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Global reach, local impact: How China's outward foreign direct investment shapes corporate carbon risk management?

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ABSTRACT

Outward Foreign Direct Investment (OFDI) has emerged as a pivotal driver of globalization, enabling firms to broaden their reach across borders and tap into diverse resources. We present evidence supporting the role of OFDI in mitigating corporate carbon risk. However, the extent of the underlying mitigation effect varies depending on factors such as corporate nature, ESG ratings, and financial constraints. We also identify several intermediaries through which OFDI exerts its mitigating influence, such as corporate reputation, downside risk exposure, debt financing costs, and the firm's ability to innovate in green technologies. Further exploration substantiates the synergistic effects between OFDI and the emissions trading scheme, which together help further reduce corporate carbon risk. These findings offer valuable insights into how enhancing OFDI can mitigate carbon risk, thus supporting China's transition toward a low-carbon economy.

1. Introduction

Amid the escalating challenges of climate change, there is an expanding international consensus on the need for sustainable development and decarbonization. With the global enforcement of the Paris Agreement, attention has shifted toward managing costs, particularly in addressing rising economic burdens, alleviating financial pressures, and mitigating the risk of widespread job losses linked to climate-related impacts (Liu et al., 2024). Carbon risk suggests the influence of policy adjustments to tackle climate change on a firm's expenses, operational outcomes, and public image, which, in turn, introduces added complexity and unpredictability into the business landscape (Li et al., 2024a).

Carbon risk manifests in three main dimensions. First, climate-induced natural disasters may alter corporate strategies, resulting in higher operational costs (Garcia-Jorcano et al., 2022). Second, companies subjected to carbon regulations face escalating financial risks as investors pressure firms to adopt low-carbon initiatives to mitigate these risks, thus raising business costs (Carney Carney, 2015). Third, carbon risk can diminish the value of company assets, leading to more stringent credit conditions, which subsequently raise financing burdens (Semieniuk et al., 2021). As China advances toward its carbon peak and neutrality targets, the demand for green and low-carbon growth strategies becomes ever more pressing.

In August 2024, the State Council released the "Opinions on Accelerating the Comprehensive Green Transformation of Economic and Social Development," emphasizing the need for companies to strengthen their energy conservation and carbon mitigation management systems. It also highlighted the importance of refining carbon emissions footprint accounting to facilitate a transition to greener, low-carbon operations. Looking ahead, Chinese firms are likely to encounter significant challenges as they shift toward clean energy solutions, enhance resource efficiency, and adapt their supply chains and business models, thereby facing increased exposure to carbon risk (Wang et al., 2024a; Zhong et al., 2024).

The ongoing transformation of China's industrial framework has heightened the challenges confronted by domestic firms. As Chinese enterprises continue to broaden their presence in global markets, alongside the swift execution of national initiatives like the Belt and Road Initiative, the nation remains committed to bolstering outward

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foreign direct investment (OFDI)[1] (Pan et al., 2020). In 2023, China's aggregate OFDI across all sectors amounted to roughly 1.04 trillion yuan, reflecting a 5.7 % increase compared to the previous year[2] (Zhao et al., 2024).

OFDI has dual effects on corporate climate risk management. On the one hand, OFDI facilitates reverse technology spillovers, where firms in the host countries replicate and integrate advanced technologies, boosting technological capabilities and strengthening their capacity to handle climate-related financial risks (Huang et al., 2017; Pan et al., 2020). On the other hand, OFDI may increase reliance on external partners and suppliers, exposing firms to greater vulnerability from restrictive regulatory frameworks, which could undermine their risk mitigation ability (Shao et al., 2024). Given that China is the largest emitter of carbon globally, the second-largest investor in OFDI, and a major manufacturing center, its role in global trade and carbon research remains critical. Research focused on China would thus provide valuable insights applicable to other nations facing similar challenges in carbon mitigation efforts (Yang et al., 2021). Therefore, exploring the intricate link between OFDI and corporate carbon risk remains both essential and meaningful.

Previous studies have identified various strategies to mitigate corporate carbon risk, including advancing green finance (Zhong et al., 2024), strengthening climate governance frameworks (Liêu et al., 2024b), and enhancing emission reduction transparency (Cheng et al., 2023). Nevertheless, there is a limited exploration of the link between OFDI and corporate carbon risk. In this scenario, the primary objectives of our study are threefold: (1) to assess whether OFDI genuinely reduces corporate carbon risks; (2) to identify the channels through which OFDI influences corporate carbon risks; and (3) to investigate the combined impact of OFDI and the Emissions Trading System (ETS) in mitigating carbon risks. Fig. 1 illustrates the research flow, and we have the following contributions.

This study, to the best of our knowledge, is the first to use a firm-level dataset to thoroughly investigate how OFDI influences carbon risk exposure among Chinese firms. Our findings underline the catalytic role of OFDI in diminishing carbon risk at the firm level. Yet the extent to which OFDI mitigates carbon risk varies across firms with different characteristics, ESG ratings, and financial constraints. Overall, our estimates provide valuable fresh perspectives on the nexus between OFDI and carbon risk, offering practical implications for policymakers in crafting targeted and context-specific strategies.

Second, we use a moderation effect model to investigate the underlying transmission pathways between OFDI and firm-level carbon risks. The mechanisms explored are corporation reputation, downside risk, debt financing cost, and green innovation efficiency. Our results highlight that OFDI significantly reduces carbon risk by enhancing corporate reputation, decreasing downside risk, minimizing debt financing costs, and fostering green innovation efficiency. These results suggest that the proposed mediation framework offers novel insights into how OFDI can diversify and mitigate carbon risk at the firm level, providing valuable guidance for stakeholders aiming to address carbon emission challenges sustainably.

Third, building on the externality theory, OFDI and ETS address emissions-related externalities through distinct mechanisms. OFDI enables firms to internalize the abatement costs by encouraging the adoption of clean technologies and practices observed in foreign markets. The ETS addresses these externalities by placing a monetary value on carbon emissions, effectively incorporating the associated cost into firms' decision-making (Hoffmann, 2007). The synergistic effect of OFDI and ETS creates a complementary dynamic: OFDI facilitates access to advanced technologies and management strategies for emissions reduction, while the ETS offers financial incentives for their (i.e., technology) adoption (Hao et al., 2020; Schleich et al., 2009). Additionally, the **Porter Hypothesis** provides a relevant lens, arguing that well-designed environmental regulations (i.e., an ETS) can spur innovation (Wei et al., 2022). Firms engaged in OFDI will likely gain a competitive edge globally, benefiting from exposure to stricter environmental regulations in host countries (Shao and Shang, 2016). By participating in the ETS, these firms are further motivated to implement energy-efficient technologies and practices, many of which they have already encountered through OFDI exposure (Hongyan et al., 2023). The result is a dual incentive to innovate and reduce emissions, amplifying the reduction of carbon risk. Therefore, we investigate the synergistic effects of China's OFDI coupled with the ETS on firm-level carbon risk, building on foundational studies that have empirically highlighted the pivotal role of China's ETS in advancing China's decarbonization process (Tao et al., 2022; Wu and Wang, 2022).

The structure of this analysis is organized as follows: Section 2 presents the literature review and hypotheses. Section 3 describes the methodology. Section 4 reports the empirical results. Section 5 details the mechanism analyses. Section 6 conducts further investigations. Conclusions are listed in Section 7.

2. Relevant studies and theoretical hypotheses

2.1. Related literature

Research on the impact of OFDI on the carbon risk of local companies primarily focuses on three key aspects. OFDI generates a reverse technology spillover effect, which is a key concept in international investment theory. This phenomenon allows firms to replicate and integrate foreign technologies, strengthening domestic technological capacities. Such advancements are instrumental in mitigating carbon risk within the home country (Huang et al., 2017). For example, Pan et al. (2020) confirmed that the reverse technology spillovers from China's OFDI significantly promote carbon productivity. Likewise, Zhang et al. (2022) demonstrated that OFDI significantly lowers corporate energy intensity through reverse technology spillovers. Wang et al. (2024b) argued that China's OFDI contributes to lower carbon emissions while simultaneously enhancing energy efficiency via reverse technology spillovers. Similarly, Kong et al. (2024) argued that China's OFDI enhances economic growth's quality, efficiency, and sustainability by leveraging reverse technology spillovers, mitigating risk likelihood.

Second, OFDI exerts a demonstration effect, which becomes apparent when the host country's advanced technologies and managerial practices are integrated into the supply chain. This knowledge transfer encourages firms in the home country to refine their industrial frameworks and incorporate more sophisticated management approaches, ultimately improving their ability to control risk. For example, Tan et al. (2021) highlighted that when manufacturers seek to increase profits through OFDI, their enhanced efficiency can serve as a model or create competitive pressures that drive improvements across industries within the supply chain, leading to broader gains in overall industry productivity. Sheng et al. (2023) contended that OFDI, by fostering competitive dynamics or acting as a catalyst for innovation, can spur the growth of related sectors within the home economy, facilitate the upgrading of domestic industries, lower carbon emissions, and enhance resilience to external climate disruptions. Similarly, Ren et al. (2022) observed that OFDI promotes greater production efficiency through its effects on competition, industrial interconnections, and knowledge diffusion.

Finally, OFDI exerts a monitoring effect. This influence arises because firms engaged in OFDI must account for the regulatory constraints of the host country, implement more rigorous corporate social responsibility strategies, and comply with stricter environmental

[1] OFDI offers firms the opportunity to make direct strategic decisions regarding sustainability in foreign markets, whereas inward foreign direct investment typically involves foreign investors controlling sustainability practices in the local context. This distinction is key in understanding why OFDI is more effective in mitigating carbon risk.

[2] See: http://file.mofcom.gov.cn/article/tongjiziliao/dgzz/202401/20240103469616.shtml.

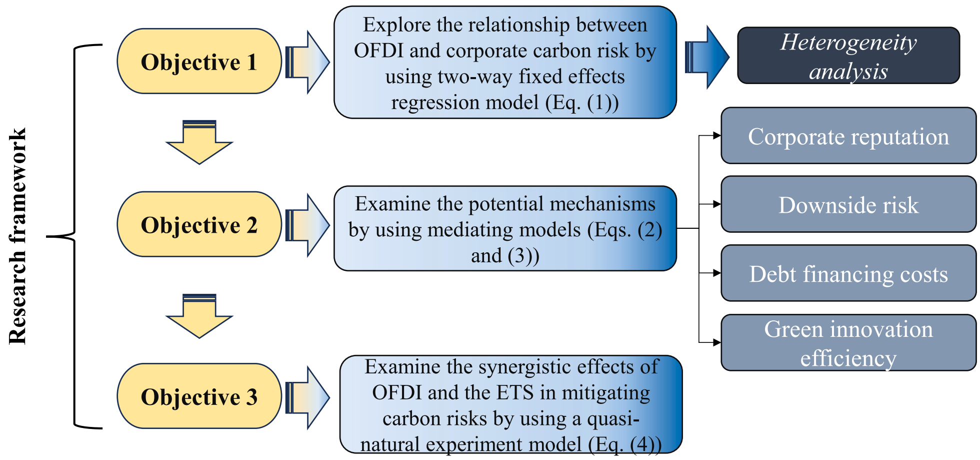

Fig. 1. The research framework.

monitoring systems, such as carbon emission controls, which help mitigate carbon risk (Zhao et al., 2024). For example, Dai et al. (2021) argued that OFDI could 'standardize' corporate green practices and boost innovation capacity, strengthening resilience to external climate shocks. Liu et al. (2021a) noted that OFDI faces dual regulatory oversight from both the home and host countries, which compels firms to provide more transparency and limits the chances for management to hide unfavorable information. This dynamic fosters stronger internal governance and strengthens oversight, lowering corporate risk. Therefore, Hypothesis 1 is as follows:

Hypothesis 1. (H1): OFDI substantially alleviates carbon risk at the firm level.

2.2. Theoretical analyses

2.2.1. Corporate reputation, OFDI, and carbon risk

Through OFDI, companies can substantially enhance their standing in global markets, driven by several interconnected mechanisms. First, OFDI enables firms to strengthen their commitment to corporate social responsibility (CSR), safeguard their reputation, and foster valuable connections with stakeholders. This, in turn, reduces the perception of agency costs and information asymmetries in foreign markets, contributing to higher levels of transparency and trust (Cheng et al., 2014). Second, engaging in OFDI provides firms with access to broader international markets, allowing them to expand their operational reach and gain increased brand visibility. This wider market presence strengthens their international influence and amplifies their recognition on the global stage (Christofi et al., 2022; Hertenstein et al., 2017). Furthermore, a solid corporate reputation can significantly boost investor trust, attracting more financial resources and improving the firm's access to capital (Herbohn et al., 2019). The link between a firm's reputation and its CSR activities is well-established, i.e., a positive reputation enhances overall firm performance, builds goodwill with stakeholders, and strengthens its resilience to potential setbacks (Bose et al., 2021). By reinforcing its CSR commitments, a company can mitigate carbon risk and align its operations with sustainable development goals, even as it expands internationally. CSR serves as a vital asset for driving global growth and securing long-term competitive advantages (Wang et al., 2023c). Therefore, we posit Hypothesis 2a:

Hypothesis 2a. (H2a): OFDI improves corporate reputation. Further, corporate reputation mediates the nexus between OFDI and carbon risk.

2.2.2. Corporate downside risk, OFDI, and carbon risk

OFDI helps minimize a firm's exposure to downside risk. By broadening its market reach, OFDI reduces dependence on a single market or geographic region, diversifying the risks associated with market fluctuations. This diversification enables firms to sustain profitability and operational continuity amidst global economic challenges (Wang et al., 2019). For example, entering markets with asynchronous economic cycles that do not align perfectly can help offset the harmful effects of downturns in specific regions. Yet engaging with varied consumer bases stabilizes demand fluctuations (De Haan et al., 2008).

Second, OFDI often facilitates improved access to financial resources, including both conventional bank loans and opportunities to secure funding through capital markets (Wang et al., 2023b). Such access further strengthens the company's financial adaptability and risk resilience against risks. Furthermore, proactive OFDI also expands avenues for capital acquisition, safeguarding against potential adverse events that might otherwise tarnish a company's reputation. This added financial flexibility further reduces downside risk (Cheng and Su, 2024).

Furthermore, reducing downside risk can simultaneously lead to a decrease in carbon risk. On the one hand, lower downside risk implies more stable profitability and cash flows, enabling firms to navigate unexpected challenges or market volatility associated with carbon emissions. On the other hand, enhanced financial stability increases a firm's appeal in capital markets, facilitating access to cost-effective financing. With improved access to capital, firms can allocate greater resources to green projects or carbon reduction strategies, thereby mitigating their carbon risk. For example, some firms have successfully leveraged low-cost funds obtained through OFDI to invest in renewable energy infrastructure. These investments have substantially reduced carbon emissions and bolstered the firms' green competitiveness on a global scale, effectively lowering their carbon risk (Liu et al., 2020; Zhang et al., 2023). Thus, our Hypothesis 2b is as follows:

Hypothesis 2b. (H2b): OFDI robustly diminishes corporate downside risks. Further, corporate downside risk mediates the nexus between OFDI and carbon risk.

2.2.3. Corporate financing cost, OFDI, and carbon risk

OFDI lowers corporate financing costs for several reasons. First, OFDI promotes improved information and communication exchange between firms, which mitigates informational imbalances and reduces the cost of capital (Ren and Yang, 2020). Second, OFDI stabilizes financial markets by improving corporate performance and governance, contributing to lower financing costs (Liu et al., 2021a). Finally, expanding operations across different countries or regions allows firms to diversify operational risks, boost investor and creditor confidence, and lead to more favorable financing terms. As a result, the reduced financing costs help reduce a firm's exposure to carbon risk.

On the one hand, reduced financing costs make it more feasible and appealing for companies to undertake forward-looking projects, including those in low-carbon technologies, clean energy, and other carbon reduction initiatives, to meet evolving regulatory requirements and market shifts (Curtin et al., 2017). On the other hand, lower financing costs provide firms with a competitive advantage by enabling them to upgrade equipment and enhance processes, thereby positioning themselves more effectively in the market and reducing carbon risk (Chen et al., 2019; Nikkeh et al., 2022). Thus, Hypothesis 2c is as follows:

Hypothesis 2c. (H2c): OFDI lowers corporate debt financing costs. Further, corporate debt financing cost mediates the nexus between OFDI and carbon risk.

2.2.4. Corporate green innovation behavior, OFDI, and carbon risk

OFDI bolsters the green innovation capabilities of companies in the home country. On the one hand, OFDI facilitates the return of foreign technologies, promoting the flow of knowledge and reverse technology spillovers. This process unlocks the innovation potential within firms and strengthens their capacity for green innovation (Kafouros and Forsans, 2012; Shi et al., 2023). For instance, companies involved in OFDI often establish R&D centers abroad or collaborate with leading research institutions, incorporating cutting-edge technologies and practices into domestic operations. On the other hand, the influence of foreign firms and the pressure transmitted through supply chains compel domestic firms to optimize industrial structure, attract talent, and foster greener technological innovations (Liu et al., 2021b). For example, domestic suppliers collaborating with multinational corporations may adopt stricter environmental standards to meet global supply chain requirements, encouraging the diffusion of green practices across industries.

Moreover, green innovation can effectively mitigate carbon risk. By enhancing a company's competitive position, green innovation allows businesses to capture a more significant market share and achieve better ratings, thus reducing carbon risk (Safiullah et al., 2024). Additionally, green innovation improves industry efficiency, energy savings, and emissions reduction, thereby improving the firm's resilience to climate-related risks (Sun et al., 2020). In addition, through green innovation, firms can enhance brand image and social responsibility, gaining greater investor trust and policy support and minimizing carbon risks (Fosu et al., 2024; Lin et al., 2021). Thus, we have Hypothesis 2d:

Hypothesis 2d. (H2d): OFDI improves corporate green innovation efficiency. Further, corporate green innovation efficiency mediates the nexus between OFDI and carbon risk.

2.2.5. China's ETS, OFDI, and carbon risk

Promoting China's ETS pilot policies in trial cities will drive more efficient resource allocation, strengthen oversight, and reduce carbon emissions in these regions. Specifically, the ETS sets carbon emission caps and introduces a trading system for carbon permits, encouraging companies to use resources more efficiently and adopt low-carbon technologies in their production processes. This mechanism not only improves resource allocation efficiency but also enhances the enforcement capabilities of local governments and enterprises in lowering carbon emissions through the establishment of carbon monitoring and management systems.

Firms within the ETS are more inclined to consider the environmental costs when engaging in OFDI, which results in lower emissions, increased green investments, and improved carbon risk management (Yu et al., 2021). As a result, businesses impacted by the ETS policies tend to prioritize environmental considerations in their global business strategies, particularly when selecting investment opportunities and markets. These firms are more likely to target regions and countries with stringent environmental standards, reducing their global carbon footprint. This approach also promotes the dissemination of green technologies via green investments, enabling a more effective response to changes in global carbon emission regulations. Furthermore, China's OFDI flows are concentrated in energy-intensive sectors such as manufacturing, chemical raw materials, and infrastructure (Ma et al., 2023). These industries, due to their substantial energy consumption and carbon emissions, are critical sectors for emission reduction under the ETS. As firms adapt to domestic carbon regulations through ETSs, they also develop advanced carbon management capabilities that they can apply to their investments abroad. These companies prioritize carbon emission control abroad, promoting the global application of their developed green technologies and management practices. Therefore, Hypothesis 3 is as follows:

Hypothesis 3. (H3): The synergy between OFDI and China's ETS on carbon risk remains harmful.

Fig. 2 visualizes the theoretical framework.

3. Methodology

3.1. Model specification

We validate the effects of OFDI on China's carbon risk at the firm level through a two-way fixed effects regression model. Formally, the benchmark model is as follows:

$$CR_{it} = \alpha + \beta OFDI_{it} + \gamma X_{it} + u_i + v_t + \varepsilon_{it} \tag{1}$$

where CR_{it} represents the carbon risk for the ith firm at year t; $OFDI_{it}$ regulates the firm-level OFDI in a logarithmic form; X_{it} denotes a vector of firm-level characteristic regressors; u_i and v_t index the firm- and year-fixed effects, respectively; ε_{it} is an error term, and others are the response parameters.

We further construct a mediation model to test Hypotheses 2a-2c by extending Eq. (1). Specifically, we first ascertain the correlation between OFDI and mediators using Eq. (2). If the coefficient of OFDI remains significant, designating that OFDI imposes certain influences on mediators. We further examine the relationship between carbon risk and OFDI, alongside the mediators, by estimating Eq. (3). Specifically, a significant coefficient for both OFDI and the mediator indicates the presence of a mediation effect for a candidate mediator. A partial mediation effect is observed if OFDI's coefficient remains statistically significant. The models are represented as follows:

$$M_{it} = \alpha_1 + \beta_1 OFDI_{it} + \gamma' X_{it} + u_i + v_t + \varepsilon_{1it} \tag{2}$$

$$CR_{it} = \alpha_2 + \rho M_{it} + \beta_2 OFDI_{it} + \gamma'' X_{it} + u_i + v_t + \varepsilon_{2it} \tag{3}$$

where M_{it} is the selected mediator; β_1 captures OFDI's effects on mediators; ρ validates the mediator's impacts on carbon risk. Other specifications are consistent with Eq. (1).

Lastly, we investigate the potential "double dividend" effects of corporate OFDI in conjunction with China's ETS. To test Hypothesis 3, we employ the following model, structured around a quasi-natural experiment design:

$$CR_{it} = \alpha + \beta OFDI\_ETS_{it} + \gamma X_{it} + u_i + v_t + \varepsilon_{it} \tag{4}$$

$OFDI\_ETS_{it}$ represents a joint setup composed of OFDI and ETS dummies. Specifically, $OFDI\_ETS_{it}$ takes a value of one if the firm, indexed by i, has a high level of OFDI and is included under China's ETS. To construct the OFDI dummy, we compare the firm's OFDI to the sample median. If the firm's OFDI exceeds the median, the dummy is set to one; otherwise, it is set to zero. Likewise, the ETS dummy is set to one if the firm is part of China's ETS in the given year; otherwise, it is set to zero. The interpretation of other variables follows the same structure as described in Eq. (1).

Yet implementing the quasi-natural experiment necessitates a common trend test. In other words, there were no noticeable variations in the carbon risk of the pilot and non-pilot groups before the policy shock.

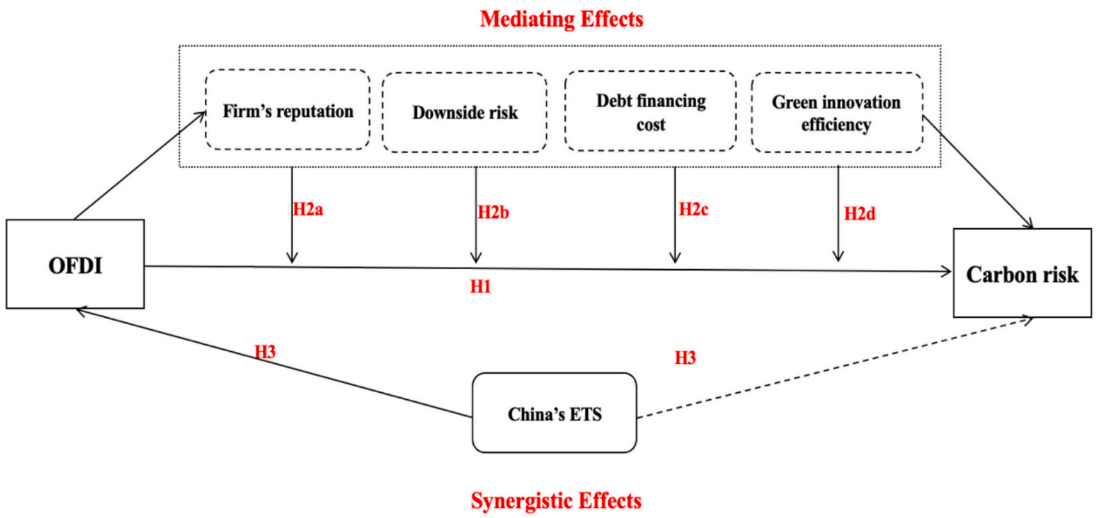

Fig. 2. Theoretical framework.

The common trend to test in our exercise follows the fashion below:

$$CR_{it} = \alpha + \sum_{\tau\{-6,\dots,0,\dots,+7\}} \phi_\tau OFDI\_ETS_{it} + \gamma X_{it} + u_i + v_t + \varepsilon_{it} \tag{5}$$

where $\sum_{\tau\{-6,\dots,0,\dots,+7\}} \phi_\tau OFDI\_ETS_{it}$ denotes a collection encompassing temporal dummies, signifying China's ETS policy shock in the τth phase. We use the parameter ϕ_τ to capture the relevant effects. Notably, $\phi_{-6,\dots,-1}$ coefficients should be strictly insignificant, implying no potentially substantial variations in the pilot and non-pilot groups. Instead, the estimates of $\phi_{0,\dots,+7}$ should be salient after the ETS enforcement.

3.2. Variable descriptions

Dependent variable: Carbon risk. Following Liêu et al. (2024a) and Tao and Wu (2025), we use carbon emission share (% of gross revenues) to measure carbon risk at the firm level. The higher the value, the greater the firm's exposure to risk. Notably, corporate emissions are the sum of four components following the seminal works of Li et al. (2024b), including emissions from fugitive and combustion, production process, waste, and land-use conversion (i.e., conversion of forests to industrial land). By doing so, we can compute emissions records for each firm and thus the carbon risk metric.

Core explanatory variable: OFDI. Cheng and Su (2024) asserted that OFDI can be perceived as economic engagement in which a firm exercises control over the operation and management of an offshore company. A transboundary investment by an enterprise in a host nation will be counted as an OFDI by the enterprise if the enterprise owns at least 10 % of the investment shares. We proxy OFDI by leveraging the total registered capital of entities, including "subsidiaries of listed firms," "joint ventures of listed firms," and "associates of listed firms," where these entities have a controlling interest of over 10 % and are registered outside mainland China. OFDI is converted to natural logarithms for empirical analyses.

Firm-level characteristic variables. Following previous studies (Che et al., 2024; Tao et al., 2023a), we select several firm-level characteristic indicators to isolate the confounding influences that may affect carbon risk, including firm age, which is proxied by the logarithmic difference between the year of firm's listing and the financial years. Cash flow represents the revenue generated before exceptional projects, plus amortization and depreciation, divided by gross assets. Return on asset is proxied by net profit ratio (% of gross assets). The leverage ratio represents the current asset ratio (% of current liabilities). We also control for the shareholding ratio (% of largest stakeholder). Return on equity expresses the net profit ratio (% of average stakeholders' equity). The firm's leverage ratio is gauged by the gross liability ratio (% of gross assets). Further, the firm's growth is also considered, representing the annual income growth rate. Lastly, Tobin's Q is selected as a regressor, measured by the market value of the firm's stock divided by gross capital cost.

Mediating variables. Our exercise has four mediators, including the firm's reputation, downside risk, debt financing cost, and green innovation efficiency. According to Ahmad et al. (2003), we select auditors from the Big Four global accounting firms as a surrogate for the firm's reputation mechanism. If a firm's auditor is from the Big Four global accounting firms, then firm reputation equals one, implying a favorable reputation; otherwise, a zero value is recorded. As Miller and Leiblein (1996) suggested, Eq. (6) is applied to evaluate the decline in firms' operations. Further, corporate debt financing cost represents the short- and long-run bonds and debt ratio (% of gross assets) (Huang et al., 2024). Lastly, the proportion of corporate innovation outputs, including green invention, design patents, and utility models, to gross R&D input is applied to represent green innovation efficiency (Che et al., 2024).

$$DR_{it} = \sqrt{0.2^* \sum_{t=1}^{5} \left(ROA_{i,t-1} - \overline{ROA}_{i,t}\right)^2} \tag{6}$$

where DR_{it} represents the downside risk for the ith firm at year t; $ROA_{i,t-1}$ is the ROA for ith at year $t\text{-}1$; $\overline{ROA}_{i,t}$ indexes the average ROA of all firms in the identical industry as firm i in year $t\text{-}1$.

3.3. Data

We leverage a firm-level dataset to evaluate the intrinsic link between OFDI and carbon risk. The study period is from 2008 (i.e., the global financial crisis and onwards) to 2022. The raw data is extracted from multiple sources, including WIND, CSMAR, the Catalogue of Overseas Investment Enterprises (Institutions) disclosed by the Ministry of Commerce, Related Party Transactions of Chinese Listed Corporates, annual reports, and social responsibility reports of listed firms. We process the raw data before running the model. First, all firms tagged "ST," "*ST," and "PT" have been excluded; simultaneously, financial sectors have also been removed due to different business structures, financial structures, and regulatory environments. Second, we winsorize all firm-level characteristic indicators at the 1th percentile to isolate outliers. Lastly, the annual exchange rate data is sourced from the World Bank, which is applied to convent the OFDI data into RMB units.

Table 1 delivers the statistical description of each indicator. The average CR indicates that, on average, firms in the sample have a

Table 1
Statistical descriptions.

Variable	Abb.	Mean	Std. Dev.	Min	Max
Carbon risk	CR	0.036	0.042	0.000	4.164
Outward foreign direct investment	OFDI	10.376	2.380	−1.139	23.028
Firm age	FA	2.884	0.350	0.000	4.174
Cash flow	CF	0.202	0.141	0.002	0.953
Return on asset	ROA	0.004	0.031	−2.961	0.745
Largest stakeholder ratio	TOP1	5.465	8.061	0.000	59.500
Return on equity	ROE	0.001	0.007	−0.530	0.169
Leverage ratio	LR	0.007	0.031	−0.165	1.985
Income growth rate	GROW	0.002	0.005	−0.010	0.188
Tobin Q	TQ	0.197	0.162	0.062	7.521

relatively low carbon risk, but the standard deviation of 0.042 suggests significant variability across firms. The maximum value of 4.164 highlights that some firms are exposed to substantially higher carbon risks, possibly due to higher emissions, stricter regulatory environments, or operational inefficiencies. Firms with higher carbon risk might face increased costs related to carbon taxes, compliance, and potential reputational damage, which can impact their long-term sustainability and profitability. A relatively high average OFDI indicates that, on average, firms are actively engaging in outward investment, which could be driven by motives such as market expansion, resource acquisition, or strategic alliances. The wide range (from −1.139 to 23.028) and the standard deviation 2.380 suggest considerable differences in OFDI activities among firms. A negative OFDI value might indicate disinvestment or the reversal of previous investments. The strategic decisions surrounding OFDI are crucial as they can affect firm growth, risk diversification, and access to new markets, influencing overall corporate performance.

4. Empirical results

4.1. Benchmark estimates

Table 2 presents the correlation coefficients between variables. Panel A shows that the correlation coefficients between all explanatory indicators are low; simultaneously, none are >0.8, confirming a low correlation between regressors. Second, Panel B delivers that all VIF values are low, with an average sample VIF of 1.16. The above findings imply no multicollinearity. Third, the preliminary estimate uncovers that the correlation between OFDI and corporate carbon risk remains salient and harmful, substantiating the proactive role of OFDI in lowering carbon risk.

Table 3 presents the benchmark results. Column (1) reports the OLS estimates, revealing a negative correlation between OFDI and carbon risk, even without firm-specific controls and fixed effects. In column (2), where we include all covariates and control for firm- and year-fixed effects, the adverse impact of OFDI on carbon risk persists and remains significant at the 1 % level. Column (3) further reinforces these findings by incorporating robust standard errors to account for heteroscedasticity. Notably, the OFDI coefficient remains consistent in significance and direction, with an estimated value of −0.0006. This indicates that OFDI contributes to reducing carbon risk at the firm level.

For the firm-level characteristic regressors, mature firms might have a more significant incentive to maintain their reputation, including environmental standards. For example, Zhang et al. (2019) uncovered that older firms tend to substantially reduce expenditure for ecological protection, evidenced by Qi et al. (2024), emphasizing that firm age

Table 3
Benchmark results.

	(1)	(2)	(3)
	OLS	FE	FE
Dep. Var.	CR	CR	CR
OFDI	−0.0003**	−0.0006**	−0.0006***
	(0.000)	(0.000)	(0.000)
FA		−0.0127**	−0.0127**
		(0.006)	(0.005)
CF		0.0324***	0.0324***
		(0.005)	(0.005)
ROA		−0.3068***	−0.3068
		(0.092)	(0.335)
TOP1		−0.0003***	−0.0003
		(0.000)	(0.000)
ROE		−0.5949***	−0.5949**
		(0.085)	(0.270)
LR		0.2058***	0.2058***
		(0.040)	(0.035)
GROW		0.2820***	0.2820*
		(0.098)	(0.161)
TQ		−0.0125***	−0.0125***
		(0.004)	(0.002)
_cons	0.0389***	0.0753***	0.0753***
	(0.002)	(0.018)	(0.015)
Firm FE	×	√	√
Year FE	×	√	√
Obs.	15,064	12,808	12,808
R-squared	0.0003	0.1523	0.1523

Notes: *, $p < 0.1$, **, $p < 0.05$, ***, $p < 0.01$; robust-heteroscedasticity standard errors are listed in ().

Table 2
Correlation matrix and VIF tests.

Panel A: Correlation matrix

	CR	OFDI	FA	CF	ROA	TOP1	ROE	LR	GROW	TQ
CR	1.000									
OFDI	−0.018**	1.000								
FA	−0.043***	0.092***	1.000							
CF	0.084***	0.091***	−0.030***	1.000						
ROA	−0.012	0.044***	−0.017**	0.044***	1.000					
TOP1	−0.015*	0.001	0.043***	0.011	0.008	1.000				
ROE	−0.071***	0.030***	−0.016**	0.043***	0.521***	0.020**	1.000			
LR	0.028***	0.083***	−0.030***	0.151***	−0.629***	−0.031***	0.071***	1.000		
GROW	0.051***	0.012	−0.109***	0.180***	0.068***	−0.003	0.058***	0.042***	1.000	
TQ	0.007	−0.047***	0.011	0.182***	−0.302***	0.001	−0.001	0.333***	0.001	1.000

Panel B: VIF test

	CR	OFDI	FA	CF	ROA	TOP1	ROE	LR	GROW	TQ
VIF		1.05	1.03	1.15	1.68	1.01	1.48	1.12	1.07	1.09
1/VIF		0.95	0.97	0.87	0.60	0.10	0.68	0.89	0.94	0.92

Notes: *, $p < 0.1$, **, $p < 0.05$, ***, $p < 0.01$.

mitigates SO_2 intensity. Second, the positive coefficient for cash flow (0.0324) indicates that firms with higher cash flows tend to have higher carbon risks. This might be because firms with abundant cash flows have more resources to engage in activities that could increase their carbon emissions, such as expanding production capacity. Third, ROA adversely relates to carbon risk, suggesting profitability could theoretically reduce carbon risk as more profitable firms might have more resources to invest in carbon-reducing technologies. The firm's ROE and Tobin's Q further support this – for example, the corresponding estimates of these two financial metrics remain salient and harmful, with an estimated −0.5949 and − 0.0125, respectively, passing the 5 % significance level test. Further, the negative correlation between TOP1 and carbon risk designates that having a dominant shareholder might reduce carbon risk, potentially due to more centralized and effective decision-making that could prioritize long-term sustainability. However, firms with higher debt levels tend to have higher carbon risks. For example, highly leveraged firms face more significant financial pressures and might prioritize short-term financial goals over long-term environmental sustainability. This viewpoint has been validated by Cui et al. (2023), showing that financially constrained firms encounter exorbitant pollution-control spending, thereby discouraging innovations. Lastly, in their quest for profitable gains, firms might chase innovations that yield labor and capital returns but harm the environment (Zhang et al., 2018). Consequently, this can induce excessive exploration and squandering of resources and environmental deterioration, increasing carbon risk, as Acheampong and Opoku (2023) suggested.

4.2. Robustness checks

We perform multiple robustness checks to verify the creditability of hypothesis 1. Essentially, Liêu et al. (2024a) suggested two focal measurements for quantifying carbon risk at the firm level. Hence, we adopt the ratio of corporate emissions to gross assets to gauge the firm-level carbon risk index. Then, Eq. (1) is applied to reevaluate OFDI's impacts on corporate carbon risk, as listed in column (1) in Table 4. OFDI generates pronounced effects on carbon risk; simultaneously, its estimate is −0.0026, passing the 1 % significance level test.

Second, since corporate carbon emissions comprise four categories, we check whether OFDI adversely affects carbon risk by lowering emission components. Columns (2)–(5) showcase the relevant estimates, uncovering that OFDI's estimates run from −0.0016 to −0.0083, with all coefficients passing the significance level test and remaining harmful. In other words, OFDI mitigates carbon risks by curtailing different carbon risk metrics at the firm level.

Third, carbon emissions have substantial accumulation effects (Tao et al., 2023b). We thus leverage the Generalized Method of Moments (GMM) for empirical estimation. Column (6) indicates that the lagged carbon risk variable retains a positive coefficient, remaining statistically significant at the 10 % level, suggesting accumulation effects. The OFDI coefficient, while showing a slight reduction in significance, still holds statistical significance at the 10 % threshold, with a value of −0.0030. Diagnostic checks for the model reveal the presence of first-order serial autocorrelation, though no higher-order autocorrelation is detected. Additionally, the Hansen test suggests that the instruments employed in the model are valid, as indicated by the *p*-value, which is not statistically significant.

Lastly, leveraging a two-stage least squares (2SLS) approach, we handle potential endogeneity concerns. Endogeneity can arise from factors such as reverse causality, omitted variable bias, and measurement errors. We introduce an instrument based on the interaction between the history of modern port openings in China (MP) and the domestic money supply (M3). We use a monthly domestic broad money index as a proxy for M3, setting 2008 as a benchmark. The period from a province's first port opening until 1949 marks the beginning of modern port accessibility, providing a historical context for the instrument.

On the one hand, shifts in the domestic money supply can influence corporate decisions to invest abroad, leading to increased OFDI (Russ, 2007). These effects often occur through exchange rate fluctuations, where greater currency volatility creates opportunities for multinational corporations to relocate production to low-cost regions (Feng et al., 2022). Additionally, firms may use OFDI to shield themselves from the adverse effects of exchange rate volatility on profitability (Itagaki, 1981). Moreover, a province's historical engagement in international trade, primarily facilitated by port access, fosters greater human capital accumulation and enhances the ability to adopt foreign technologies (Dong et al., 2024). Therefore, these factors confirm the relevance of the instrument. The central bank largely determines the money supply, making it exogenous to both firms' overseas investment decisions and provincial intensity levels within the same year (Dong et al., 2024). Additionally, port opening policies are shaped by political and economic factors, unrelated to individual firm decisions, further ensuring the exogeneity of the instrument.

Columns (7) & (8) in Table 4 show the outcomes of the first- and second-stage results, respectively. The findings illustrate a significant relationship between the instrument and OFDI, with a coefficient of 0.6211, passing the 1 % significance level test. Further column (8)

Table 4
Robustness tests.

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
	FE	FE	FE	FE	FE	GMM	1st stage	2nd stage
Dep. Var.	CR	CR1	CR2	CR3	CR4	CR	LNMP*M3	CR
OFDI	−0.0036***	−0.0083**	−0.0016***	−0.0019**	−0.0018**	−0.0030**		−0.0008*
	(0.001)	(0.003)	(0.001)	(0.001)	(0.001)	(0.001)		(0.000)
L.CR						0.0095*		
						(0.005)		
LNMP*M3							0.6211***	
							(0.018)	
Controls	√	√	√	√	√	√	√	√
Firm FE	√	√	√	√	√		√	√
Year FE	√	√	√	√	√		√	√
_cons	0.4858***	0.9898***	0.1983***	0.2186***	0.2064***	0.0499***		/
	(0.083)	(0.195)	(0.039)	(0.048)	(0.044)	(0.014)		
Obs.	12,808	12,808	12,808	12,808	12,808	10,345		12,808
R-squared	0.5825	0.1543	0.1510	0.1482	0.1604			0.0206

Notes: *, $p < 0.1$, **, $p < 0.05$, ***, $p < 0.01$; robust-heteroscedasticity standard errors are listed in (). The underlying tests for column (6) are: AR(1) = −9.90 (*p*-value = 0.000), AR(2) = 0.26 (*p*-value = 0.722), Hansen test = 19.16 (*p*-value = 0.118). Moroever, CR1, CR2, CR3, and CR4 refer to emissions from fugitive and combustion, emissions from production processes, emissions from waste, and emissions from land-use change (conversion of forests to industrial land). The first-stage F statistic for the 2SLS estimation is 1878.682, which exceeds the threshold of 10, indicating no weak instrument concerns. Simultanouesly, the Hansen J statistic is 0.000, suggesting no overidentification concerns. These diagnostic tests confirm the validity of the 2SLS results.

indicates a negative connection between OFDI and carbon risk. Overall, both the benchmark and robustness tests support our Hypothesis 1.

5. Mechanism investigations

5.1. Mediating analysis

5.1.1. The mediating role of corporate reputation

Column (1) of Table 5 assesses the relationship between OFDI and corporate reputation (FR), with a coefficient of 0.0046, statistically salient at the 5 % level. This suggests that OFDI positively influences corporate reputation. In column (2), both OFDI and corporate reputation are included. The results indicate that corporate reputation has a negative coefficient of −0.0038, significant at the 1 % level ($p < 0.01$), and OFDI continues to affect carbon risk, with a coefficient of −0.0006 negatively. These findings imply that OFDI reduces carbon risk by strengthening corporate reputation, supporting Hypothesis 2a.

Signaling theory provides a fundamental framework for understanding how firms communicate their quality and reliability to external stakeholders, particularly in markets characterized by information asymmetry (Spence, 1973). In the context of OFDI, firms that invest abroad often encounter stricter regulatory environments and heightened scrutiny from international stakeholders. Firms may engage reputable global auditors to navigate these challenges and signal their commitment to ethical practices, including environmental responsibility. The selection of a Big Four auditor serves (Deloitte, EY, KPMG, and PwC) as a credible signal of the firm's commitment to high-quality financial reporting and adherence to international standards (Krishnan and Zhang, 2019). This credibility extends beyond financial integrity to encompass broader governance and sustainability practices, enhancing the firm's overall reputation.

Firms undertaking OFDI are typically exposed to diverse regulatory landscapes, which often include stringent environmental regulations and greater stakeholder expectations regarding sustainability (Barker, 2010). These firms, aiming to maintain or enhance their access to international markets and capital, have strong incentives to build and protect reputational capital. Reputational capital refers to the perceived value of a firm's brand and trustworthiness in the eyes of investors, customers, and regulators. By employing reputable auditors, firms signal their commitment to transparency and adherence to high standards, which can reduce perceived risks. Reputable auditors play a crucial role in enhancing a firm's environmental performance by ensuring the accuracy and reliability of sustainability disclosures. The involvement of a Big Four auditor is often associated with higher-quality environmental reporting and greater adherence to international sustainability standards (Simnett et al., 2009). When firms disclose their environmental impact accurately and transparently, they are more likely to adopt rigorous carbon management practices, which directly contribute to carbon risk reduction.

Furthermore, the reputation of these auditors extends to their ability to influence firm behavior. Firms audited by reputable global auditors are often held to higher standards, not only in financial reporting but also in their ESG practices. This is because the reputational risk for Big Four auditors is substantial if they are found to have certified misleading or substandard reports. Thus, firms are more likely to adhere to stricter environmental standards to maintain their relationship with these auditors, leading to improved environmental performance and reduced carbon risk.

5.1.2. The mediating role of downside risk

Column (3) in Table 5 documents the correlation between OFDI and downside risk (DR), consolidating the pivotal role of OFDI in mitigating downside risk – for example, OFDI's coefficient remains negative at the 1 % significance level. Further, column (4) shows that downside risk and OFDI contribute robustly to carbon risk alleviation. Therefore, the mediating effect of downside risk is verified.

In the portfolio theory, diversification reduces a portfolio's overall risk by combining assets that do not perfectly correlate with each other (Markowitz, 1952). Similarly, OFDI allows firms to tap into multiple markets with varying economic cycles, regulatory environments, and consumer behaviors. When one market experiences a downturn, gains in another can offset potential losses, stabilizing overall returns and reducing downside risk. Elango and Sethi (2007) stated that multinational enterprises (MNEs) engaging in OFDI experience lower overall volatility in their returns than domestic firms. This is because the income streams generated from diverse geographical locations smooth out the fluctuations in earnings, thereby mitigating downside risk. Further, exposure to different markets and consumer preferences can drive firms to innovate, creating products and services more resilient to market changes. This innovation not only strengthens the firm's competitive position but also reduces the likelihood of significant downturns in financial performance. For example, Cantwell and Mudambi (2005) asserted that MNEs often achieve superior innovation outcomes due to their ability to integrate knowledge from various international

Table 5
Mediating analysis results.

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Dep. Var.	FR	CR	DR	CR	DFC	CR	GIE	CR
OFDI	0.0046**	−0.0006**	−0.0041***	−0.0007***	−0.0068**	−0.0006**	0.0014*	−0.0012***
	(0.002)	(0.000)	(0.001)	(0.000)	(0.003)	(0.000)	(0.001)	(0.000)
FR		−0.0038***						
		(0.001)						
DR				−0.0109**				
				(0.006)				
DFC						0.0047***		
						(0.001)		
GIE								−0.0047**
								(0.002)
Controls	√	√	√	√	√	√	√	√
Firm FE	√	√	√	√	√	√	√	√
Year FE	√	√	√	√	√	√	√	√
_cons	0.6952***	0.0780***	0.4054***	0.0797***	0.2307	0.0743***	0.0978	0.0941***
	(0.142)	(0.015)	(0.036)	(0.014)	(0.176)	(0.015)	(0.061)	(0.014)
Obs.	12,808	12,808	12,786	12,786	12,808	12,808	9199	9199
R-squared	0.6237	0.1531	0.8229	0.1528	0.4731	0.1544	0.6703	0.3888

Notes: *, $p < 0.1$, **, $p < 0.05$, ***, $p < 0.01$; robust-heteroscedasticity standard errors are listed in (). The abbreviations "FR," "DR," "DFC," and "GIE" stand for firm reputation, downside risk, debt financing expenses, and green innovation effectiveness, respectively. The results in Table 5 are estimated based on the two-way fixed effects regression model.

subsidiaries. This innovation capability enhances the firm's adaptability and reduces downside risk, as the firm can respond quickly to market changes and maintain steady returns. At the same time, when firms are confronted with unpredictable risks, they are more likely to engage in green innovation, thereby mitigating carbon risk (Liêu et al., 2024a). Therefore, Hypothesis 2b remains reliable.

5.1.3. The mediating role of debt financing cost

Similarly, columns (6) & (7) confirm the mediating effect of debt financing cost (DFC) because OFDI substantially lessens debt financing cost. However, such cost is expected to tighten carbon risk, with an estimated 0.0047; simultaneously, OFDI remains negative and salient. These estimates support Hypothesis 2c.

Firms engaged in OFDI often have better access to international capital markets, where they can tap into a broader range of financing options. This access can lead to lower financing costs compared to domestic-only firms. According to the Capital Structure theory, firms with access to international markets can leverage different financing structures and interest rates, optimizing their capital costs. Desai et al. (2004) provided evidence that multinational firms benefit from the ability to arbitrage different capital markets, thus reducing their overall cost of capital. From an improved creditworthiness perspective, engaging in OFDI allows firms to diversify their operations across various geographical regions, spreading and reducing their overall risk. According to the Portfolio theory, diversification reduces the unsystematic risk associated with a firm's operations. When a firm's revenue streams are diversified through international operations, it becomes less vulnerable to domestic economic fluctuations, enhancing its creditworthiness. Creditors perceive these firms as safer investments due to their ability to generate stable cash flows from multiple markets, leading to lower debt financing costs. For example, Alfaro and Chen (2012) held that multinational corporations enjoy lower borrowing costs due to reduced risk exposure.

Firms with higher debt costs may find it more challenging to comply with environmental regulations, increasing their risk of facing penalties or market backlash. The higher the debt servicing burden, the less likely a firm is to allocate resources toward ensuring compliance with evolving carbon regulations. This can result in fines, legal challenges, or loss of market share, all of which contribute to an elevated carbon risk. The Regulatory Risk Theory suggests that firms with limited resources due to high debt are more exposed to regulatory risks, which can be particularly damaging in industries with heavily regulated carbon emissions.

5.1.4. The mediating role of green innovation efficiency

Columns (7) & (8) deliver the estimates about the mediating role of green innovation efficiency (GIE). For example, OFDI boosts green innovation efficiency. Furthermore, the resulting bonus (i.e., the enhanced efficiency gains) helps reduce carbon risk. Hence, Hypothesis 2d is supported.

OFDI facilitates the acquisition of advanced technologies and innovative practices from more developed economies. When firms invest abroad, they often engage in joint ventures, mergers, or acquisitions with foreign companies that possess superior technological capabilities. This interaction leads to knowledge spillovers, where firms absorb new techniques and methodologies, which can be pivotal in improving their green innovation efficiency. For instance, accessing cutting-edge technologies related to renewable energy can enhance a firm's ability to innovate in these areas, leading to more efficient and sustainable practices. The absorptive capacity theory supports that firms with the capability to recognize, assimilate, and apply external knowledge are better positioned to enhance their innovation outcomes (Cohen and Levinthal, 1990). For example, Wang et al. (2023a) demonstrated that Chinese firms with significant OFDI activities exhibited higher levels of green practices, resulting in enhanced green efficiency. Likewise, Shi et al. (2023) consolidated the proactive role of OFDI in empowering green innovation in China's MNEs. Unsurprisingly, green innovation has been demonstrated as an essential enabler for facilitating low-carbon transition (Che et al., 2024).

5.2. Heterogeneity analysis

The sample is categorized according to the firm's attributes, ESG ratings, and financial constraints. The heterogeneity analysis is presented in Table 6. First, columns (1) & (2) give the estimates based on state-owned enterprises (SOEs) and non-SOEs. OFDI remains negative but insignificant in both SOEs and non-SOEs. However, the mitigation effect of OFDI on carbon risk is greater in non-SOEs regarding the absolute magnitude. SOEs usually face different incentives compared to non-SOEs. Their investment decisions are often guided by broader socio-economic goals and political considerations rather than purely financial objectives. This can lead to a more conservative approach toward OFDI, as SOEs might prioritize stability and compliance with national regulations over aggressive international expansion. Consequently, their ability to mitigate carbon risk through OFDI might be limited. In contrast, non-SOEs are driven more by profit maximization and market competitiveness. They may be more flexible and responsive to market signals, which includes leveraging OFDI to access advanced technologies and greener practices. This increased flexibility can enhance the impact of OFDI on reducing carbon risk, making the mitigation effect more pronounced in non-SOEs.

Second, we divide the sample into subgroups by checking whether a firm's ESG rating is $>$ than the sample median. Results demonstrate that OFDI's mitigation effects are more pronounced in firms with a high ESG rating; the relevant effect remains insignificant. Firms with high ESG ratings typically exhibit more vital environmental stewardship, social responsibility, and governance practices. These firms are generally more committed to sustainable practices in their domestic and international operations. When these firms engage in OFDI, they carry high ESG standards into their international ventures. This practice can lead to more stringent environmental controls, energy-efficient technologies, and sustainable practices across their global operations. The high ESG-rated firms are likely to implement advanced technologies and management practices that minimize carbon emissions more effectively than their low ESG-rated counterparts. This alignment with high ESG standards magnifies the positive impact of OFDI on reducing carbon risk. Specifically, Lioui and Sharma (2012) stated that high-ESG firms often allocate capital toward sustainable practices that directly lower emissions.

Third, we adopt the FC index to categorize the sample into subgroups: high financial constraints vs. low ones, as listed in columns (5) & (6). Our results confirm that OFDI's effect on carbon risk is more salient in firms with low financial constraints. In contrast, OFDI tends to exacerbate such a risk in firms with high financial constraints. Essentially, firms with low financial constraints have greater access to capital and resources, enabling them to invest in high-quality, innovative technologies. These firms can afford to implement advanced carbon mitigation strategies and compliance measures, leading to more pronounced reductions in carbon risk. They are better positioned to undertake significant OFDI projects aligned with sustainability goals and can absorb the associated costs without financial strain.

Conversely, firms with high financial constraints face limitations in accessing necessary capital for international investments. These firms may struggle to finance advanced environmental technologies or comply with stringent regulations abroad. As a result, their OFDI may not be as effective in reducing carbon risk. The inability to invest in state-of-the-art technologies or adhere to rigorous environmental standards can lead to higher carbon emissions and greater carbon risk.

6. Further discussion

As described earlier, we investigate whether OFDI coupled with China's ETS can substantially alleviate carbon risk by leveraging a quasi-

Table 6
Heterogeneity analysis results.

	(1)	(2)	(3)	(4)	(5)	(6)
Dep. Var.	CR	CR	CR	CR	CR	CR
	Firm's attribute		ESG ratings		Financial constraints	
	SE	Non-SOE	High	Low	High	Low
OFDI	−0.0002	−0.0008	−0.0002*	−0.0005	0.0012	−0.0014***
	(0.000)	(0.001)	(0.000)	(0.000)	(0.001)	(0.000)
Controls	√	√	√	√	√	√
Firm FE	√	√	√	√	√	√
Year FE	√	√	√	√	√	√
_cons	0.0776***	0.0613*	0.0831***	0.0639**	0.0017	0.0560***
	(0.015)	(0.033)	(0.014)	(0.029)	(0.030)	(0.015)
Obs.	5827	6974	6498	5616	5604	6741
R-squared	0.3763	0.1472	0.4614	0.1401	0.2312	0.4129

Notes: *, $p < 0.1$, **, $p < 0.05$, ***, $p < 0.01$; robust-heteroscedasticity standard errors are listed in (). The results in Table 6 are estimated based on the two-way fixed effects regression model.

natural experiment model. We first use Eq. (5) to scrutinize the common trend test. Expressly, Fig. 3 confirms the efficacy of the common trend test. The estimates show that all coefficients remain insignificant before policy shock, yet the relevant estimates remain negative and significant after the policy placement.

The results from OLS, FE, and robust-FE estimations, corresponding to columns (1) through (3) of Table 7, are presented. Notably, the interaction between OFDI and China's ETS in reducing carbon risk remains robust under OLS estimation, as seen in column (1), with a coefficient of −0.0018. Column (2) reports outcomes after adjusting for all firm-level characteristics, showing a slight increase in the mitigation effect of OFDI_ETS. However, its significance diminishes slightly and remains significant at 5 %. When robust standard errors are considered, the OFDI_ETS coefficient continues to exhibit a significantly negative relationship. These findings suggest that combining OFDI and the ETS effectively and consistently reduces carbon risk for firms operating in China. As a result, our Hypothesis 3 is valid.

We carry out additional tests to validate the robustness of the results in Table 7. First, the placebo test is considered because other potential factors, known as unobservable factors, may confound the estimates. Specifically, we design a random experiment by selecting cities involved in the ETS (i.e., $OFDI\_ETS^{false}$) and randomly determining the policy shock (i.e., $Policy^{random}$). The analysis proceeds using the setup from column (3) of Table 3, and the validity of the outcomes is assessed based on the predicted coefficients from the benchmark model. The process is carried out 500 times to construct the distribution of the estimated coefficients. If this distribution is centered around zero under random assignment, it suggests that important variables have not been excluded. As shown in Fig. 4, the coefficient distribution clusters near zero, indicating that no key factors are missing from the model, thus confirming the robustness of the results.

We apply a propensity score matching process combined with a quasi-natural experiment design to determine whether our previous findings are robust after addressing self-selection bias concerns. Following Tao et al. (2022), the *K*-nearest matching module with a (1:2) setup is considered. Precisely, we treat all organizational indicators as covariates. Through this, we should first check the reasonability of the matching process. Fig. 5 illustrates substantial variations in the pre-

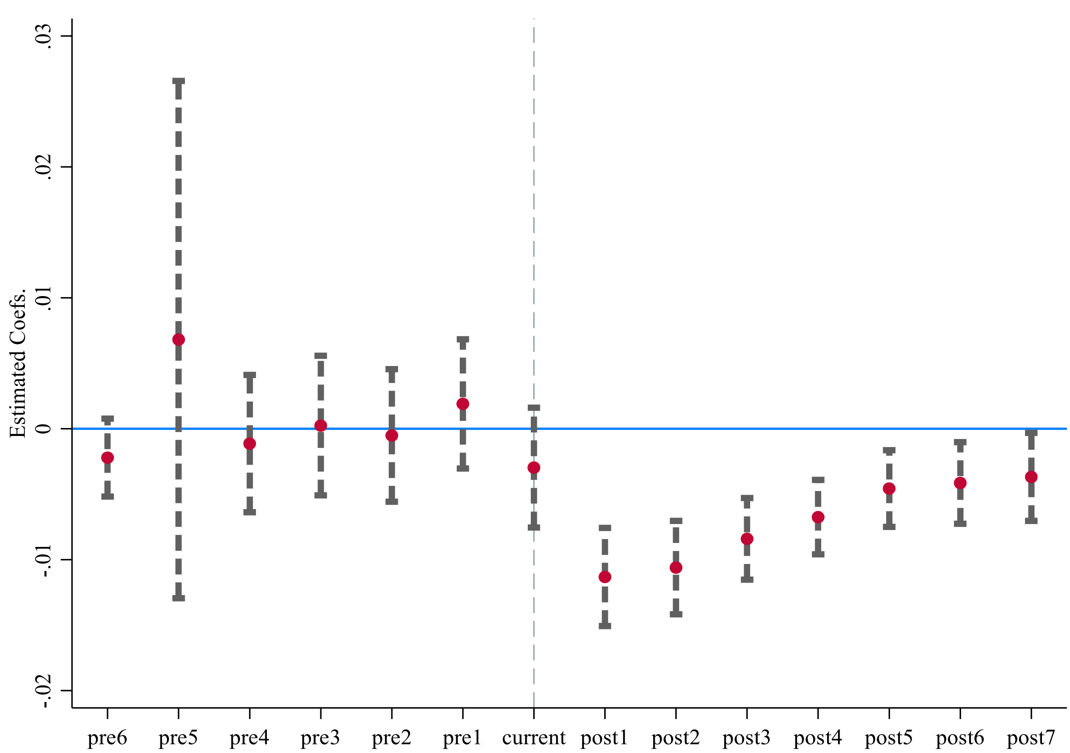

Fig. 3. Common trend test.

Table 7
Benchmark results: Synergestic effect between OFDI and the ETS.

	(1)	(2)	(3)
	OLS	FE	FE
Dep. Var.	CR	CR	CR
OFDI_ETS	−0.0018***	−0.0029**	−0.0029***
	(0.001)	(0.001)	(0.001)
FA		−0.0132**	−0.0132**
		(0.006)	(0.005)
CF		0.0325***	0.0325***
		(0.005)	(0.005)
ROA		−0.3104***	−0.3104
		(0.092)	(0.334)
TOP1		−0.0003***	−0.0003
		(0.000)	(0.000)
ROE		−0.5960***	−0.5960**
		(0.085)	(0.269)
LR		0.2055***	0.2055***
		(0.040)	(0.036)
GROW		0.2860***	0.2860*
		(0.098)	(0.162)
TQ		−0.0125***	−0.0125***
		(0.004)	(0.002)
Firm FE	×	√	√
Year FE	×	√	√
_cons	0.0364***	0.0716***	0.0716***
	(0.001)	(0.018)	(0.014)
Obs.	15,064	12,808	12,808
R-squared	0.0004	0.1524	0.1524

Notes: *, $p < 0.1$, **, $p < 0.05$, ***, $p < 0.01$; robust-heteroscedasticity standard errors are listed in ().

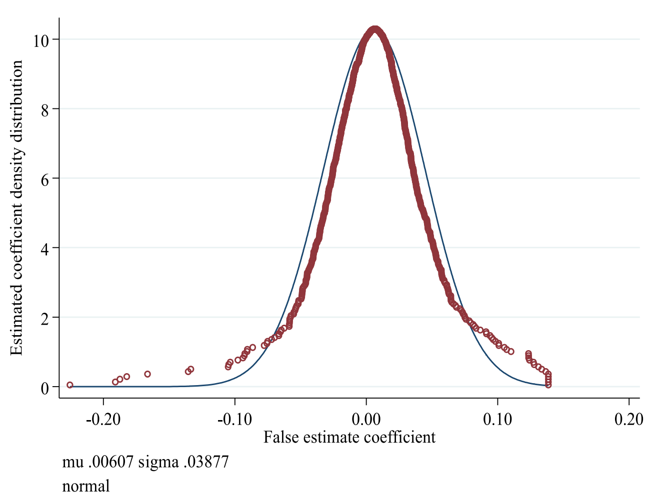

Fig. 4. Placebo test.

matching process, especially for TOP1. In contrast, all standardized % biases have been tremendously alleviated after the *K*-nearest matching process. Hence, our matching process is reliable. Column (1) in Table 8 presents the quasi-natural experiment test for post-matching, showing that OFDI_ETS remains remarkable at the 5 % significance level after handling possible selection bias.

Baker et al. (2022) opined that the quasi-natural experiment estimates may be subject to estimation bias because of heterogeneous treatment effects. Precisely, β^{true} in Eq. (4) can be perceived as the weighted sum of the impacts of all piloted firms in our exercise, with the following specification:

$$\beta^{true} = E\left(\sum_{\{\Theta,t\}:treated_{\Theta,t}=1} \varpi_{\Theta,t}\Delta_{\Theta,t}\right)\# \tag{6}$$

where $\varpi_{\Theta,t}$ and $\Delta_{\Theta,t}$ represent the weight and treatment impact of the Θ-*th* experimental cities in year *t*. Notably, the weight, $\varpi_{\Theta,t}$, even can be damaging. However, as de Chaisemartin and D'Haultfœuille (2020) stated, although the weight's sum of the treatment effect equals one, the actual estimate remains harmful due to the negative weights. In other words, the previous estimate may not be robust if negative weights account for a sizeable proportion. Instead, de Chaisemartin and D'Haultfœuille (2020) suggested a heterogeneity check for robustness. Precisely, the reliability of the heterogeneity test is higher when the heterogeneity processing robustness index approaches one, whereas an index closer to zero indicates reduced robustness. This study employs this method to evaluate the benchmark regression model. The findings suggest that the annual treatment effect for all pilot cities, denoted as $\Delta_{\Theta,t}$, is optimistic. Furthermore, the heterogeneity treatment estimation is 0.997, demonstrating that the heterogeneity treatment effect does not significantly impact the estimation results. Column (2) validates the role of OFDI in mitigating carbon risk. Therefore, the results can be considered robust.

Our quasi-natural experiment outcomes deliver the following interpretations. OFDI allows firms to access and adopt advanced technologies and best practices from more developed markets. When these firms engage in OFDI, they often seek to integrate these innovations into their operations, which can significantly improve their environmental performance. This integration of cutting-edge technologies can reduce carbon emissions by enhancing energy efficiency and enabling cleaner production processes. China's ETS further amplifies this effect by imposing a cost on carbon emissions, encouraging firms to adopt lower-carbon technologies to minimize compliance costs under the cap-and-trade scheme (Tao et al., 2022). The combination of OFDI and ETS can thus create a powerful synergy. While OFDI facilitates the transfer of clean technologies, the ETS incentivizes their adoption and continuous improvement, directly lowering carbon risk at the firm level.

In addition, firms that engage in OFDI are often exposed to stricter environmental regulations and standards in host countries, which can lead to improved managerial practices, especially in carbon accounting and sustainability reporting. These practices enable firms to monitor their carbon emissions more accurately and manage them effectively. These firms benefit from a regulatory framework that rewards precise carbon management when coupled with the ETS. The ETS's requirement for accurate emissions data pushes firms to develop robust internal controls and practices, reducing their carbon risk. This argument aligns with the findings by Yu et al. (2021), asserting that firms subject to China's ETS and with experience in OFDI demonstrated improved transparency and accountability in their carbon disclosures, lowering their carbon risk. Fundamentally, our conclusions align with Ma et al. (2023), designating that two-way FDI (i.e., OFDI and inward FDI) coupled with China's ETS help curtail China's emissions, with the logical chain of corporations encountering stringent environmental supervision → lowering emissions per unit of output → boosting carbon efficiency (Tao et al., 2024) → assessing technologies through knowledge spillovers through OFDI → reducing emissions and the associated risks.

7. Conclusions

7.1. Main findings

We use a firm-level dataset to assess the significant impact of China's OFDI on firm-level carbon risk exposure from 2008 to 2022. We also explore the underlying mechanisms that connect OFDI and carbon risk. We confirm that China's OFDI significantly reduces carbon risk at the firm level. However, the impact of OFDI on carbon risk varies depending on firm attributes, ESG ratings, and financial constraints. Second, a mediation analysis reveals several pathways through which OFDI affects carbon risk, including corporate reputation, downside risk, debt financing costs, and green innovation efficiency. These channels exhibit distinct and significant mediating effects in enhancing OFDI's role in reducing carbon risk at the firm level. Third, steered by the Porter hypothesis, our analysis demonstrates synergistic effects between China's

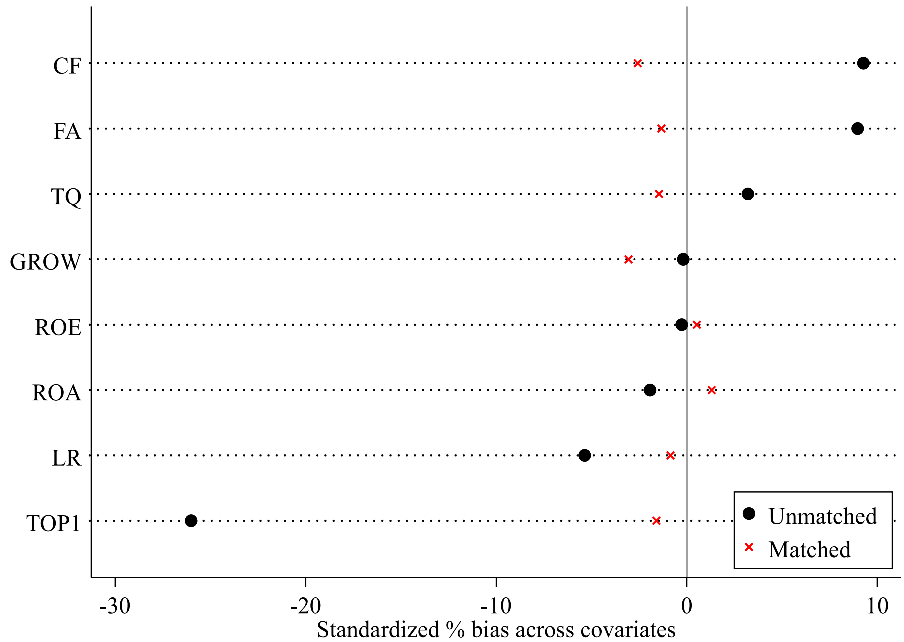

Fig. 5. Standardized %bias across covariates.

Table 8
FE estimation in post-matching.

	(1)	(2)
Dep. Var.	CR	CR
	FE	FE
	K-nearest matching	Frequency-weighted treatment
OFDI_ETS	−0.0025**	−0.0026***
	(0.001)	(0.001)
Controls	√	√
Firm FE	√	√
Year FE	√	√
_cons	0.0602***	0.0679***
	(0.017)	(0.013)
Obs.	9597	16,378
R-squared	0.1600	0.2208

Notes: *, $p < 0.1$, **, $p < 0.05$, ***, $p < 0.01$; robust-heteroscedasticity standard errors are listed in ().

OFDI and the ETS, highlighting the combined impact of these factors in mitigating carbon risk.

7.2. Policy implications

The above empirical findings deliver several policy implications. First, our estimates uncover that China's OFDI robustly reduces carbon risk at the firm level, implying that policymakers should consider expanding and encouraging OFDI to enhance environmental sustainability. Hence, policymakers could introduce incentives that specifically promote OFDI activities that are aligned with environmental goals. For example, tax incentives or financial subsidies could be offered to firms investing in green technologies or sustainable practices in foreign markets. By reducing the financial burden of such investments, these incentives would encourage more firms to engage in OFDI that directly contributes to lower carbon emissions. Moreover, policymakers should focus on creating a supportive regulatory environment that facilitates OFDI in sectors and regions where environmental impact can be maximized. This includes negotiating bilateral agreements with host countries to ensure that investments contribute to environmental sustainability. Additionally, the government could establish guidelines and standards for OFDI projects that align with both China's domestic environmental goals and international environmental commitments. By doing so, the state can ensure that outbound investments reduce carbon risk for individual firms and contribute to global climate goals. Thus, policies should be tailored to the characteristics and needs of different types of firms to address the variability in OFDI's effectiveness across firms. In other words, a "one-size-fits-all" policy architecture should be firmly forbidden. For example, policies could be crafted for firms with high ESG ratings to incentivize investments in green technologies and sustainable practices. These firms are already inclined toward sustainability, which could drive broader industry change. The government could introduce recognition programs or public endorsements for firms that achieve significant reductions in carbon risk through OFDI, thereby enhancing their market reputation and encouraging others to follow suit. Such programs would leverage the market's competitive dynamics, where firms strive for recognition and improved ESG scores to promote sustainable investments. In contrast, policymakers might consider more direct support measures for firms with lower ESG ratings or those facing significant financial constraints. These could include access to low-interest loans or grants earmarked explicitly for sustainable projects abroad. By reducing the financial barriers to investing in environmentally friendly initiatives, such policies would enable these firms to participate in OFDI activities that contribute to carbon risk mitigation.

Second, the role of firm reputation in mediating the impact of OFDI on carbon risk suggests that policies aimed at enhancing corporate transparency and accountability could have significant environmental benefits. By requiring firms to disclose more detailed information about their environmental practices and the carbon footprint of their OFDI activities, policymakers can create a more vital link between firm reputation and sustainability outcomes. This could involve the introduction of mandatory environmental reporting standards for firms engaged in OFDI, as well as public databases that allow stakeholders to assess the environmental impact of these investments. Increased transparency would enhance a firm's reputation and drive competition to adopt more sustainable practices. Second, the finding that downside risk mediates the relationship between OFDI and carbon risk highlights the importance of risk management in promoting sustainable investments. Policies could be designed to encourage firms to integrate environmental risk assessments into their broader risk management frameworks. For example, regulatory bodies could develop guidelines for assessing the environmental risks associated with OFDI and require firms to report on their risk management strategies. By incorporating environmental considerations into their risk assessments, firms would be better positioned to mitigate carbon risk through strategic investments. Third, the mediation role of debt financing costs indicates that access to affordable capital is crucial for firms to invest in sustainable practices. Policymakers could explore options for expanding access to green finance, particularly for firms engaging in OFDI. This could involve creating green bonds or other financial instruments to support environmentally sustainable investments abroad. Additionally, the government could collaborate with international financial institutions to provide low-interest loans or guarantees for green OFDI projects. Lowering the cost of capital would make it easier for firms to invest in initiatives that reduce carbon emissions and risk. Lastly, the significant mediating effect of green innovation efficiency underscores the need for policies that foster innovation in environmentally sustainable technologies and practices. Policymakers could introduce grants, tax credits, or other incentives for firms that invest in green innovation as part of their OFDI strategies. Additionally, support for R&D in clean technologies could be expanded, focusing on applications relevant to domestic and international markets.

Third, the synergistic effects observed between China's OFDI and the ETS indicate that coordinated policy measures can amplify the impact of both strategies on carbon risk reduction. This finding underscores the potential for integrated policy frameworks that leverage the strengths of both domestic environmental regulations and international investments to achieve significant environmental outcomes. Hence, policymakers should consider developing comprehensive strategies that align the objectives of OFDI with the goals of the ETS. One approach could be creating incentives for firms that achieve carbon reductions domestically under the ETS and internationally through OFDI. For example, firms demonstrating substantial carbon emission reductions abroad could receive additional allowances or credits under the ETS. This would create a direct financial incentive for firms to engage in OFDI that contributes to global carbon reduction goals. Moreover, policymakers could enhance the effectiveness of both OFDI and the ETS by improving the coordination between domestic and international environmental policies. This could involve aligning the carbon reduction targets and metrics used in the ETS with those applied to OFDI activities.

7.3. Research suggestions

This study suggests that future validations could assess whether China's OFDI activities lead to significant shifts in production and emissions to host countries with weaker environmental standards. Understanding the magnitude of carbon leakage can help identify which sectors and regions are most prone to such shifts. Additionally, examining the specific mechanisms through which OFDI leads to carbon leakage – such as changes in production processes, technology adoption, or shifts in input usage – could provide insights into how policy measures might mitigate these effects. For instance, does OFDI primarily increase carbon emissions due to increased energy use in the host country, or does it result from adopting more carbon-intensive technologies?

CRediT authorship contribution statement

Miaomiao Tao: Writing – review & editing, Writing – original draft, Validation, Software, Methodology, Formal analysis, Data curation, Conceptualization. **Jianda Wang:** Writing – review & editing, Writing – original draft, Validation, Conceptualization. **David Roubaud:** Writing – review & editing, Visualization, Software, Project administration. **Lingli Qi:** Writing – review & editing, Writing – original draft, Formal analysis, Data curation, Conceptualization.

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 A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.eneco.2025.108391.

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