YES	YES	YES
Firm Fixed Effects	YES	YES	YES	YES	YES	YES
Year Fixed Effects	YES	YES	YES	YES	YES	YES

*Notes: ***, **, and * represent significance levels of 1%, 5%, and 10%, respectively. The value in parenthesis represents t-statistics, and the value in square bracket represents p-value. L.dep represents the lag term of dependent variable.*

4.4 The impacts of DERs on ODI and productivity through three responses

Section 4.3 demonstrates that all three responses exist for cross-border investors when facing more stringent DERs. As discussed in section 2, different responses may have diverse impacts on ODI and productivity. In this section, we will distinguish the different impacts of DERs on firms' ODI and productivity through different responses.

With regard to ODI, it has been confirmed that firms' ODI will increase if they choose production relocation response or technology acquisition response, according to columns (1-4) in Table 5. We further use model (6) to verify whether the R&D expenditures is an effective mediating channel through which DERs affect ODI. The results shown in column (1) of Table 6 demonstrate that both the absolute value and the significance level of the explanatory variable are lower than the benchmark result (column (3) of Table 2) after introducing R&D as a mediating variable. It suggests that R&D expenditure plays a mediating role in DERs and firms' ODI. The reasons behind the results are that the increase of R&D expenditure will improve firms' productivity (which will be improved in column (4) of Table 5). Moreover, the promotion of productivity will improve firms' competitiveness and thus enhance their overall performance and profitability (Tian and Yu, 2022). As a result, it ultimately enables firms to overcome the cost threshold and promote their ODI. The above results confirm hypothesis H2 that R&D expenditures response improves firms' ODI.

Regarding the impacts on productivity, model (7) is used to verify whether the three responses enhance productivity. The results are shown in columns (2-4) of Table 6. Column (2) reports the regression results with ODI^{LOW-ER} being the mediating variable. The significance level and absolute value of the regression coefficient for $L.DER$ are not lower than that in column (6) of Table 2. It suggests that ODI^{LOW-ER} does not play a mediating role in DERs and productivity, confirming hypothesis H1 that if firms merely choose production relocation response when DERs become more stringent, their productivity cannot be enhanced. Relocating production to countries with lax environmental regulations can reduce environmental costs (Chen et al., 2020), but do not necessarily contribute to productivity improvement. Countries that impose lax environmental regulations often tend to possess less-advanced technologies. This provides few opportunities for cross-border firms to gain technological advancements through spillover effects, resulting in insignificant effect regarding productivity improvement.

Column (3) shows the mediating effect of $ODI^{ADV-TEC}$ on productivity, in which the significance and absolute value of the coefficient of *L.DER* have decreased compared to that in column (6) of Table 2. The results confirm hypothesis H3 that technology acquisition response improves firms' productivity. By investing in technologically advanced countries, the cross-border subsidiaries have the opportunity to assimilate advanced knowledge from local enterprises (Piperopoulos et al., 2018). This knowledge can then be transferred back to the parent company through internal interactions, such as intra-firm labor dispatch. This influx of technology can significantly bolster the innovative capacity and productivity of the parent firms (Cheng and Yang, 2017).

The last column (4) examines whether the R&D expenditure is an effective mediating channel that affects productivity. We observe that both the significance level and absolute value of the coefficient of *L.DER* have decreased compared to that in column (6) of Table 2. The R&D expenditure response induced by the tightened DERs also contributes to the enhancement of firms' productivity. This is supported by the fact that investments in R&D facilitate the development and assimilation of advanced technologies, the update of production processes (Matsumura et al., 2013), leading to an overall improvement in productivity. Thus, hypothesis H2 that R&D expenditure response improves firms' productivity holds.

Table 6: Different channels' impacts on ODI and productivity.

	(1)	(2)	(3)	(4)
	ODI	*TFP*	*TFP*	*TFP*
L.dep	-0.0501**	0.7902***	0.7974***	0.7597***
	(-2.0085)	(14.4780)	(14.1872)	(13.6180)
L.DER	0.2067**	0.1180*	0.0277	0.0804
	(2.3656)	(1.6506)	(0.2798)	(1.1725)
ODI_LOW_ER		-0.0199		
		(-0.1801)		
ODI_HIGH_TECH			0.2653*	
			(1.9369)	
RD	0.1633**			0.0641
	(2.3270)			(0.5469)
Constant	-2.8310**	-0.8492**	-1.0964**	-0.8939
	(-2.0119)	(-2.1952)	(-2.4844)	(-1.4983)
AR (1)	[0.000]	[0.000]	[0.000]	[0.000]
AR (2)	[0.723]	[0.718]	[0.363]	[0.173]

Overidentification test	[0.335]	[0.292]	[0.811]	[0.265]
Controls	YES	YES	YES	YES
Firm Fixed Effects	YES	YES	YES	YES
Year Fixed Effects	YES	YES	YES	YES

*Notes: ***, **, and * represent significance levels of 1%, 5%, and 10%, respectively. The value in parenthesis represents t-statistics, and the value in square bracket represents p-value. L.dep represents the lag term of dependent variable.*

5. Heterogeneity analysis

Different types of enterprises exhibit significant variations in terms of financial capacity, social responsibility, technological upgrading level, and more. These disparities can result in different responses to more stringent DERs. For example, LCEs generally possess higher financial capacity compared to HCEs, which reduces the financial pressures of LCEs to invest in long-term technological innovation. SOEs typically bear a higher degree of social responsibility than non-SOEs (Bai et al., 2023), which may make SOEs less inclined to relocate production abroad, especially given the associated job demand. Furthermore, firms with different pollution intensities face different compliance costs. HPEs might face a more pressing need to comply with DERs in the short term compared to LPEs. This urgency could push HPEs to choose production relocation as a response. Consequently, investigating the diverse responses of different types of enterprises to DERs provide important implications for formulating differentiated and effective environmental policies.

5.1 Firms with high versus low financing constraints

The financial condition is identified as the most critical factor affecting firms' decision-making, which includes their responses to more stringent DERs (Hu et al., 2023). To discern the differential effects between HCEs and LCEs, we group the listed companies according to their SA index (Cheng et al., 2023; Hadlock and Pierce, 2010). If a firm's SA index exceeds the average, it is classified as an HCE. Otherwise, it is considered an LCE.

The results for HCEs in Table 7 suggest that HCEs tend to respond to tightened DERs by opting for production relocation rather than pursuing technology acquisition or increasing R&D expenditure. This is primarily because the latter two responses entail longer cycles, require substantial upfront investments, offer relatively low initial returns, and involve significant risks. All of these features demand robust financial support, which is often challenging for HCEs to provide. For example, the technology acquisition response typically involves cross-border mergers and acquisitions (M&A) (Yang et al., 2021). M&A typically demands high upfront acquisition costs due to the necessity for substantial one-time payments related to the transfer of fixed capital and intellectual property. Hence, compared to greenfield investments utilized for production relocation, M&A usually necessitates stronger financing capabilities. Consequently, for firms confronting significant financing constraints, relocating production aboard emerges as a more viable strategy to deal with the strengthened DERs.

Table 7: Channel analysis for HCEs.

	(1) ODI^{LOW-ER}	(2) $ODI^{HIGH-ER}$	(3) $ODI^{ADV-TEC}$	(4) $ODI^{BACK-TEC}$	(5) RD
L.dep	-0.0350	-0.0821**	-0.0777**	-0.0185	1.0480***
	(-0.9098)	(-2.3523)	(-2.1266)	(-0.5138)	(49.7390)
L.DER	0.0880**	0.0580	0.0194	0.1141**	0.0080
	(2.1753)	(0.7277)	(0.2501)	(2.4189)	(0.6535)
Constant	-1.1286*	-3.7205**	-3.7328**	-1.3647*	-0.3104***
	(-1.6941)	(-2.4178)	(-2.4715)	(-1.8655)	(-3.7671)
AR (1)	[0.000]	[0.000]	[0.000]	[0.000]	[0.157]
AR (2)	[0.732]	[0.465]	[0.510]	[0.725]	[0.366]
Overidentification test	[0.656]	[0.317]	[0.242]	[0.676]	[0.308]
Controls	YES	YES	YES	YES	YES
Firm Fixed Effects	YES	YES	YES	YES	YES
Year Fixed Effects	YES	YES	YES	YES	YES

*Notes: ***, **, and * represent significance levels of 1%, 5%, and 10%, respectively. The value in parenthesis represents t-statistics, and the value in square bracket represents p-value. L.dep represents the lag term of dependent variable.*

In contrast, the results for LCEs in Table 8 suggest that LCEs are more inclined to invest in advanced technology acquisition and increase R&D expenditure when DERs are strengthened. LCEs typically have better access to capital at a lower cost, which reduces their financial pressure and enhances their abilities to withstand innovation risks, ultimately facilitating technology upgrading. Low financing constraints also signify that firms attract more attention from stakeholders, which, in turn, encourage these firms to seek a "win-win" strategy that aligns with the strengthened DERs (Zhang et al., 2023). Furthermore, low financing constraints aid firms in surpassing the cost threshold associated with M&A, thereby promoting their ability to acquire advanced technologies in technologically advanced regions.

As concluded in section 4, if firms merely choose production relocation as a response to strengthened DERs, their productivity cannot be promoted. They can improve the productivity if they opt for technology acquisition response or R&D expenditure response. Combining this with the analysis of financing constraints above, it can be concluded that more stringent DERs can lead to productivity gains in LCEs, but not in HCEs. To further test this conclusion, we use the sub-sample of HCEs and LCEs to rerun model (2). The results do support it (see Table 9).

Table 8: Channel analysis for LCEs.

	(1)	(2)	(3)	(4)	(5)

	ODI^{LOW-ER}	$ODI^{HIGH-ER}$	$ODI^{ADV-TEC}$	$ODI^{BACK-TEC}$	RD
L.dep	0.0004	-0.0491	-0.0584	0.0225	0.4941***
	(0.0084)	(-1.3214)	(-1.5573)	(0.4574)	(8.0019)
L.DER	0.1017	0.3374**	0.3456**	0.1127	0.2714***
	(1.4847)	(2.4293)	(2.5166)	(1.4316)	(2.9529)
Constant	-1.0536	-0.5826	-0.4236	-1.1785	0.0389
	(-1.1335)	(-0.4286)	(-0.3207)	(-1.2848)	(0.0523)
AR (1)	[0.000]	[0.000]	[0.000]	[0.000]	[0.017]
AR (2)	[0.793]	[0.668]	[0.573]	[0.663]	[0.027]
Overidentification test	[0.507]	[0.549]	[0.612]	[0.444]	[0.178]
Controls	YES	YES	YES	YES	YES
Firm Fixed Effects	YES	YES	YES	YES	YES
Year Fixed Effects	YES	YES	YES	YES	YES

*Notes: ***, **, and * represent significance levels of 1%, 5%, and 10%, respectively. The value in parenthesis represents t-statistics, and the value in square bracket represents p-value. L.dep represents the lag term of dependent variable.*

Table 9: Heterogeneous effects of DERs on the productivity of HCEs v.s. LCEs.

	(1)	(2)
	HCEs	LCEs
	TFP	*TFP*
L.dep	0.5866***	0.6024***
	(6.3730)	(7.9738)
L.DER	0.1992	0.3291*
	(1.0186)	(1.8060)
Constant	-1.3905	-1.4030*
	(-1.5804)	(-1.8013)
AR (1)	[0.000]	[0.000]
AR (2)	[0.537]	[0.169]
Overidentification test	[0.888]	[0.221]
Controls	YES	YES
Firm Fixed Effects	YES	YES
Year Fixed Effects	YES	YES

*Notes: ***, **, and * represent significance levels of 1%, 5%, and 10%, respectively. The value in parenthesis represents t-statistics, and the value in square bracket represents p-value. L.dep represents the lag term of dependent variable.*

5.2 State-owned versus non-state-owned firms

SOEs and non-SOEs exhibit substantial differences in terms of social responsibility, which influences their responses to environmental regulations. The results for SOEs in Table 10 suggest that they are more inclined to adopt the technology acquisition response and R&D expenditure response when DERs are strengthened, instead of the production relocation response. This preference for avoiding production relocation is mainly due to the fact that such a move typically leads to a decline in employment demand and social welfare losses (Walker, 2011). However, SOEs are subject to the stringent regulations of State-owned Assets Supervision and Administration Commission (SASAC) as well as central and local governments, which require them to bear a greater degree of social responsibility (Bai et al., 2023). For example, *Research Report on Corporate Social Responsibility of Central Enterprises (2021)* published by SASAC emphasizes that SOEs play a significant role in social responsibilities, including ensuring people's livelihood and employment. Consequently, when facing strengthened DERs, SOEs are less likely to relocate production abroad. Furthermore, SOEs own government endorsement and more fixed assets as credit guarantees. As a result, banks are more inclined to grant loans to SOEs compared to non-SOEs (Qi et al., 2023). This powerful financing ability and stable funding sources empower SOEs to adopt the technology acquisition response and increase R&D expenditure.

Table 10: Channel analysis for SOEs.

	(1) ODI^{LOW-ER}	(2) $ODI^{HIGH-ER}$	(3) $ODI^{ADV-TEC}$	(4) $ODI^{BACK-TEC}$	(5) RD
L.dep	-0.1501***	-0.1447***	-0.1340***	-0.1423***	0.1668***
	(-3.1609)	(-3.9003)	(-3.4717)	(-3.1113)	(5.6703)
L.DER	0.0025	0.2614**	0.2454**	0.0205	0.7611***
	(0.0439)	(2.5315)	(2.4236)	(0.3177)	(4.6559)
Constant	-3.4325***	-3.9821**	-3.9535**	-4.2860***	-0.6372
	(-3.0816)	(-2.2260)	(-2.2309)	(-3.4766)	(-1.0104)
AR (1)	[0.000]	[0.000]	[0.000]	[0.000]	[0.083]
AR (2)	[0.745]	[0.347]	[0.428]	[0.999]	[0.599]
Overidentification test	[0.148]	[0.287]	[0.282]	[0.175]	[0.154]
Controls	YES	YES	YES	YES	YES
Firm Fixed Effects	YES	YES	YES	YES	YES
Year Fixed Effects	YES	YES	YES	YES	YES

*Notes: ***, **, and * represent significance levels of 1%, 5%, and 10%, respectively. The value in parenthesis represents t-statistics, and the value in square bracket represents p-value. L.dep represents the lag term of dependent variable.*

In comparison, non-SOEs tend to choose production relocation response when facing tightened DERs (Table 11). The rationale behind is that non-SOEs typically receive less financial support, and it involves a considerable amount of time and financial investment to obtain the corresponding economic and environmental benefits, regardless of whether they acquire technology abroad or increase R&D expenditures. It may be challenging for non-SOEs to bear such costs because of financial pressures and other factors. Moreover, the primary objective of non-SOEs is often to maximize stakeholder profits, rather than prioritizing social benefits. Therefore, the most cost-effective option for non-SOEs in the short term is to relocate production to countries with less stringent environmental regulations.

Once again, similar to the explanations in section 5.1, it can be inferred that more stringent DERs can lead to productivity gains in SOEs, but not in non-SOEs. We similarly use the subsample of SOEs and non-SOEs to rerun model (2), and the results support this conclusion (see Table 12).

Table 11: Channel analysis for non-SOEs.

	(1) ODI^{LOW-ER}	(2) $ODI^{HIGH-ER}$	(3) $ODI^{ADV-TEC}$	(4) $ODI^{BACK-TEC}$	(5) RD
L.dep	0.0239	-0.0347	-0.0362	0.0320	0.8696***
	(0.5195)	(-1.1082)	(-1.1424)	(0.8011)	(77.8482)
L.DER	0.1249***	0.0487	0.0252	0.1334***	0.0177
	(2.7185)	(0.5106)	(0.2657)	(2.7120)	(1.3780)
Constant	-0.2231	-2.0696	-1.9956	-0.2309	-0.4486***
	(-0.2921)	(-1.4295)	(-1.4008)	(-0.2830)	(-6.5498)
AR (1)	[0.000]	[0.000]	[0.000]	[0.000]	[0.186]
AR (2)	[0.514]	[0.646]	[0.823]	[0.725]	[0.246]
Overidentification test	[0.638]	[0.566]	[0.559]	[0.405]	[0.079]
Controls	YES	YES	YES	YES	YES
Firm Fixed Effects	YES	YES	YES	YES	YES
Year Fixed Effects	YES	YES	YES	YES	YES

*Notes: ***, **, and * represent significance levels of 1%, 5%, and 10%, respectively. The value in parenthesis represents t-statistics, and the value in square bracket represents p-value. L.dep represents the lag term of dependent variable.*

Table 12: Heterogeneous effects of DERs on the productivity of SOEs v.s. non-SOEs.

	(1) SOEs *TFP*	(2) non-SOEs *TFP*
L.dep	0.9754***	0.6955***
	(7.7480)	(5.1679)
L.DER	0.6706**	-0.4717
	(2.1420)	(-1.0511)
Constant	1.8444	-2.8448**
	(1.5014)	(-2.1426)
AR (1)	[0.000]	[0.000]
AR (2)	[0.006]	[0.951]
Overidentification test	[0.676]	[0.229]
Controls	YES	YES

Firm Fixed Effects	YES	YES
Year Fixed Effects	YES	YES

*Notes: ***, **, and * represent significance levels of 1%, 5%, and 10%, respectively. The value in parenthesis represents t-statistics, and the value in square bracket represents p-value. L.dep represents the lag term of dependent variable.*

5.3 Firms in high-polluting versus low-polluting industries

There are significant disparities in compliance costs among firms with different pollution intensities, which influence their responses to environmental regulations. We divide the sample into firms in high-polluting industries[6] (HPEs) and firms in low-polluting industries (LPEs) to explore the heterogeneous effects between the two groups.

The results for HPEs in Table 13 suggest that HPEs mainly take the production relocation response. In other words, when DERs become more stringent, HPEs are primarily affected by the Pollution Haven Hypothesis. The possible interpretation behind is that HPEs would need more time and a larger amount of financial support to transition to green production through technology innovation. Moreover, technologically advanced countries often maintain stringent environmental regulations, resulting in a more rigorous investment review for HPEs. Consequently, it becomes challenging for HPEs to access technologically advanced countries and acquire advanced techniques. However, HPEs are confronted with a more pressing need for pollution control as they are more likely to be responsible for environmental pollution (Li et al., 2022b). Therefore, relocating production to countries with less stringent environmental regulations becomes a more feasible approach for them.

Table 13: Channel analysis for HPEs.

	(1) ODI^{LOW-ER}	(2) $ODI^{HIGH-ER}$	(3) $ODI^{ADV-TEC}$	(4) $ODI^{BACK-TEC}$	(5) RD
L.dep	-0.1098**	-0.0185	-0.0158	-0.0679	0.1227***
	(-2.0162)	(-0.3977)	(-0.3299)	(-1.5354)	(8.3142)
L.DER	0.1339*	0.0331	0.0309	0.1278	-0.0366
	(1.7786)	(0.2207)	(0.2086)	(1.5713)	(-0.8036)
Constant	-1.3499*	-2.1608	-2.3746	-1.6509*	-2.0246***
	(-1.6459)	(-1.0633)	(-1.1616)	(-1.7000)	(-10.0084)
AR (1)	[0.000]	[0.000]	[0.000]	[0.000]	[0.199]
AR (2)	[0.340]	[0.400]	[0.323]	[0.146]	[0.140]

[6] According to *Listed companies environmental protection verification industry classification management directory* published by the Ministry of Ecology and Environment of the People's Republic of China, this paper defines the following industries as high-polluting industries: Coal mining and processing, Oil and gas mining, Ferrous mining and processing, Non-ferrous metal mining and processing, Textiles, Leather, fur, feathers and their products and footwear, Paper and paper products, Petroleum processing, Coking and nuclear fuel processing, Chemical raw materials and chemical products, Chemical fiber manufacturing, Rubber and plastic products, Non-metallic mineral products, Ferrous smelting and rolling processing, Non-ferrous metal smelting and rolling processing, Production and supply of electricity and heat . The other industries are defined as low-polluting industries.

Overidentification test	[0.691]	[0.147]	[0.154]	[0.576]	[0.141]
Controls	YES	YES	YES	YES	YES
Firm Fixed Effects	YES	YES	YES	YES	YES
Year Fixed Effects	YES	YES	YES	YES	YES

*Notes: ***, **, and * represent significance levels of 1%, 5%, and 10%, respectively. The value in parenthesis represents t-statistics, and the value in square bracket represents p-value. L.dep represents the lag term of dependent variable.*

On the contrary, LPEs tend to choose technology acquisition response and R&D expenditure response (Table 14). This phenomenon can be attributed to several factors. Firstly, LPEs typically face lower compliance costs and encounter fewer challenges when upgrading to greener practices. Hence, it is more probable for them to address pollution problems through technological innovation. Secondly, LPEs are more likely to navigate investment restrictions, enabling them to acquire foreign advanced technologies. Therefore, from the perspective of long-term development, LPEs are more inclined to improve their production processes, optimize resource utilization, reduce pollution emissions, and ultimately improve their long-term sustainable development capabilities.

Similarly, the heterogenous effects on productivity from different responses suggest that tightened DERs can enhance the productivity of LPEs, but not of HPEs. We use the subsample of HPEs and LPEs to rerun model (2), and the results confirm this conclusion (see Table 15. This finding is also in line with the results of Li et al., 2022b).

Table 14: Channel analysis for LPEs.

	(1) ODI^{LOW-ER}	(2) $ODI^{HIGH-ER}$	(3) $ODI^{ADV-TEC}$	(4) $ODI^{BACK-TEC}$	(5) RD
L.dep	-0.0091	-0.0543**	-0.0526**	0.0062	0.6037***
	(-0.3051)	(-2.1653)	(-2.0436)	(0.1924)	(9.0552)
L.DER	0.0563	0.1419*	0.1336*	0.0658	0.7831***
	(1.4977)	(1.7605)	(1.6725)	(1.5648)	(2.9346)
Constant	-1.2416**	-1.3903	-1.1819	-1.0907	0.8529
	(-1.9668)	(-1.1381)	(-0.9785)	(-1.5896)	(1.1321)
AR (1)	[0.000]	[0.000]	[0.000]	[0.000]	[0.057]
AR (2)	[0.551]	[0.644]	[0.562]	[0.520]	[0.334]
Overidentification test	[0.033]	[0.423]	[0.501]	[0.105]	[0.193]
Controls	YES	YES	YES	YES	YES
Firm Fixed Effects	YES	YES	YES	YES	YES
Year Fixed Effects	YES	YES	YES	YES	YES

*Notes: ***, **, and * represent significance levels of 1%, 5%, and 10%, respectively. The value in parenthesis represents t-statistics, and the value in square bracket represents p-value. L.dep represents the lag term of dependent variable.*

Table 15: Heterogeneous effects of DERs on the productivity of HPEs v.s. LPEs.

	(1)	(2)
	HPEs	LPEs
	TFP	*TFP*
L.dep	0.8005***	0.6964***
	(11.1706)	(8.4552)
L.DER	0.0494	0.4571*
	(0.4439)	(1.6708)
Constant	-0.6886	-0.3170
	(-1.5396)	(-0.2932)
AR (1)	[0.000]	[0.000]
AR (2)	[0.956]	[0.445]
Overidentification test	[0.139]	[0.130]
Controls	YES	YES
Firm Fixed Effects	YES	YES
Year Fixed Effects	YES	YES

*Notes: ***, **, and * represent significance levels of 1%, 5%, and 10%, respectively. The value in parenthesis represents t-statistics, and the value in square bracket represents p-value. L.dep represents the lag term of dependent variable.*

6. Conclusion

Since many countries across the world have committed to the Sustainable Development Goals of the United Nations, these nations are increasingly motivated to impose stringent environmental regulations to ensure economic development and environmental sustainability in tandem. In this paper, we zoom in the effects of environmental regulations on firms' ODI and productivity by conducting solid empirical tests. The results reveal a positive association between stringent DERs and ODI as well as productivity. We further examine firms' three responses (production relocation, technology acquisition, and increasing R&D expenditure) to stricter DERs and investigate how they affect the outcomes. We find that all three responses boost ODI, but only the latter two responses contribute significantly to productivity improvement.

Moreover, we conduct three groups of heterogeneity analyses to examine how firms' financing constraint, state ownership and pollution intensity matter. The results suggest that LCEs, SOEs and LPEs are inclined to respond to stricter DERs by acquiring advanced techniques from technologically advanced countries or by increasing their own R&D expenditures to upgrade their technology levels. In contrast, HCEs, non-SOEs and HPEs usually choose to shift production to countries with less stringent environmental regulations due to financial constraints, a greater urgency to generate economic benefits, and to reduce pollutant emissions. Consequently, stricter

DERs can enhance productivity for LCEs, SOEs and LPEs, but not for HCEs, non-SOEs or HPEs.

Our empirical findings point to some valuable policy recommendations with respect to guiding firms' responses to DERs in a sustainable way. First, policies should guide enterprises to upgrade their own production technology to a cleaner level instead of simply relocating production abroad since our results demonstrates that shifting production to countries with lenient environmental regulations does not contribute to productivity improvement. To achieve this, two essential measures can be taken. On one hand, it is very necessary to strengthen international coordination to accelerate the diffusion of cleaner production technologies to firms that are lagging behind. This may be achieved through collaborative efforts, knowledge sharing, and technology transfer initiatives on a global scale. On the other hand, domestic business environment should be further improved to provide enterprises stronger incentives to raise the capacity for technology upgrading. This may involve creating favorable conditions for R&D investment and fostering a culture of technological advancement. These actions can collectively drive the capacity for technology upgrading and facilitate a more sustainable approach to complying with environmental regulations.

Second, categorized and targeted measures should be adopted for different enterprises based on their specific characteristics, including financing constraints, ownership structures, and pollution intensities. Our results reveal that more stringent DERs do not stimulate technological innovation for HCEs, non-SOEs or HPEs. These firms, due to higher compliance costs and a lack of financial support, prefer to shift production to countries with lenient environmental regulations. In light of this, it becomes essential to increase financial and tax support for these enterprises. For instance, one approach could involve establishing special funds dedicated to HCEs, non-SOEs, and HPEs that urgently need green technology transformations but have limited financial capacity. These funds can incentivize these firms to increase their R&D expenditures and upgrade their technology. Financial or tax support provided by governments may exert considerable fiscal pressure. Hence, governments are encouraged to facilitate collaboration between financial institutions (such as venture capitalists and banks) and innovative firms. For example, governments can improve regulatory mechanisms and infrastructure to create an investment-friendly environment, attracting private investors and financial institutions to actively engage in financing innovative firms and fostering investment opportunities specifically targeted at innovation.

Third, considering that HPEs are significant sources of pollution, it is important to make substantial efforts to enhance their technology. HPEs exhibit characteristics of urgent pollution reduction and difficult technological transformation. Consequently, they are more inclined to relocate production abroad than to improve their technology. As a result, it is advisable to provide HPEs with an adequate timeframe for achieving overall emission reduction targets rather than to impose oppressive green schedules. Moreover, universities and research institutions should strengthen collaboration with HPEs, jointly advancing research and development of crucial technologies. This collaborative approach can help alleviate the technological transformation challenges faced by HPEs, ultimately supporting their efforts in achieving more environmentally friendly production processes.

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