Global Currency Risk and Corporate Carbon Emissions

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Abstract

We construct a panel of international firms with foreign revenues and carbon emissions to examine whether their revenue-weighted exposures to foreign exchange (FX) volatility influence their emission intensity. Firms facing higher FX risk release more carbon emissions in their own and upstream operations. Identification tests based on regime changes in exchange rates and launches of FX derivatives support a causal interpretation. Firms facing higher FX risk (i) reduce environmental investment and (ii) use new, short-term suppliers, both leading to more emissions, especially when firms are financially constrained. Finally, the FX effect is mitigated by FX derivatives usage and carbon taxation.

Keywords**:** Foreign Exchange Volatility, Carbon Emissions, Operational Hedging, Offshore Operations

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1. Introduction

Externalities from economic activities are central to the analysis of corporate decision-making and managerial incentives. Among these, carbon emissions have garnered significant attention due to growing concerns about climate change and its economic consequences.[1] Over the past few decades, the global markets and offshore outsourcing are two major trends and both increase firms' exposure to foreign exchange (FX) uncertainty.[2] Moreover, such globalization also requires more transportation and production in low-cost countries that often feature weaker environmental regulations (Li and Zhou, 2017; Shapiro and Walker, 2018; Berry, Kaul, and Lee, 2021; Bartram, Hou, and Kim, 2022; Choi et al., 2025). This globalization dynamic underscores the potential role of FX risk in shaping firms' carbon emissions and environmental engagement.

While extensive existing research examines the determinants of corporate carbon emissions, most previous studies focus on *microeconomic* factors such as cost of capital (Sharfman and Fernando, 2008; Levine et al., 2018; Flammer, 2021), reputational concerns (Matsumura, Prakash, and Vera-Muñoz, 2014; Li, Xu, and Zhu, 2025), and environmental regulation (Ramadorai and Zeni, 2024). In this paper, we investigate the influence of a key *macroeconomic* factor—FX risk, an essential factor on global trades—on corporate carbon emissions, especially on how such an effect is driven by logistics strategies and financial constraints.

If a firm can perfectly predict the amount of foreign currency revenue it will generate, it can hedge its FX risk with a forward contract for that specific amount (Kerkvliet and Moffett, 1991). However, foreign revenues are often uncertain, which results in FX risk that increases financial constraints and reduces firms' incentive and ability to invest in emissions abatement (Fang, Hsu, and Tsou, 2024). Alternatively, firms may respond to FX risk and associated financial pressure by sourcing from lower-cost overseas suppliers (Chowdhry and Howe, 1999),[3] often leading to higher carbon emissions due to laxer environmental

[1]See, for example, The Paris Agreement: https://www.un.org/en/climatechange/paris-agreement. At the corporate level, the CEOs of leading US companies supported a comprehensive policy to reduce GHG emissions and transition to a low-carbon future. The Business Roundtable: https://www.businessroundtable.org/climate.

[2]In 2024, according to UN Trade and Development calculations based on national statistics, the global trade value was nearly 33 trillion USD, accounting for 30% of global GDP. Moreover, World Trade Report issued by WTO in 2024 says 28% jobs worldwide depend on exports, and the OECD notes that 30–60% of European business jobs rely on foreign markets. Source: OECD trade in employment database https://www.oecd.org/en/data/datasets/trade-in-employment.html.

[3]In the S&P Compustat Global database, 72% of international firms that are publicly listed reported FX transactions in 2021, a remarkable increase compared to 36% in 2002. The percentage is calculated as the number of firms that reported

standards and increased transportation needs (Ugarte, Golden, and Dooley, 2016).

To empirically assess this relation, we construct a large international database from a wide range of sources. We measure firm-specific FX risk using exposure-weighted FX volatility by calculating the variance-covariance matrix of currency pairs and interacting it with firms' geographic revenue shares from Factset Revere.[4] For robustness, we also model the variance-covariance matrix using the multivariate generalized autoregressive conditional heteroskedasticity (GARCH) model (Bollerslev, 1986; Engle and Kroner, 1995). Since a firm's foreign revenue composition varies over time, this measure captures firm-specific, time-varying FX risk that is driven by external exchange rate fluctuations (given that firms cannot perfectly predict exchange rates and their foreign revenues) rather than firm-specific strategic decisions. As such, it aligns with the logic of a Bartik-style instrument (Bartik, 1991; Borusyak, Hull, and Jaravel, 2022), where pre-existing revenue distributions determine firm-level exposure to macroeconomic uncertainty.

We collect firm-level carbon emissions data from the Trucost database, which is widely used in academic studies (Azar et al., 2021; Bolton and Kacperczyk, 2021; Ehlers, Packer, and de Greiff, 2022; Raghunandan and Rajgopal, 2022). We examine scope 1, scope 2, and scope 3 emissions (upstream and downstream separately) and focus on firm carbon intensity, defined as the number of tonnes of CO_2 equivalent per million USD of revenue (Aswani, Raghunandan, and Rajgopal, 2024).[5] We also collect environmental expenditure and environmental rating-agency scores from the Refinitiv ASSET4 ESG database and negative environmental news from the RepRisk database for alternative indicators of firm performance in environmental issues.

Our baseline empirical results reveal that firm-level, exposure-weighted FX volatility is positively associated with future increases in scope 1 and scope 3 upstream carbon intensity, even after controlling for firm, market-year, and industry-year fixed effects, as well as firm characteristics. Economically, a 1% increase in FX risk leads to a 4.3% increase in scope 1 carbon intensity and a 1.3% increase in scope

"Foreign Exchange Income (Loss) (FCA)" divided by the total number of firms.

[4]In contrast to studies that assume marginal impacts of currency co-movements (Deng, 2020; Taylor, Wang, and Xu, 2021; Hsu et al., 2022), our methodology explicitly accounts for co-movements among multiple currencies, providing a more comprehensive measure of FX risk.

[5]Scope 1 emissions are direct emissions from sources owned or controlled by a company, such as fuel combustion in company vehicles or manufacturing processes. Scope 2 emissions are indirect emissions from purchased electricity, steam, heating, or cooling used by the company. Scope 3 emissions include all other indirect emissions within the company's value chain, such as those from suppliers (upstream) and product use, transportation, and waste disposal (downstream).

3 upstream carbon intensity. The latter finding suggests that firms facing higher FX risk tends to use less environment-friendly suppliers.[6] In addition, we show that firms with higher FX risk receive lower environmental scores and more negative environmental news coverage, further supporting a negative FX risk-emission relation.

To examine whether our baseline results have a causal interpretation, we leverage two sets of major events in FX markets. First, using exchange rate regimes documented by Ilzetzki, Reinhart, and Rogoff (2019), we show that firms with higher revenue in currencies moving from floating to fixed regimes (from fixed to floating regimes) decrease (increase) carbon intensity in the next year. Second, we examine the introduction of new currency derivative products by the Chicago Mercantile Exchange (CME), which enhanced firms' ability to hedge FX risk (Hoberg and Moon, 2017). We find that firms with higher revenue in currencies affected by such events exhibit lower future carbon intensity. While these events may not always be "unexpected", their occurrence still constitutes legitimate exogenous changes as that switches expected probability to one. In addition, our changes in FX risk are based on firms' pre-event revenue sources, which constitutes a Bartik-style instrument (Bartik, 1991; Borusyak, Hull, and Jaravel, 2022). Overall, our identification tests support a causal effect of FX risk on carbon emissions.

We further implement several tests to understand how firms' FX risk changes their incentives and adjusts policies and operations accordingly. First, we collect environmental expenditure reported in the Refinitiv and find that FX risk leads to lower environmental investment, which leads to higher carbon emissions. More importantly, firms' environmental investment decreases more than capital expenditure upon volatile exchange rates, suggesting that the negative effect on pollution abatement is distinct from that on regular investment level. We also show that such an effect is more pronounced among more financial constrained firms. All these results are consistent with the model implication of Fang, Hsu, and Tsou (2024) that environmental investment is more sensitive than capital investment to financial constraints.

Using firm-level supply chain data from Factset Revere, we show that firms facing higher FX risk increase the use of short-term contracts and tend to use new or private suppliers—who tend to have

[6] The empirical literature has documented that operational adjustment is much more common than financial hedging (Brown, 2001; Guay and Kothari, 2003), and has provided several explanations. For example, Hoberg and Moon (2017) argue that the market lacks liquid derivatives for multinational corporations to hedge their offshore risks effectively. Kim, Mathur, and Nam (2006) show that operational adjustment can mitigate more long-term and permanent risk exposures, thereby enhancing firm value. Deng (2020) illustrates that transferring incomes to low-tax jurisdictions for tax savings is another advantage of operational hedging.

weaker environmental compliance—but maintain long-term customer contracts. In addition, these effects increase with firms' financial constraints. All of these results confirm that firms adjust their supply chains in response to FX risk but such adjustment has environmental externalities (Hörisch, Johnson, and Schaltegger, 2015). The FX risk effect is also stronger for firms with lower supply chain switching costs, as those firms are more likely to exploit suppliers and thus lead to more carbon emissions.

We further explore the mitigating role of FX derivatives and carbon tax in order to understand how policies and regulations may affect firms' emission decisions. Firms that hedge FX risk through derivatives are less likely to adjust sourcing strategies in ways that increase emissions. Given the rise of carbon taxation in regions such as the European Union, we examine whether such policies mitigate the FX risk effect. We find that such an effect is weakened among firms located in or serving markets with carbon taxes, supporting that these policies partially internalize the externalities associated with globalization that increases emissions. These results confirm that the FX-emission relation we discover is indeed specific to exchange rate fluctuations and carbon emissions.

We contribute to the literature on firms' operational adjustments and FX hedging by introducing a new perspective—corporate carbon emissions. Our analysis of operational adjustments highlights the environmental externalities of firms' flexible supply contracts as a response to FX risk (Huchzermeier and Cohen, 1996; Kamrad and Siddique, 2004; Kazaz, Dada, and Moskowitz, 2005). To maintain operational flexibility amid FX volatility, firms may increase transportation frequency, thereby raising the carbon intensity of downstream customers (Ugarte, Golden, and Dooley, 2016).[7] Prior research on FX hedging has primarily examined its benefits for corporate production and profitability (Géczy, Minton, and Schrand, 1997; Allayannis and Weston, 2001; Allayannis, Lel, and Miller, 2012), overlooking its broader environmental impact. We show that FX hedging mitigates firms' financial uncertainty, increasing their incentives for environmental investment and forming long-term partnership with suppliers.

Our study also contributes to the literature on the real effects of FX volatility on corporate decisions. Previous research has focused on firm-specific benefits such as capital investment and innovation (Taylor, Wang, and Xu, 2021; Hsu et al., 2022) and has largely ignored the externalities of corporate operations. In this paper, we adopt a stakeholders' perspective perspective and highlight the consequences on carbon

[7]On average, the logistics and transport carbon emissions are 5% to 15% of the total carbon emissions of the global supply chain. World Economic Forum, 2009. Supply Chain Decarbonization: The Role of Logistics and Transport in Reducing Supply Chain Carbon Emissions: https://www3.weforum.org/docs/WEF_LT_SupplyChainDecarbonization_Report_2009.pdf.

emissions, environmental investment, and pollution news. Finally, we add to the literature on the determinants of pollution and emission. Different from most prior studies that are based on a single country (e.g. Hettige, Mani, and Wheeler, 2000; Doonan, Lanoie, and Laplante, 2005; Clarkson et al., 2011; Jiang, Lin, and Lin, 2014), we take a global approach and emphasize the role of FX volatility in shaping international firms' emission and investment decisions. Our mechanism tests, based on global supply chain data, provide direct empirical evidence at the contract level.

The remainder of the paper is organized as follows. Section 2 describes data sources and variable construction used in the construction of our database. Section 3 presents the main empirical test results for the relation between firm-specific FX risk and carbon emissions. Section 4 further investigates how FX risk influences firms' incentives and policies that explain carbon emissions, including environmental investment, supply chain contracts, financial constraints, the use of currency derivatives, and carbon tax. Section 5 summarizes and concludes the paper.

2. Data and Variable Construction

2.1. Foreign Exchange Rate Volatility

To construct pairwise foreign exchange rates, we collect daily US dollar (USD) denominated exchange rates of 48 currencies from the WMR/Reuters database via Datastream.[8] We do not include US firms in our study, and an increase in the exchange rate indicates an appreciation of the foreign currency against the USD. This database and USD-denominated exchange rates are commonly referenced in the field of international finance and foreign exchange studies (Froot, O'connell, and Seasholes, 2001; Menkhoff et al., 2012). Next, we use USD-denominated exchange rates to calculate the exchange rate between each pair of the 48 currencies.

We begin by computing the daily pairwise log exchange rate change as follows:

$$r_{i,j,d} = s_{i,j,d} - s_{i,j,d-1} \tag{1}$$

[8]The 48 currencies are for the European Monetary Union and the following 47 economies: Australia, Austria, Belgium, Brazil, Bulgaria, Canada, Croatia, Cyprus, Czech Republic, Denmark, Egypt, Finland, France, Germany, Greece, Hong Kong, Hungary, India, Indonesia, Ireland, Israel, Italy, Iceland, Japan, Kuwait, Malaysia, Mexico, Netherlands, New Zealand, Norway, Philippines, Poland, Portugal, Russia, Saudi Arabia, Singapore, Slovakia, Slovenia, South Africa, South Korea, Spain, Sweden, Switzerland, Taiwan, Thailand, Ukraine, and United Kingdom.

where r denotes the log exchange rate change, s denotes the log spot exchange rate, and the subscripts i, j, and d refer to the domestic currency i, foreign currency j, and the trading day d, respectively. The annualized log exchange rate change can be calculated as the sum of daily changes within the same year.

Then we use the daily log exchange rate changes to construct the annualized exchange rate volatility. In our main analysis, we focus on the realized exchange rate volatility and consider the co-movement among the 48 currencies. Specifically, we calculate the variance-covariance matrix, denoted as $\Sigma_{i,t}$ with the subscript i and t representing the domestic currency i and year t, of our sample as follows:

$$\Sigma_{i,t} = \begin{bmatrix} var(\mathbf{r}_{i,1,t}) & \cdots & cov(\mathbf{r}_{i,1,t}, \mathbf{r}_{i,n,t}) \\ \vdots & \ddots & \vdots \\ cov(\mathbf{r}_{i,n,t}, \mathbf{r}_{i,1,t}) & \ldots & var(\mathbf{r}_{i,n,t}) \end{bmatrix} \tag{2}$$

where $var(\cdot)$ and $cov(\cdot)$ is the annualized variance and covariance function, respectively; $\mathbf{r}_{i,j,t} = [r_{i,j,1}, \cdots, r_{i,j,k}]$ is the vector of daily pairwise log exchange rate against foreign currency j in year t with k trading days; n is the number of foreign currencies under consideration.[9] As a robustness check, we consider an alternative measure of exchange rate variance-covariance using the multivariate GARCH model (Bollerslev, 1986; Engle and Kroner, 1995).

2.1.1. Firm-Level Exposure-weighted FX Risk

To proxy a firm's FX risk, we obtain the firm's annual revenue from different markets via the FactSet Geographic Revenue Exposure (GeoRev) database. GeoRev offers comprehensive coverage of international firms by combining revenue shares disclosed in corporate filings, along with estimated revenue shares generated through a proprietary algorithm when self-disclosed values are unavailable (Pankratz, Bauer, and Derwall, 2023; Colacito, Qian, and Stathopoulos, 2025).[10]

We define the exposure $w_{f,i,j,t}$ of a firm f with domestic currency i to foreign currency j in year t as

[9] The number of currencies available varies each year because of the introduction of the euro, the expansion of the eurozone, and the increasing accessibility of data from emerging markets.

[10] Approximately 90% of the values in our GeoRev-Trucost merged sample are based on data vendor estimates. However, the average confidence score is 0.9, where this score is based on how much information the GeoRev estimation algorithm had at its disposal when making an estimate. Therefore, we argue that the results are quite reliable.

the ratio of foreign revenue denominated by j to its total revenue, specified as follows:

$$w_{f,i,j,t} = \frac{revenue_{f,j,t}}{\sum_m revenue_{f,m,t}}, \tag{3}$$

where the numerator, $revenue_{f,j,t}$, denotes the firm f's revenue denominated by foreign currency j in year t and denominator, $\sum_m revenue_{f,m,t}$, denotes the firm f's total revenue in year t. The denominator includes the domestic revenue to get a more accurate measure of FX risk exposure.

We measure a firm's FX risk using its exposure-weighted FX volatility, which is calculated as follows:

$$FX\ Vol\ (Exposure\ Weighted)_{f,t} = \sqrt{\mathbf{w_{f,t}} \cdot \Sigma_{i,t} \cdot \mathbf{w}'_{f,t}}, \tag{4}$$

where $FX\ Vol\ (Exposure\ Weighted)_{f,t}$ is the geographical revenue-weighted FX volatility of firm f in year t; $\mathbf{w_{f,t}} = [w_{f,i,1,t}, \cdots, w_{f,i,n,t}]$ is a vector of firm f exposure on foreign currency $1, 2, \cdots, n$ in year t; $\Sigma_{i,t}$ is the variance-covariance matrix of the domestic currency i in year t described in Section 2.1. The volatility of the domestic currency is defined as zero. For example, consider a firm headquartered in market i that serves both the domestic market i and two foreign markets, j and k. The firm's foreign revenue exposure can be represented by the vector $\mathbf{w_f} = [w_j, w_k]$ as specified in Equation (3). For example, $w_{f,j} = revenue_{f,j}/(revenue_{f,i} + revenue_{f,j} + revenue_{f,k})$. Then the firm-level revenue-weighted FX volatility is calculated as:

$$FX\ Vol\ (Exposure\ Weighted)_f = \begin{bmatrix} w_i & w_j & w_k \end{bmatrix} \begin{bmatrix} 0 & 0 & 0 \\ 0 & var(\mathbf{r}_{i,j}) & cov(\mathbf{r}_{i,j}, \mathbf{r}_{i,k}) \\ 0 & cov(\mathbf{r}_{i,j}, \mathbf{r}_{i,k}) & var(\mathbf{r}_{i,k}) \end{bmatrix} \begin{bmatrix} w_i \\ w_j \\ w_k \end{bmatrix} \tag{5}$$

where $\mathbf{r}_{i,j}$ and $\mathbf{r}_{i,k}$ are vectors representing the log exchange rate changes of currencies j and k, respectively, denominated in currency i. The domestic exposure w_i carries no foreign exchange risk.

The intuition of our FX risk measure is that if a firm earns more revenue from a specific foreign market, the bilateral exchange rate volatility from that market is expected to have a greater impact. Conversely, if a firm has diversified revenue sources from different foreign markets, the bilateral exchange rate volatility is expected to have a lesser impact. As noted, our method aligns logically with the instrument proposed by Bartik (1991), in that pre-existing revenue distributions determine firm-level exposure to macroeconomic shocks that may be considered exogenous at the firm level. The aggregated volatility can be decomposed as the product of the revenue-based exposure vector and the currency variance-covariance matrix. Our firm-specific FX risk takes into account the co-movement of multiple currencies.

2.1.2. Major Changes in FX Markets and Identification

Although a firm's revenue distribution across markets reflects its policies, a single firm is unlikely to influence market-level exchange rates. Thus, reverse causality is less likely a major concern. To address potential omitted variable bias and to establish the causal effect of FX risk on corporate environmental performance, we leverage two major changes to the foreign exchange market: (1) shifts in exchange rate regimes, either from fixed to floating or vice versa and (2) the introduction of new currency derivative products by the Chicago Mercantile Exchange (CME). While we cannot fully rule out firms' expectation of these changes, we argue that realized changes lead to exogenous changes for two reasons: first, the realization itself switches the expected probability to one; and second, firms' existing exposure to multiple markets (i.e., foreign revenue) are decided before the event, which aligns with the logic of a Bartik-style instrument (Bartik, 1991; Borusyak, Hull, and Jaravel, 2022).

Exchange Rate Regime Change Following the classification of exchange rate regimes by Ilzetzki, Reinhart, and Rogoff (2019), we define an exchange rate regime as floating if the exchange rate is freely floating and as fixed otherwise. We then construct two dummy variables: $\mathbb{1}_{\text{floating},i,j,t}$ equals one if the exchange rate regimes of both currencies i and j are floating in year t and zero otherwise, and $\mathbb{1}_{\text{fixed},i,j,t}$ equals one if either currency i or j has a fixed exchange rate regime in year t, and zero otherwise. The effect on firm f's foreign revenue of a shift from fixed to floating exchange rates can then be measured as:

$$\mathit{FixedToFloat}\ (\mathit{Exposure\ Weighted})_{f,t} = \sum_{j,j\neq i} w_{f,i,j,t} \cdot \mathbb{1}_{\text{fixed},i,j,t-1} \cdot \mathbb{1}_{\text{floating},i,j,t}, \tag{6}$$

and the effect of a switch from floating to fixed regime can be measured as:

$$\mathit{FloatToFixed}\ (\mathit{Exposure\ Weighted})_{f,t} = \sum_{j,j\neq i} w_{f,i,j,t} \cdot \mathbb{1}_{\text{floating},i,j,t-1} \cdot \mathbb{1}_{\text{fixed},i,j,t} \tag{7}$$

where $w_{f,i,j,t}$ is the firm exposure defined in Section 2.1.1, with subscripts f, i, j, t denoting firm f, domestic currency i, foreign currency j, and year t, respectively; the term $\mathbb{1}_{\text{fixed},i,j,t-1} \cdot \mathbb{1}_{\text{floating},i,j,t}$ ($\mathbb{1}_{\text{floating},i,j,t-1} \cdot \mathbb{1}_{\text{fixed},i,j,t}$) indicates the transition of exchange rate regime from floating to fixed (fixed to floating). We propose that $\textit{FixedToFloat (Exposure Weighted)}_{f,t}$ reflects a positive shock to firm f's FX risk, and $\textit{FloatToFixed (Exposure Weighted)}_{f,t}$ reflects a negative shock to the firm's FX risk.

CME Currency Derivative Launch We collect the historical first trade dates of FX derivative products from the CME.[11] The introduction of new FX products was staggered over time and only certain markets were affected. In addition, even firms that heavily rely on over-the-counter (OTC) contracts are still affected as such derivatives increase market liquidity and create opportunities for cross-market arbitrage (Hoberg and Moon, 2017); thus, the introduction of FX products reduces firms' exposure to FX volatility. We construct a dummy variable $\mathbb{1}_{j,t}$ that equals one if any derivative of currency j is listed on CME in year t. The firm-level shock is the proportion of foreign revenue affected by the launch events, calculated as:

$$\textit{CME Derivative (Exposure Weighted)}_{f,t} = \sum_{j,j\neq i} w_{f,i,j,t} \cdot \max(\mathbb{1}_{i,t}, \mathbb{1}_{j,t}) \tag{8}$$

where $w_{f,i,j,t}$ is the firm exposure defined in Section 2.1.1, with subscripts f, i, j, t denoting firm f, domestic currency i, foreign currency j and year t, respectively; the function $\max(\cdot)$ returns the maximum value of the input – we assume that firms are indifferent to hedging the FX risk using derivatives of either domestic currency or foreign currency. We propose that the launch of FX products for a firm's domestic currency i (its foreign revenue from foreign currency j) is a negative shock to its FX risk in the magnitude of one unit ($w_{f,i,j,t}$ unit).[12]

[11] The dates are publicly available on the CME website: https://www.cmegroup.com/media-room/historical-first-trade-dates.html#fx

[12] Suppose a firm is headquartered in Europe and earns foreign income from Japan. The risk is that the Japanese yen may depreciate (or equivalently, the euro may appreciate). To manage this risk, the firm can choose to buy a put option on the yen (allowing it to sell yen at a strike price if the yen depreciates against the euro) or a call option on the euro (allowing it to buy euros at a strike price if the euro appreciates against the yen).

2.2. Corporate Emissions, Environmental Investment, and Environmental Performance

We collect firm-level carbon emission data from the S&P Trucost database, which covers listed firms across major developed and emerging markets since 2002. Trucost collects carbon emission data from public sources (e.g., the Carbon Disclosure Project, the EPA, firm's sustainability reports) and measures corporate emissions following the standard by Greenhouse Gas (GHG) Protocol.[13] Trucost also estimates the carbon emissions of firms without publicly available disclosure using the environmental profiling model of Ung et al. (2016). The database is commonly referenced in recent studies (Azar et al., 2021; Ehlers, Packer, and de Greiff, 2022; Raghunandan and Rajgopal, 2022), and Bolton and Kacperczyk (2021) find a strong correlation coefficient of 0.99 among the emissions reported by Trucost and five other major data vendors.

We analyze corporate emissions from different sources: scope 1 refers to the emissions directly associated with the firm, scope 2 refers to the energy consumption by the firm, and scope 3 upstream (downstream) refers to the indirect emissions from production inputs (outputs) of the firm; accordingly, we construct four corresponding dependent variables: *Scope 1, Scope 2, Scope 3 (Up)*, and *Scope 3 (Down)*. We use carbon intensity, defined as the ratio between a firm's carbon emissions (tonnes of CO_2 equivalent) and its revenue (USD millions), to proxy firm environmental performance. As suggested by Aswani, Raghunandan, and Rajgopal (2024), total carbon emissions are more reflective of the relation between firm size and growth, while carbon intensity better represents the firm's carbon footprint and related risks.

We also collect firm-level environmental investment data from Refinitiv ESG database. Similar to Skiadopoulos and Xue (2024), we proxy such investment using firms' reported environmental expenditures, which encompass expenses for environmental protection or to prevent, reduce, or control environmental aspects, impacts, and hazards. We acknowledge that these green expenditures are self-reported and may therefore be susceptible to selection bias.

To measure corporate environmental performance, we consider both the ESG rating agency's scores and media news about environmental incidents. We first collect the firm's overall environmental and subcategory rating-agency performance scores (*Environmental, Resource Use, Emission, Environmental*

[13] The Greenhouse Gas Protocol: https://ghgprotocol.org/

Innovation) from the Refinitiv ASSET4 ESG database following Dyck et al. (2019). The ASSET4 ESG data have been widely used in academic research;[14] the data are available from 2002.

We then collect news data from the RepRisk database, which covers global news about firms' ESG issues. It includes firm identifier (ISIN), news date, a story ID to link all related news about the same event, a severity score (1 to 3), a novelty score (1 to 2), and a reach score (1 to 3). We focus on firms' negative environmental news.[15] It is an extremely rich data source from which to capture global firms' realized environmental issues that are objective and less subject to measurement errors (Gantchev, Giannetti, and Li, 2022; Houston and Shan, 2022; Hsu, Li, and Pan, 2025). We calculate the number of news about a firm's environmental incidents in each year (*Events*), and further extend the measure to the weighted sum by severity, novelty, and/or reach. The data are available from 2007.

2.3. The Use of Foreign Exchange Derivatives

International firms facing FX risk may use derivatives to hedge exposure to exchange rate fluctuations and to improve their competitive position in an uncertain global market (Brown, 2001). Following the methodology outlined in previous studies (Géczy, Minton, and Schrand, 1997; Allayannis, Lel, and Miller, 2012; Hoberg and Moon, 2017; Hsu et al., 2022), we manually collect firm-level derivatives-use data from company annual reports sourced from the Reuters/LSEG Eikon database. We construct a dummy variable *FX Derivative* that equals one if firms report using FX derivatives in their annual report. We confirm a firm's FX derivative use if we find "futures", "swap", "derivative", "option" or "hedge" and "foreign exchange", "exchange rate" or "currency" in the same paragraph of a firm's annual report. The sample size for the analysis of FX derivative use is smaller than that of the main results due to the limited availability of annual reports through Eikon.

2.4. Firm-level Supply Chain Relation

We collect details of the contractual relationships between customers and suppliers from the Factset Revere database to proxy the firm's operational shift policy. The database provides details on supply

[14] A recent study has raised concerns about the reliability of these scores (Berg, Fabisik, and Sautner, 2021).

[15] News about violating United Nations Global Compact's (UNGC) "Principle 7: Businesses should support a precautionary approach to environmental challenges," Principle 8: undertake initiatives to promote greater environmental responsibility," or "Principle 9: encourage the development and diffusion of environmentally friendly technologies" tagged by RepRisk.

chain relations for both public and private global firms dating back to 2003. Factset Revere hand-collects and verifies the information from various publicly available sources, including corporate filings, investor presentations, conference call transcripts and media websites. In comparison to the Compustat Segment database, Factset Revere offers much broader coverage in terms of both time and entities, with approximately 20,000 supply chain links per year in Factset versus 2,000 links per year in Compustat (Agca et al., 2021).

Following Darendeli et al. (2022), we construct four proxies to capture the contractual characteristics between corporate customers and suppliers: 1) *Contract Num* is the number of newly initiated contracts with suppliers or customers; 2) *Contract Num (Private)* is the number of newly initiated contracts with private suppliers or customers; 3) *Contract Num (New Partner)* is the number of newly initiated contracts with suppliers or customers that have no contract commenced in the past; 4) *Contract Duration* is the average duration of newly initiated contracts with suppliers in months. We utilize the contractual relationships with suppliers and customers to analyze the firm's operational adjustments regarding its upstream and downstream.

2.5. Corporate Fundamentals

We collect data on international firms' financial fundamentals from the Worldscope database. We include various firm-year characteristics in our analysis to control for firm fundamentals that may affect carbon emissions: 1) *FX Rate Change* represents the geographic-revenue-weighted average of spot exchange rate change – this variable captures the *first-moment effect* of exchange fluctuations; 2) *Foreign Income* denotes the proportion of foreign income; 3) *TobinQ* is Tobin's Q ratio; 4) *Tangibility* denotes the ratio of tangible assets to total assets; 5) *Leverage* is the total debt scaled by total assets; 6) *Pretax Income* represents pretax income scaled by total assets; 7) *Pretax Income Vol* is the standard deviation of pretax income scaled by total assets over the past five fiscal years; 8) *Size* represents the natural logarithm of total assets in US Dollars.

2.6. Sample Construction

We start with the S&P Trucost database, which covers 123,353 firm-year observations of 17,465 unique firms from 2002 through 2021. Then, we merge the sample with the FactSet Geographic Revenue Exposure, exclude US firms and keep international firms with foreign revenues. After this step, we have 38,691 firm-year observations left because only a minority of firms have available foreign revenues. We then merge our sample with the WMR/Reuters database to construct firm-level geographic revenue-weighted FX volatility and keep the observations with available FX rates from the 48 markets. After this step, we have 14,209 observations left. Finally, we merge the sample with the Worldscope database to get firm control variables and keep the observations with valid firm-year control observations. After removing the markets with only a few observations, we are left with 11,323 observations, representing 2,159 firms in 21 markets from 2002 to 2021 in our main sample.[16] Continuous variables are winsorized at the 1st and 99th percentiles. Table 1 presents the summary statistics and Table 2 shows the sample distribution of each market. All variable definitions can be found at Internet Appendix Table A1.

[Place Tables 1 and 2 Here]

3. Empirical Analysis

3.1. Baseline Results

In this section, we empirically examine the relation between FX volatility and a firm's environmental performance. As the first step, we estimate the following baseline model by ordinary least square (OLS):

$$Carbon_{f,t+1} = \alpha + \beta \cdot FX\ Vol\ (Exposure\ Weighted)_{f,t} + \mathbf{X}_{f,t} + \Phi_f + \Phi_{market,t} + \Phi_{ind,t} + \epsilon_{f,t}, \quad (9)$$

where $Carbon_{f,t+1}$ is the carbon intensity (*Scope 1* to *Scope 3*) of firm f in year $t+1$, as defined in section 2.2; $FX\ Vol\ (Exposure\ Weighted)_{f,t}$ is the geographic revenue-weighted FX volatility of firm f

[16]The remaining 21 markets, measured relative to the USA, are: Australia (AUS), Belgium (BEL), Germany (DEU), Denmark (DNK), Spain (ESP), Finland (FIN), France (FRA), United Kingdom (GBR), Hong Kong (HKG), India (IND), Italy (ITA), Japan (JPN), South Korea (KOR), Malaysia (MYS), Netherlands (NLD), Norway (NOR), Singapore (SGP), Sweden (SWE), Thailand (THA), Taiwan (TWN), and South Africa (ZAF).

in year t, as defined in section 2.1.1; and $\mathbf{X}_{f,t}$ is the vector of firm-year control variables including *FX Rate Change, Foreign Income, TobinQ, Tangibility, Leverage, Pretax Income, Pretax Income Vol, Size*, and *Firm Age*. Variable definitions can be found in Internet Appendix Table A1.

It is worth noting that we also include an extensive list of fixed effects to rule out confounding factors. We include firm fixed effects Φ_f to absorb all firm-specific omitted variables (e.g., corporate culture, managerial style and ability). We further include market-year fixed effects $\Phi_{market,t}$ to incorporate all market/country-specific time-varying factors (e.g., economic development, FX policies, environmental policies, government orientation). Finally, industry-year fixed effects $\Phi_{ind,t}$ are used to account for all industry-level time trends (e.g., production technologies, environmental standards, competition). Our industry classification is based on two-digit SIC code. $\epsilon_{f,t}$ is the normally distributed error term with a zero mean. The standard errors are clustered at the market level because the estimation errors of all firms in the same market are correlated by being subject to the same environmental, economic, and FX policies.

Table 3 presents estimation results for Equation (9). As shown in column (1) of Table 3, firms facing higher FX risk also produce higher scope 1 carbon intensity in the following year. The results are not only statistically significant but also economically meaningful. A one-standard deviation increase in exposure-weighted FX volatility is associated with a 2.2% increase in scope 1 carbon intensity.[17] In contrast, the estimation result for scope 2 carbon intensity in column (2) is insignificant, indicating that increased FX risk does not lead to more intensive energy consumption. Interestingly, the results shown in columns (3) and (4) indicate that FX risk significantly increases scope 3 carbon intensity related to upstream activities but does not affect downstream carbon emissions. In particular, a one-standard deviation increase in exposure-weighted FX volatility is associated with a 0.68% increase in scope 3 carbon intensity. [18] These baseline results suggest that emissions from a firm and its suppliers substantially increase with the FX risk it faces.

[Place Table 3 Here]

For robustness checks, we find consistent results from (i) clustering standard errors at the firm level, (ii) excluding the energy sector, (iii) considering a multivariate GARCH model for expected volatility, (iv)

[17] 2.2% is calculated as: 5.01 (coefficient) × 0.53 (standard deviation) / 119.81 (mean of scope 1 carbon intensity) × 100%.

[18] 0.68% is calculated as: 2.87 (coefficient) × 0.53 (standard deviation) / 226.54 (mean of scope 3 upstream carbon intensity) × 100%.

using the total amount of carbon emissions as the dependent variable, and (v) implementing a placebo test using lagged emissions as the dependent variable.

Given that our main explanatory variable is firm-specific, we cluster the standard errors at the firm level and find consistent results as shown in Internet Appendix Table A3. To mitigate the concern that our results are driven by firms depending on commodities that are primarily USD-priced and/or are more sensitive to foreign exchange rate fluctuations, we also perform a robustness check by excluding firms in the gas, oil, and utility industries. Consistent results are found in Internet Appendix Table A4.

As shown in Internet Appendix Table A5, we fit FX volatility using a multivariate GARCH model and reconstruct our exposure-weighted FX risk using the pairwise volatility predicted by the GARCH$(1, 1)$ model. Based on the assumptions of the GARCH model, the next-period variance consists of a constant long-term average variance, today's shock, and today's predicted variance. Therefore, the current predicted volatility can serve as a proxy for the expected volatility for the next period.

We show in Internet Appendix Table A6 that using the log of total carbon emissions as the dependent variable delivers consistent results, suggesting that the pattern we discover is not only about intensity but also scale. We note that, a one-standard deviation increase in exposure-weighted FX volatility is related with an increase of 0.25% (0.08%) in total scope 1 (3) emissions.

We acknowledge the concern about reverse causality that firms in a country experiencing increased trade with foreign markets may benefit from stable exchange rates and subsequently reduce their carbon emissions. To mitigate this concern, we conduct a placebo test using carbon intensity from years $t-3$ to $t-1$ as the dependent variable in . We find no significant relation between lagged emission levels and FX risk in Internet Appendix Table A7, which contradicts the reverse causality hypothesis.

3.2. Environmental Performance Ratings and News

Our baseline findings indicate that firms' carbon intensity levels increase with their FX risk. In this section, we further validate this relation using firms' environmental performance scores from a rating agency and their news about environmental concerns. For the former, we use the environmental scores from Refinitiv ASSET4 as an alternative measure of firm environmental performance and re-estimate our baseline model:

$$Env_{f,t+1} = \alpha + \beta \cdot FX\ Vol\ (Exposure\ Weighted)_{f,t} + \mathbf{X}_{f,t} + \Phi_f + \Phi_{market,t} + \Phi_{ind,t} + \epsilon_{f,t}, \tag{10}$$

where $Env_{f,t+1}$ is the overall (*Environmental*) or subcategory (*Resource Use, Emission, Environmental Innovation*) scores of firm f in year $t+1$. Our estimation is based on 5,187 observations of 812 unique firms from the year 2003 to 2020. The remaining specifications are the same as our baseline model outlined in Equation (9).

Panel A of Table 4 reports the results of Equation (10). We find that all environmental rating scores are negatively affected by firm-specific FX volatility. The results are consistent with our baseline regressions and the increased carbon intensity levels. Poor environmental performance in subcategories, especially environmental innovation, suggests that firms facing more volatile exchange rates may postpone irreversible environment-related projects, such as the adoption of green technology and investment in eco-efficient supply chains. Consistent results are found when we cluster the standard errors at the firm level (Internet Appendix Table A8) and when we measure FX volatility based on the GARCH model (Internet Appendix Table A9).

We also collect news about firm-specific environmental incidents from the RepRisk dataset, as such news reflects the public's concerns about firms' environmental performance and thus serves as an inverse indicator. We estimate the following Poisson regressions:

$$\mathbb{E}[Event_{f,t+1}|X] = exp\{\alpha + \beta \cdot FX\ Vol\ (Exposure\ Weighted)_{f,t} + \mathbf{X}_{f,t} + \Phi_f + \Phi_{market,t} + \Phi_{ind,t}\}, \tag{11}$$

in which $Event_{f,t+1}$ denotes *Events*, *Events (Severity)*, *Events (Severity-Novelty)*, *Events (Severity-Reach)*, and *Events (Severity-Novelty-Reach)* of firm f in year $t+1$. *Events* denotes the number of environmental events a firm is involved in a year. *Events (Severity)* denotes a firm's number of environmental events weighted by their severity score in a year. *Events (Severity-Novelty)* denotes a firm's number of environmental events weighted by their severity scores times novelty scores in a year. *Events (Severity-Reach)* and *Events (Severity-Novelty-Reach)* are defined similarly based on the corresponding combinations of different scores. All other variables have been defined earlier, and all estimation settings are the same.

Our estimation is based on 4,630 observations of 658 unique firms from the year 2007 (the first year of RepRisk data) to 2020.

The estimation results of Equation (11) are reported in Panel B of Table 4. We find that, across all columns, the frequency of environmental issues is positively related to firm-specific, exposure-weighted FX volatility. This finding is consistent with our prior results based on emissions and environmental ratings. Given that our measures of environmental issues are actual news raising the public's concerns about a firm, our empirical evidence points to real environmental risk. We also find consistent results by clustering the standard errors at the firm level in Internet Appendix Table A10 and estimating volatility based on the GARCH model in Internet Appendix Table A11.

[Place Table 4 Here]

3.3. Identification Strategy

It is important to know whether the reported positive relation between FX risk and firms' carbon intensity has any causal implication. A key concern is that both foreign revenue and carbon intensity result from firms' endogenous decisions, raising the possibility that omitted variables may drive both outcomes. To establish a causal interpretation of our baseline results, we leverage two sets of events that substantially change firms' FX risk: (1) shifts in exchange rate regimes and (2) the introduction of new FX derivative products by the Chicago Mercantile Exchange (CME). We would not dismiss firms' anticipation of those events. However, their occurrence still constitutes legitimate exogenous changes as their expected probability switches to one. In addition, firms' existing exposure shares are decided before the event, which enhances the degree of random assignments. Moreover, unlike the conventional Bartik instrument that assumes the sum of exposure shares equal to one, our setting does not impose this constraint, as firms' foreign revenue shares do not necessarily sum to a fixed value. Borusyak, Hull, and Jaravel (2022) demonstrate that the incomplete share method remains valid under the assumption of conditional shock exogeneity as long as the sum of exposure shares is properly accounted for in the analysis.

3.3.1. Changes in exchange rate regimes

Our first event sets is the exchange rate regime change. Firms will encounter increased FX risk if their domestic or major foreign currencies shift from a fixed regime to a floating regime. For instance, global exchange rate volatility increased dramatically following the collapse of the Bretton Woods system (Smith Jr, Smithson, and Wilford, 1989). The timing of such changes is beyond the control of individual firms. Following the classification of exchange rate regimes by Ilzetzki, Reinhart, and Rogoff (2019), we define an exchange rate system as floating if the exchange rate is freely floating and as fixed otherwise. We replace the *FX Vol* (*Exposure Weighted*) in Equation (9) with two firm-specific exchange regime changes and estimate the following regression:

$$\begin{aligned} Carbon_{f,t+1} = \; & \alpha + \beta_1 \cdot FixedToFloat\ (Exposure\ Weighted)_{f,t} + \beta_2 \cdot FloatToFixed\ (Exposure\ Weighted)_{f,t} \\ & + \mathbf{X}_{f,t} + \Phi_f + \Phi_{market,t} + \Phi_{ind,t} + \epsilon_{f,t}, \end{aligned} \tag{12}$$

where $Carbon_{f,t+1}$ is the scope 1 or scope 3 carbon intensity from upstream operations for firm f in year t; $FixedToFloat\ (Exposure\ Weighted)_{f,t}$ and $FloatToFixed\ (Exposure\ Weighted)_{f,t}$ denote the percentage of firm revenue affected by the floating-to-fixed and fixed-to-floating regime changes, respectively, as defined in Section 2.1.2. The variables are conditional measures that denote the proportion of the firm's foreign sales affected during the year of an exchange rate regime change and are set to zero in all other periods. In addition, the variable is set to zero whenever the exchange rate system, whether freely floating or fixed, remains unchanged from the previous year. The variable construction has been detailed in Section 2.1.2. The remaining specifications are the same as our baseline model outlined in Equation (9).

Table 5 reports the results of estimating Equation (12). As shown in Table 5, the estimated effects of fixed-to-float transitions (i.e., increased FX risk) are negative and statistically significant for firm carbon emissions. The estimated effects of float-to-fixed transitions (i.e., reduced FX risk) hold the opposite sign. In other words, firms with more exposure to exchange rates switching from floating to fixed increase their carbon emissions more. Similarly, firms with more exposure to exchange rates switching from fixed to floating reduces their carbon emissions more. These results not only confirm our baseline findings but also support a causal effect of firm-specific, exposure-weighted FX fluctuations on carbon emissions.

[Place Table 5 Here]

3.3.2. Launch of new currency products

Our second event sets is the launch of new FX derivative products on the Chicago Mercantile Exchange (CME), which was staggered in time and only affected firms located or trading in specific markets. During our sample periods, the CME introduced several new products for currencies included in our sample in three distinct years: 2004 (Polish Zloty, Hungarian Forint, Czech Koruna), 2006 (Korean Won, Israeli Shekel), and 2013 (Indian Rupee). Since FX derivatives are efficient tools for international firms to hedge their FX risk exposure,[19] we expect that after their introduction, firms could take advantage of liquid products to protect themselves against uncertain FX rates.

We estimate the following empirical model:

$$Carbon_{f,t+1} = \alpha + \beta \cdot CME\ Derivative\ (Exposure\ Weighted)_{f,t} + \mathbf{X}_{f,t} + \Phi_f + \Phi_{market,t} + \Phi_{ind,t} + \epsilon_{f,t}, \quad (13)$$

where $Carbon_{f,t+1}$ is the scope 1 or scope 3 carbon intensity from upstream operations for firm f in year t; $CME\ Derivative\ (Exposure\ Weighted)_{f,t}$ is the percentage of foreign revenue affected by the CME launch of new currency products and the construction details are outlined in Section 2.1.2. We include firm-year controls and a set of fixed effects the same as those in our baseline model.

[Place Table 6 Here]

Table 6 presents the estimation results for Equation (13). We find that after the CME shocks, firms affected more by such shocks reduce their carbon emissions compared to those being affected less. Our findings are consistent with previous studies that document that firms reduce operational hedging when more liquid FX instruments are available (Hoberg and Moon, 2017).

In order to check for the absence of any pre-existing trends before the events, we conduct a dynamic event analysis using a subsample from $e - 5$ to $e + 5$, with event year e as the reference year. We define the event year e for firm f as the earliest year when the CME introduced new currency products for the

[19] We acknowledge that some firms may rely on OTC contracts; however, such firms still benefit from increased market liquidity and cross-market arbitrages (Hoberg and Moon, 2017).

home market of firm f or foreign markets in which firm f traded. In particular, we estimate the following regressions:

$$Carbon_{f,t+1} = \alpha + \sum_{y=-5,y\neq 0}^{+5} \beta_y \cdot D_{f,e-1} \cdot Event_{f,e+y} + \mathbf{X}_{f,t} + \Phi_f + \Phi_{market,t} + \Phi_{ind,t} + \epsilon_{f,t}, \qquad (14)$$

where $D_{f,e-1}$ is firm f's foreign income (treatment intensity) prior to the event year e and $Event_{f,e+y}$ is the year to event dummy that equals one y years to the event and zero otherwise. All other variables have been defined earlier. The event year e serves as the reference year and the coefficient estimate in this year is omitted from the regression analysis.

The estimation results for the coefficients on β_y are illustrated in Figure 1: Panels A and B present the results of using the scope 1 and scope 3 (Upstream) carbon intensity as the dependent variables, respectively. The dots denote the estimated coefficients and vertical lines denote the 90% confidence intervals. The figure suggests an insignificant difference among firms with different exposures to FX risk before the shock, which supports the parallel trend assumption; on the other hand, we observe a persistent FX volatility effect after the shock, confirming the causal effect of firm-specific FX risk.

[Place Figure 1 Here]

4. Corporate Incentives and Policies

In this section, we implement more empirical tests to understand the incentives of and the policies adopted by firms in responding to FX risk, and how such decisions result in changes in their emissions. These analyses not only offer more micro-level evidence for the mechanisms underlying the FX risk-emission relation but also offer specific policy implications.

4.1. Environmental Investment

We have implemented an extensive list of analyses showing that firms experiencing higher FX risk tend to have more intensive carbon emissions. This may be due to underinvestment in pollution abatement technologies (Akey and Appel, 2021). Firms might reduce or postpone environmental investments when facing revenue uncertainty in order to maintain their daily operations. Compared with physical investments, environmental investments are more sensitive to financial frictions, as physical capital is more collateralizable for firms and can ease financial constraints (Fang, Hsu, and Tsou, 2024). To empirically investigate the firms' environmental investment, we estimate the following regression:

$$EnvInvest_{f,t+1} = \alpha + \beta \cdot FX\ Vol\ (Exposure\ Weighted)_{f,t} + \mathbf{X}_{f,t} + \Phi_f + \Phi_{market,t} + \Phi_{ind,t} + \epsilon_{f,t}, \quad (15)$$

where $EnvInvest_{f,t+1}$ denotes the proxies of pollution abatement investment of in year $t+1$. We employ two proxies for pollution abatement investment: 1) the environmental expenditure scaled by capital expenditure; 2) the natural logarithm of total amount of environmental expenditure in US dollars following the literature (Jing et al., 2024; Jiang, Lin, and Lin, 2014). Since environmental expenditure is self-reported by firms, we restrict our sample to those firms that disclose such information and thus have a smaller sample. The remaining settings are the same as our baseline model.

Table 7 presents the estimation results of Equation (15), which shows that firm-specific FX risk leads to a reduction in both the proportion of environmental expenditure to total capital expenditure (column (1)) and the total amount of environmental expenditure (column (2)). These results have the following implications: first, a larger reduction in environmental investment relative to physical investment suggests that the FX risk-emission relation we document is different from the effect on regular investment. In fact, it is consistent with the proposition of Fang, Hsu, and Tsou (2024) that financial constraints make firms prioritize physical investment over environmental investment. Second, our use of environmental investment data offers micro-evidence for how FX risk leads to higher scope 1 emissions: firms facing higher FX risk tend to reduce environmental investment, which results in more emissions.

[Place Table 7 Here]

4.2. Operational Adjustment

4.2.1. Supply chain restructuring

As shown in our baseline results, firms' FX risk leads to higher carbon intensity associated with their upstream rather than downstream. We are thus motivated to analyze how exposure-weighted FX volatility changes firms' contractual relations with suppliers and customers. Specifically, we estimate the following regression:

$$\begin{aligned} Contract_{f,t+1} = \; & \alpha + \beta \cdot FX\ Vol\ (Exposure\ Weighted)_{f,t} + Expired_{f,t} + \mathbf{X}_{f,t} \\ & + \Phi_f + \Phi_{market,t} + \Phi_{ind,t} + \epsilon_{f,t}, \end{aligned} \tag{16}$$

where the $Contract_{f,t+1}$ denotes measures for the firm's contractual relations with its suppliers (customers) in year $t + 1$, which includes *Contract Num*, *Contract Num*, *Contract Num*, and *Contract Duration* for suppliers or customers.[20] As defined earlier, *Contract Num* denotes the number of newly initiated contracts with suppliers or customers, *Contract Num (Private)* denotes the number of newly initiated contracts with private suppliers or customers, *Contract Num (New Partner)* denotes the number of newly initiated contracts with new suppliers or customers, and *Contract Duration* denotes the average duration of newly initiated contracts with suppliers (months). We also control for $Expired_{f,t}$, the number of expired contracts with suppliers (customers) in year t. The remaining specifications are the same as our baseline model.

Table 8 presents the estimation results for Equation (16) – Panel A is for contracts with suppliers and Panel B is for contracts with customers. As shown in Panel A for supplier contracts, increased FX risk reduces the number and the average duration of newly initiated contracts in the following year. More importantly, increased FX risk increases the number of contracts with new suppliers and private suppliers. These findings confirm our baseline results on scope 3 emissions by showing that firms adjust their supplier sourcing which may lead to more carbon emissions.[21] More short-term contracts make it easier for firms to keep their supply chain flexible, which is good for firms' operational adjustment but bad for carbon emissions because it reduces the incentives for suppliers in long-term investment such as environmental ones. In addition, the increased number of private and new suppliers leads to more small-size orders and more transportation, resulting in increased greenhouse gas emissions within the supply chain. Compared to large public suppliers, small private ones have fewer sustainability management tools

[20] We do not analyze the revenue percentage of the contract because it is not required to be disclosed and less than 5% of the data is available.

[21] They are also in line with the theoretical operational hedging frameworks, which suggest that firms tend to keep flexible productions and that switch-option values dominate the cost under extreme uncertain exchange rates (Kamrad and Siddique, 2004).

and resources to reduce the emission levels (Hörisch, Johnson, and Schaltegger, 2015). All these results provide empirical evidence that the operational policies adopted by firms to mitigate the influence of FX uncertainty may end up increasing supply-chain carbon emissions.

In Panel B for contracts with customers, we find no significant results in all columns except column (3) for the number of new customers, in which the coefficient on exposure-weighted FX volatility is significantly negative. These results suggest that firm-specific FX risk reduces new customers, which is intuitive as firms facing greater FX risk are less likely to take new orders that may further increase their FX risk exposure. Another possibility is that these firms are subject to higher financial constraints and thus have lower capacity and incentive to supply new customers.

[Place Table 8 Here]

4.2.2. Costs of switching suppliers

As shown in previous studies (Huchzermeier and Cohen, 1996; Kamrad and Siddique, 2004; Kazaz, Dada, and Moskowitz, 2005), the cost of switching suppliers is an important determinant of firms' optimal operation adjustment policy. The concept suggests that if switching from existing suppliers to new ones is less costly, the option to allocate production to particular locations with more stable exchange rates is more appealing (Ding, Dong, and Kouvelis, 2007). To empirically test the hypothesis, we estimate the following model:

$$\begin{aligned} Y_{f,t+1} = \; & \alpha + \beta_1 \cdot FX\ Vol\ (Exposure\ Weighted)_{f,t} \cdot AccountPayable_{f,t} + \beta_2 \cdot AccountPayable_{f,t} \\ & + \beta_3 \cdot FX\ Vol\ (Exposure\ Weighted)_{f,t} + \mathbf{X}_{f,t} + \Phi_f + \Phi_{market,t} + \Phi_{ind,t} + \epsilon_{f,t}, \end{aligned} \tag{17}$$

where the $Y_{f,t+1}$ represents the measures of carbon intensity or contractual relation of firm f in year $t+1$ and $AccountPayable_{f,t}$ is the account payable scaled by sales of firm f in year t. A higher ratio of accounts payable to sales reflects a stronger market power against suppliers and thus negatively relates to the firm's cost to switch suppliers (Dass, Kale, and Nanda, 2015). In other words, high $AccountPayable$ denotes lower costs to switching suppliers (and higher operational flexibility). The remaining specifications are the same as our baseline model.

Table 9 presents the results of estimating Equation (17). Columns (1) and (2) show that the interaction terms (*FX Vol* (*Exposure Weighted*) · *AccountPayable*) are positive and significant for carbon intensity, indicating that firms tend to increase emission intensity when they have greater flexibility in switching suppliers. In Columns (3) to (6), the coefficients on the interaction terms are significant and in the same signs as FX risk in Equation (16), suggesting that firms with greater market power respond to FX risk by using even more new or private suppliers and further shortening the contract duration. As discussed earlier, such a practice likely leads to even more carbon emissions due to cost-down and the lack of long-term commitment. These findings highlight that firms' operational flexibility actually exacerbates the impact of FX risk on carbon emissions.

[Place Table 9 Here]

4.3. Financial Constraints

Previous studies have documented that financial constraints play a vital role for carbon emissions (Bartram, Hou, and Kim, 2022; Xu and Kim, 2022). Increasing carbon emissions can potentially harm the long-term value of a firm, yet it may lead to a short-term boost in financial performance (Maeckle, 2024). When foreign markets create uncertainty to firms, financially constrained ones are more sensitive to FX risk and are thus likely increase their carbon emissions to maintain their financial performance. We empirically examine if the effect of firm-specific FX risk is more pronounced for financially constrained firms by estimating the following model:

$$\begin{aligned} Y_{f,t+1} = \; & \alpha + \beta_1 \cdot FX\ Vol\ (Exposure\ Weighted)_{f,t} \cdot FinConstraint_{f,t} + \beta_2 \cdot FinConstraint_{f,t} \\ & + \beta_3 \cdot FX\ Vol\ (Exposure\ Weighted)_{f,t} + \mathbf{X}_{f,t} + \Phi_f + \Phi_{market,t} + \Phi_{ind,t} + \epsilon_{f,t}, \end{aligned} \tag{18}$$

where $Y_{f,t+1}$ is the carbon intensity, environmental expenditure, or contractual relationship of firm f in year t; $FinConstraint_{f,t}$ denotes the measures of firm f's financial constraint in year t. We consider two indices to proxy the extent of financial constraints: the *KZ* index proposed by Kaplan and Zingales (1997) and the *WW* index proposed by Whited and Wu (2006). A greater value of either index indicates a higher degree of financial constraints. The remaining specifications are the same as in our baseline model.

Table 10 presents the results of estimating Equation (18), where Panel A (B) presents the results using *KZ* (*WW*) to measure financial constraints. The estimated coefficients of the interaction terms, $FX\ Vol\ (Exposure\ Weighted) \cdot FinConstraint$, are all statistically significant and are in the same direction as that of exposure-weighted FX volatility, confirming that the effect of FX risk is more pronounced for more financially constrained firms. It is worth noting that financially constrained firms reduce or postpone environmental expenditures more than physical investments, as shown in column (3) of both panels of Table 10. These results support our proposition that financial pressure is one of the driving forces for FX risk to increase carbon emissions.

More importantly, we note that the coefficient estimates of $FX\ Vol\ (Exposure\ Weighted)$ are consistent with the baseline results as shown in Table 3, Table 7, and Table 8. The fact that the effect of FX risk alone remains statistically significant in our interacted regressions indicates that financial constraints are *not* the only reason for FX risk to increase carbon emissions.

[Place Table 10 Here]

4.4. Use of Currency Derivatives

Firms exposed to greater FX volatility may use currency derivatives to hedge their FX risk. When they do so, they are less subject to financial pressure from exchange rate fluctuations; thus, the negative impact on carbon emissions is mitigated as shown in Section 4.3. To further substantiate this viewpoint, we consider firms' use of currency derivatives by estimating the following model:

$$\begin{aligned} Y_{f,t+1} = \ & \alpha + \beta_1 \cdot FX\ Vol\ (Exposure\ Weighted)_{f,t} \cdot FX\ Derivative_{f,t} + \beta_2 \cdot FX\ Derivative_{f,t} \\ & + \beta_3 \cdot FX\ Vol\ (Exposure\ Weighted)_{f,t} + \mathbf{X}_{f,t} + \Phi_f + \Phi_{market,t} + \Phi_{ind,t} + \epsilon_{f,t}, \end{aligned} \tag{19}$$

where $Y_{f,t+1}$ is the carbon intensity or contractual relationships of firm f in year $t+1$; $FX\ Derivative_{f,t}$ is a dummy variable that equals one if firm f reports currency derivatives use in its annual report of year t and zero otherwise (more details are provided in Section 2.3). The remaining specifications are the same as our baseline model.

[Place Table 11 Here]

Table 11 presents the results of estimating Equation (19). The interaction terms ($FX\ Vol\ (Exposure\ Weighted) \cdot FX\ Derivative$) are significantly negative in each case—opposite in sign to the estimated coefficients of $FX\ Vol\ (Exposure\ Weighted)$. The results suggest that the use of currency derivatives can effectively mitigate the risk of uncertain FX fluctuations and reduce firms' operational adjustments (such as switching to new suppliers or using more short-term contracts). The use of currency derivatives is also economically meaningful: it mitigates the marginal effect of FX risk on scope 1 emission intensity by 34%.[22] More importantly, our evidence confirms that the FX-emission relation we present is indeed specifically attributable to firms' reactions to exchange rate fluctuations.

4.5. Reactions to Carbon Tax

Many countries or subnational jurisdictions have implemented Pigovian carbon tax systems. For example, the European Union has carbon emission regulations that require importers of carbon-intensive goods to pay a charge. We expect that the FX risk effect on carbon emissions to be mitigated if they locate or trade with markets with a carbon tax. To empirically test our prediction, we estimate the following model:

$$\begin{aligned} Carbon_{f,t+1} = \ & \alpha + \beta_1 \cdot FX\ Vol\ (Exposure\ Weighted)_{f,t} \cdot CarbonTax_{f,t} + \beta_2 \cdot CarbonTax_{f,t} \\ & + \beta_3 \cdot FX\ Vol\ (Exposure\ Weighted)_{f,t} + \mathbf{X}_{f,t} + \Phi_f + \Phi_{market,t} + \Phi_{ind,t} + \epsilon_{f,t} \end{aligned} \tag{20}$$

where $Carbon_{f,t+1}$ is the scope 1 or scope 3 upstream carbon intensity of firm f in year $t+1$; $CarbonTax_{f,t}$ is the percentage of domestic income subject to carbon tax of firm f in year t. We also consider another measure, $CarbonTax\ (Customer)_{f,t}$, that represents the proportion of foreign revenues that firm f generates from countries that have implemented a carbon tax in year t. The carbon tax data are obtained from the global carbon pricing databases constructed by Dolphin and Xiahou (2022) – the detailed carbon tax implementation regimes for our sample countries are presented in Table A2. The remaining specifications are the same as our baseline model.

Table 12 presents the results of estimating Equation (20). Columns (1) and (3) are based on firms' domestic carbon tax, and columns (2) and (4) are based on carbon taxation in their foreign markets.

[22] 34% is calculated as: (-20.33 × 0.53 + 7.77) (marginal effects of FX Derivative) / (16.44 × 0.53) (marginal effects of FX Volatility), where 0.53 is the standard deviation of exposure-weighted FX volatility in our sample.

As shown in Table 12, the estimated coefficients of interaction terms, *FX Vol* (*Exposure Weighted*) · *CarbonTax*, are negative and statistically significant. Both the carbon tax imposed by firms' home country and their customers' countries matter, aligning with studies suggesting that firm carbon abatement policies are determined by current or anticipated future carbon regulations (Ramadorai and Zeni, 2024). We note that the economic magnitude of the interaction terms for foreign markets is greater than that for domestic countries. This is intuitive in the following sense: if firm X is fully dependent on a foreign market and if firm Y is fully reliant on domestic market, then firm X is subject to higher pressure to reduce emissions after carbon tax being adopted in both countries because it incurs transportation. Moreover, our results suggest that our baseline FX risk-emission relation is specific to carbon emissions but not other corporate operation issues.

[Place Table 12 Here]

5. Conclusion

In this paper, we have empirically demonstrated that foreign exchange (FX) risk has a significant impact on firms' greenhouse gas (GHG) emissions. Our findings reveal a positive relation between firms' exposure-weighted FX volatility and their carbon intensity in both their direct operations (scope 1) and upstream activities (scope 3). This relation is further supported by evidence of lower environmental scores from rating agencies and increased negative environmental news coverage for firms facing higher FX uncertainty. We design identification strategies based on the shifts in exchange rate regimes and the introduction of currency derivatives, and find supportive evidence for a causal effect of FX risk.

Further empirical analyses shed light on firms' incentives and policies. We find that multinational firms adjust their operations in response to FX risk by cutting environmental investments, reducing long-term contracts with suppliers, and using short-term contracts, particularly with private suppliers who may have less stringent environmental standards. These effects are more more pronounced among financial constrained firms, supporting the financial pressure due to FX risk to be the underlying mechanism. Moreover, firms' use of operational flexibility and cost-efficient procurement contributes to higher carbon emissions, especially for firms with lower costs associated with switching suppliers.

We also consider the mitigating roles of the use of FX derivatives and carbon tax, which deliver policy implications. Firms using FX derivatives are less inclined to alter their supply chain strategies in ways that increase emissions, highlighting the mitigating role of financial hedging. In addition, carbon tax mitigates the impact of FX risk on carbon emissions, supporting the effectiveness of such policies in internalizing the environmental costs of corporate financial and operational decisions. Moreover, the result that firm-specific FX risk contributes to increased carbon emissions, particularly for financially constrained firms, suggests that policies aimed at fostering greater exchange rate stability or easing financial constraints could indirectly support environmental goals.

While our study provides novel firm-level evidence of a significant microeconomic environmental consequence of a key macroeconomic risk—FX volatility, it is important to note that our analysis primarily focuses on these firm-level responses and their immediate environmental impacts. We acknowledge that we cannot fully capture the broader implications for aggregate global supply chain dynamics, such as large-scale shifts in international trade patterns or the overall equilibrium effects in global markets.

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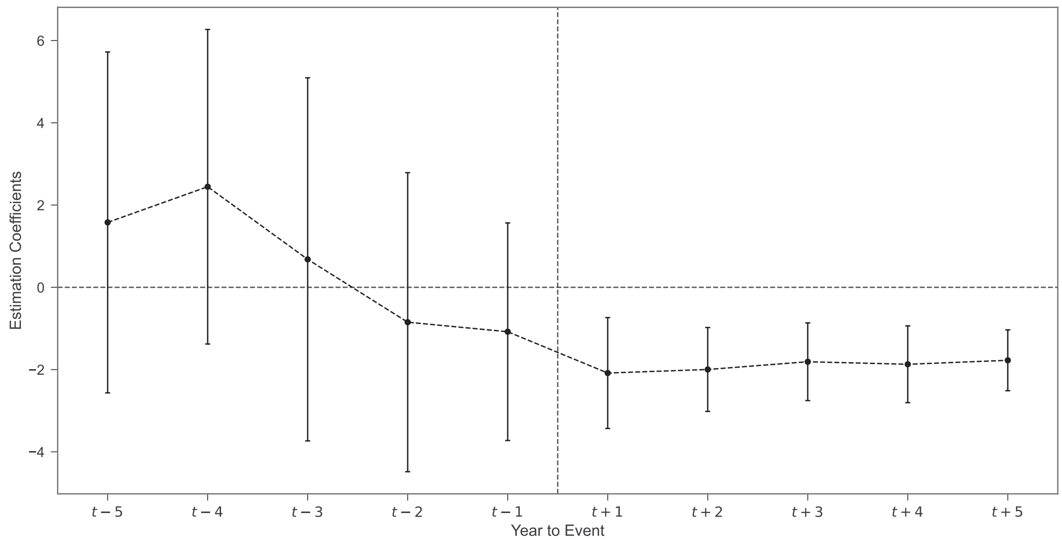
Tables and Figures

Figure 1. CME FX Derivatives: Pre-trend Analysis

This figures plot the dynamic effects of CME currency product launch events spanning from year $t-5$ to $t+5$, where t refers to the earliest year for firms. The dots indicate the estimated coefficients from OLS regressions in Equation (14), and the vertical lines denote the 90% confidence intervals. The event year t serves as the reference year and is omitted from the regression analysis. Panel A and B present the results of using the scope 1 and scope 3 (Upstream) carbon intensity as the dependent variables, respectively.

Panel A. Scope 1 Carbon Intensity



Panel B. Scope 3 (Upstream) Carbon Intensity

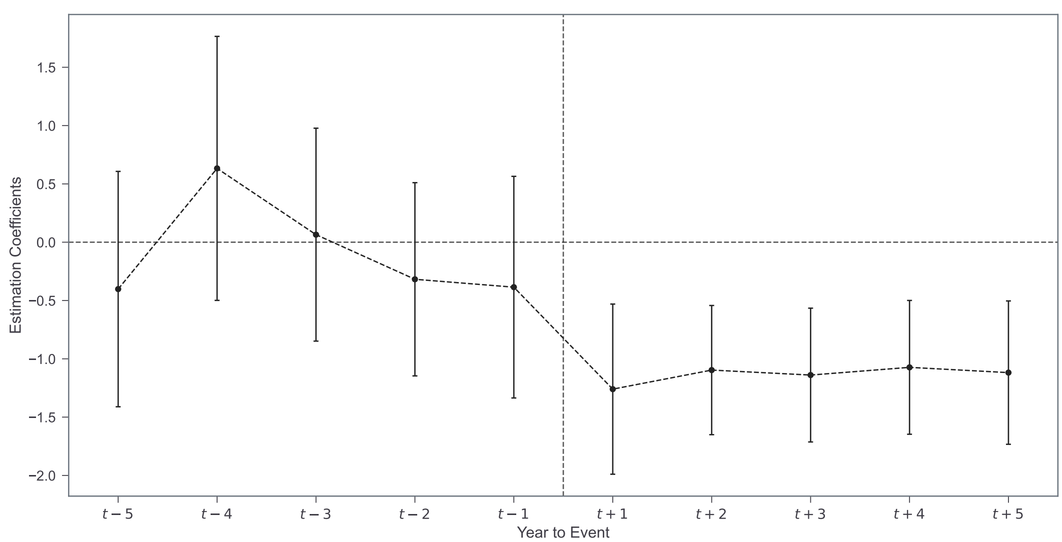


Table 1. Summary Statistics

This table presents the summary statistics for our firm-year samples. The OLS sample for firm carbon emissions (*Scope 1* to *Scope 3*) consists of 11,323 firm-year observations associated with 2,159 firms over the year 2003 to 2020. The OLS sample for firm ESG rating scores (*Environmental, Resource Use, Emission, Environmental Innovation*) consists of 5,187 firm-year observations associated with 812 firms over the year 2003 to 2020. The Possion sample for firm pollution news events (*Events, Events (Severity), Events (Severity-Novelty), Events (Severity-Reach), Events (Severity-Novelty-Reach)*) consists of 4,630 observations associated with 658 firms over the year 2007 to 2020. Variables are defined in Internet Appendix Table A1.

Variable	Obs	Mean	Std	25%	50%	75%
Dependent Variable						
Scope 1	11,323	119.81	330.81	9.35	19.95	58.03
Scope 2	11,323	46.68	66.69	12.31	23.60	47.72
Scope 3 (Up)	11,323	226.54	160.50	114.23	187.90	306.28
Scope 3 (Down)	5,741	773.43	1475.24	54.31	230.52	613.60
Environmental	5,187	62.35	20.49	48.82	65.14	78.12
Resource Use	5,187	65.15	24.91	48.05	69.35	86.22
Emission Reduction	5,187	64.15	26.11	46.22	69.28	86.36
Environmental Innovation	5,187	57.62	26.36	36.52	57.08	81.25
Environmental Expense / Capex	2,395	0.14	0.19	0.02	0.06	0.18
log(Environmental Expense)	2,395	16.54	3.13	15.49	16.93	18.31
Events	4,630	1.16	3.78	0.00	0.00	1.00
Events (Severity)	4,630	1.68	5.43	0.00	0.00	1.00
Events (Severity-Novelty)	4,630	2.71	7.82	0.00	0.00	2.00
Events (Severity-Reach)	4,630	2.71	7.82	0.00	0.00	2.00
Events (Severity-Novelty-Reach)	4,630	4.78	12.85	0.00	0.00	4.00
Contract Num (Supplier)	4,352	10.07	18.08	2.00	4.00	10.00
Contract Num (Private Supplier)	4,352	1.76	3.45	0.00	1.00	2.00
Contract Num (New Supplier)	4,352	4.33	7.73	0.00	2.00	5.00
Contract Duration (Supplier)	4,352	14.97	11.59	7.50	13.00	19.84
Contract Num (Customer)	4,888	12.28	17.88	2.00	5.00	14.00
Contract Num (Private Customer)	4,888	4.37	8.41	0.00	1.00	4.00
Contract Num (New Customer)	4,888	4.96	8.57	0.00	2.00	5.00
Contract Duration (Customer)	4,888	14.37	11.06	7.00	12.50	19.00
Independent Variable						
FX Vol (Exposure Weighted)	11,323	0.21	0.53	0.04	0.09	0.21
FX GarchVol (Exposure Weighted)	11,323	0.64	0.96	0.19	0.36	0.72
CME Derivative (Exposure Weighted)	11,323	18.26	25.90	3.74	6.77	14.96
FixedToFloat (Exposure Weighted)	11,323	0.18	3.59	0.00	0.00	0.00
FloatToFixed (Exposure Weighted)	11,323	0.10	2.53	0.00	0.00	0.00
FX Derivative	4,075	0.47	0.50	0.00	0.00	1.00

Continued on next page

Table 1. Summary Statistics - Continued

KZ	9,775	-3.12	5.12	-4.68	-1.36	0.38
WW	10,171	-1.00	0.08	-1.06	-1.00	-0.94
AccountPayable	10,608	0.11	0.07	0.07	0.10	0.15
CarbonTax	11,323	28.32	35.81	0.00	0.00	64.76
CarbonTax (Customer)	11,323	23.02	20.64	7.74	17.01	33.14
Control Variable						
Expired Contract Num (Supplier)	4,352	8.38	16.13	1.00	3.00	8.00
Expired Contract Num (Customer)	4,888	10.44	17.14	2.00	4.00	11.00
FX Rate Change	11,323	0.68	2.96	-0.83	0.59	2.01
Foreign Income	11,323	39.86	15.22	27.95	36.06	48.67
TobinQ	11,323	1.68	1.06	1.03	1.34	1.92
Tangibility	11,323	0.25	0.16	0.12	0.23	0.35
Leverage	11,323	0.21	0.14	0.10	0.20	0.31
Pretax Income	11,323	0.07	0.07	0.03	0.06	0.10
Pretax Income Vol	11,323	0.04	0.03	0.02	0.03	0.05
Size	11,323	21.62	1.71	20.31	21.62	22.82
Firm Age	11,323	2.95	0.43	2.77	3.04	3.26

Table 2. Lists of Markets

This table presents the distribution the markets (ISO 3-digit codes) of the sample firms in our main analyses, including the number of unqiue firms, the number of firm-year observations, and the first and last year of each market.

Market	Firm Num	Obs	Year Start	Year End
AUS	83	391	2005	2020
BEL	21	123	2003	2020
DEU	127	866	2003	2020
DNK	31	207	2003	2020
ESP	34	207	2007	2020
FIN	31	235	2003	2020
FRA	115	867	2003	2020
GBR	144	1,134	2003	2020
HKG	47	156	2007	2020
IND	114	447	2004	2020
ITA	45	228	2006	2020
JPN	428	2,394	2003	2020
KOR	232	817	2008	2020
MYS	66	238	2007	2020
NLD	30	251	2003	2020
NOR	31	166	2003	2020
SGP	31	150	2006	2020
SWE	123	630	2003	2020
THA	29	115	2010	2020
TWN	362	1,533	2003	2020
ZAF	35	168	2006	2020
Total	2,159	11,323	2003	2020

Table 3. Carbon Emissions

This table presents the OLS regression results for Section 3.1. The dependent variables are the firm's carbon intensity in different scopes in the next year (year $t+1$). The key independent variable is the firm-specific FX volatility in year t. Industry×Year fixed effects, Market×Year fixed effects, firm fixed effects and firm-year controls including *FX Rate Change, Foreign Income, TobinQ, Tangibility, Leverage, Pretax Income, Pretax Income Vol, Size and Firm Age*, are included in all regressions. Standard errors are clustered at the market level, and t-statistics are in parentheses. Variables are defined in Internet Appendix Table A1. *, **, and *** indicate significance at 1%, 5% and 10%.

	(1) Scope 1	(2) Scope 2	(3) Scope 3 (Up)	(4) Scope 3 (Down)
FX Vol (Exposure Weighted)	5.01***	-0.68	2.87***	-11.46
	(3.00)	(-0.48)	(3.57)	(-0.41)
FX Rate Change	-0.85*	0.06	-0.19	0.06
	(-1.71)	(0.22)	(-0.88)	(0.01)
Foreign Income	-0.12	0.06	0.01	-0.28
	(-1.03)	(1.10)	(0.16)	(-0.13)
TobinQ	0.41	-0.60	-1.65*	18.89
	(0.33)	(-1.03)	(-1.88)	(1.30)
Tangibility	-80.96	-7.16	51.98**	369.19
	(-1.36)	(-0.40)	(2.08)	(0.88)
Leverage	25.96	1.70	-11.91	-252.21
	(0.75)	(0.16)	(-0.91)	(-1.13)
Pretax Income	-31.16	-27.63***	-20.82	-174.62
	(-1.13)	(-2.81)	(-0.70)	(-0.65)
Pretax Income Vol	178.49*	6.51	48.92*	886.60*
	(1.91)	(0.32)	(1.77)	(1.71)
Size	-21.91**	-4.79	-5.01	151.08**
	(-2.30)	(-1.63)	(-0.86)	(2.18)
Firm Age	5.48	31.45**	-14.06	-290.39
	(0.16)	(2.22)	(-1.10)	(-0.73)
Constant	Yes	Yes	Yes	Yes
Market×Year FE	Yes	Yes	Yes	Yes
Industry×Year FE	Yes	Yes	Yes	Yes
Firm FE	Yes	Yes	Yes	Yes
Cluster	Market	Market	Market	Market
Observations	11,323	11,323	11,323	5,741
R-squared	0.95	0.86	0.96	0.91

Table 4. ESG Rating and News

This table presents the OLS regression results for Equation (10) and Possion regression results for Equation (11). The dependent variables are the firm's ASSET4 environmental rating scores and the number of firm's pollution news events weighted with different schemes in the next year (year $t+1$). The key independent variable is firm-specific FX volatility in year t. Industry×Year fixed effects, Market×Year fixed effects, firm fixed effects and firm-year controls including *FX Rate Change, Foreign Income, TobinQ, Tangibility, Leverage, Pretax Income, Pretax Income Vol, Size and Firm Age*, are included in all regressions. Standard errors are clustered at the market level, and t-statistics are in parentheses. Panel A and B present the regression results of ESG ratings and pollution news events, respectively. Variables are defined in Internet Appendix Table A1. *, **, and *** indicate significance at 1%, 5% and 10%.

Panel A. ESG Ratings

	(1) Environment	(2) Resource Use	(3) Emission Reduction	(4) Environmental Innovation
FX Vol (Exposure Weighted)	-1.44***	-1.03**	-1.89***	-1.19**
	(-5.99)	(-2.62)	(-7.04)	(-2.51)
FX Rate Change	0.26***	0.08	0.31***	0.38**
	(3.34)	(0.87)	(3.68)	(2.13)
Foreign Income	-0.02	0.00	-0.05*	-0.01
	(-0.58)	(0.04)	(-1.74)	(-0.16)
TobinQ	1.00**	0.65	1.41**	0.95
	(2.45)	(0.73)	(2.20)	(1.18)
Tangibility	-6.39	-18.16**	-7.73	5.25
	(-1.02)	(-2.13)	(-0.61)	(0.71)
Leverage	-1.06	2.28	-0.75	-4.51
	(-0.18)	(0.51)	(-0.10)	(-0.53)
Pretax Income	-7.10	-9.97	-0.82	-10.61
	(-1.19)	(-1.35)	(-0.11)	(-1.62)
Pretax Income Vol	-22.91*	-39.31***	-21.20	-7.89
	(-1.77)	(-3.65)	(-1.11)	(-0.36)
Size	2.90*	3.32*	4.72***	0.59
	(2.05)	(1.84)	(4.40)	(0.19)
Firm Age	14.57*	12.21	2.97	29.00**
	(1.92)	(1.64)	(0.33)	(2.68)
Constant	Yes	Yes	Yes	Yes
Market×Year FE	Yes	Yes	Yes	Yes
Industry×Year FE	Yes	Yes	Yes	Yes
Firm FE	Yes	Yes	Yes	Yes
Cluster	Market	Market	Market	Market
Observations	5,187	5,187	5,187	5,187
R-squared	0.88	0.86	0.86	0.81

Panel B. Pollution News Events

	(1)	(2)	(3)	(4)	(5)
	Number of Pollution News Events				
	Events	Events (Severity)	Events (Severity-Novelty)	Events (Severity-Reach)	Events (Severity-Novelty-Reach)
FX Vol (Exposure Weighted)	0.19***	0.20***	0.21***	0.21***	0.21***
	(3.12)	(2.92)	(3.03)	(3.03)	(3.07)
FX Rate Change	-0.01	-0.02	-0.03	-0.03	-0.03
	(-0.86)	(-1.28)	(-1.38)	(-1.38)	(-1.40)
Foreign Income	-0.01*	-0.01*	-0.01	-0.01	-0.01
	(-1.83)	(-1.80)	(-1.55)	(-1.55)	(-1.39)
TobinQ	0.12**	0.13**	0.14**	0.14**	0.14**
	(2.20)	(2.04)	(2.30)	(2.30)	(2.38)
Tangibility	-0.88	-1.41	-1.46	-1.46	-1.55
	(-1.06)	(-1.51)	(-1.54)	(-1.54)	(-1.60)
Leverage	-1.06	-1.28	-1.12	-1.12	-1.02
	(-1.41)	(-1.64)	(-1.40)	(-1.40)	(-1.25)
Pretax Income	0.19	0.12	0.28	0.28	0.35
	(0.24)	(0.14)	(0.36)	(0.36)	(0.43)
Pretax Income Vol	0.68	0.72	1.16	1.16	1.48
	(0.59)	(0.53)	(0.71)	(0.71)	(0.78)
Size	0.91***	0.95***	0.94***	0.94***	0.95***
	(5.24)	(4.96)	(4.80)	(4.80)	(4.63)
Firm Age	0.33	0.26	0.06	0.06	-0.09
	(0.43)	(0.27)	(0.06)	(0.06)	(-0.10)
Constant	Yes	Yes	Yes	Yes	Yes
Market×Year FE	Yes	Yes	Yes	Yes	Yes
Industry×Year FE	Yes	Yes	Yes	Yes	Yes
Firm FE	Yes	Yes	Yes	Yes	Yes
Cluster	Market	Market	Market	Market	Market
Observations	4,630	4,630	4,630	4,630	4,630

Table 5. FX Regime Change

This table presents the OLS regression results for Equation (12). The dependent variables are the firm's scope 1 and 3 carbon intensity in the next year (year $t+1$). The key independent variables are the firm-specific FX rate regime change events (from fixed to freely floating, or vice versa) in year t. Industry×Year fixed effects, Market×Year fixed effects, firm fixed effects and firm-year controls including *FX Rate Change, TobinQ, Tangibility, Leverage, Pretax Income, Pretax Income Vol, Size and Firm Age*, are included in all regressions. Standard errors are clustered at the market level, and t-statistics are in parentheses. Variables are defined in Internet Appendix Table A1. *, **, and *** indicate significance at 1%, 5% and 10%.

	(1) Scope 1	(2) Scope 3 (Up)
FixedToFloat (Exposure Weighted)	0.94**	0.54***
	(2.60)	(3.29)
FloatToFixed (Exposure Weighted)	-1.03***	-0.41**
	(-5.50)	(-2.70)
FX Rate Change	-0.45	0.03
	(-0.91)	(0.18)
Foreign Income	-0.05	0.05
	(-0.46)	(0.57)
TobinQ	0.36	-1.68*
	(0.29)	(-1.91)
Tangibility	-81.26	51.83*
	(-1.37)	(2.08)
Leverage	26.67	-11.55
	(0.77)	(-0.87)
Pretax Income	-31.69	-21.12
	(-1.15)	(-0.72)
Pretax Income Vol	178.34*	48.83*
	(1.91)	(1.76)
Size	-22.19**	-5.15
	(-2.31)	(-0.87)
Firm Age	5.42	-14.09
	(0.15)	(-1.11)
Constant	Yes	Yes
Market×Year FE	Yes	Yes
Industry×Year FE	Yes	Yes
Firm FE	Yes	Yes
Cluster	Market	Market
Observations	11,323	11,323
R-squared	0.95	0.96

Table 6. CME FX Derivatives

This table presents the OLS regression results for Equation (13). The dependent variables are the firm's scope 1 and 3 carbon intensity in the next year (year $t + 1$). The key independent variable is the interaction of firm-specific exposure and CME currency product launch events (*CME Derivative*) in year t. Industry×Year fixed effects, Market×Year fixed effects, firm fixed effects and firm-year controls including *FX Rate Change, Foreign Income, TobinQ, Tangibility, Leverage, Pretax Income, Pretax Income Vol, Size and Firm Age*, are included in all regressions. Standard errors are clustered at the market level, and t-statistics are in parentheses. Variables are defined in Internet Appendix Table A1. *, **, and *** indicate significance at 1%, 5% and 10%.

	(1) Scope 1	(2) Scope 3 (Up)
CME Derivative (Exposure Weighted)	-0.99**	-0.33**
	(-2.53)	(-2.51)
FX Rate Change	-0.45	0.03
	(-0.92)	(0.18)
Foreign Income	0.02	0.07
	(0.15)	(0.79)
TobinQ	0.37	-1.67*
	(0.30)	(-1.91)
Tangibility	-78.96	52.68**
	(-1.36)	(2.11)
Leverage	27.04	-11.50
	(0.79)	(-0.87)
Pretax Income	-31.35	-20.92
	(-1.16)	(-0.71)
Pretax Income Vol	182.65*	50.30*
	(1.97)	(1.80)
Size	-22.39**	-5.19
	(-2.34)	(-0.88)
Firm Age	6.07	-13.83
	(0.17)	(-1.09)
Constant	Yes	Yes
Market×Year FE	Yes	Yes
Industry×Year FE	Yes	Yes
Firm FE	Yes	Yes
Cluster	Market	Market
Observations	11,323	11,323
R-squared	0.95	0.96

Table 7. Investments in Pollution Abatement

This table presents the OLS regression results for Equation (15). The dependent variables are the firm's environmental investment scaled by capital expenditure and the natural logarithm of environmental investment in the next year (year $t + 1$). The key independent variable is the firm-specific FX volatility in year t. Industry×Year fixed effects, Market×Year fixed effects, firm fixed effects and firm-year controls including *FX Rate Change, Foreign Income, TobinQ, Tangibility, Leverage, Pretax Income, Pretax Income Vol, Size and Firm Age*, are included in all regressions. Standard errors are clustered at the market level, and t-statistics are in parentheses. Variables are defined in Internet Appendix Table A1. *, **, and *** indicate significance at 1%, 5% and 10%.

	(1) Environmental Expense / Capex	(2) log (Environmental Expense)
FX Vol (Exposure Weighted)	-0.06***	-1.19*
	(-3.11)	(-1.91)
FX Rate Change	0.01***	0.03
	(2.77)	(0.52)
Foreign Income	-0.00	0.02*
	(-0.25)	(1.76)
TobinQ	-0.00	-0.13
	(-0.10)	(-1.02)
Tangibility	-0.21	0.86
	(-1.40)	(0.63)
Leverage	0.14	-0.96
	(1.35)	(-1.13)
Pretax Income	-0.11	0.37
	(-1.00)	(0.33)
Pretax Income Vol	-0.10	1.45
	(-0.31)	(0.62)
Size	-0.12***	0.46*
	(-3.76)	(1.95)
Firm Age	-0.06	-3.01*
	(-0.64)	(-1.66)
Constant	Yes	Yes
Market×Year FE	Yes	Yes
Industry×Year FE	Yes	Yes
Firm FE	Yes	Yes
Cluster	Market	Market
Observations	2,214	2,214
R-squared	0.88	0.92

Table 8. Supply Chain Contractual Relations

This table presents the OLS regression results for Equation (16). The dependent variables are the firm's contractual relation measures with supplier (customer) in the next year (year $t+1$) and the key independent variable is the firm-specific FX volatility in year t. Industry×Year fixed effects, Market×Year fixed effects, firm fixed effects and firm-year controls including *Expired Contract Num, FX Rate Change, Foreign Income, TobinQ, Tangibility, Leverage, Pretax Income, Pretax Income Vol, Size and Firm Age*, are included in all regressions. Standard errors are clustered at the market level, and t-statistics are in parentheses. Variables are defined in Internet Appendix Table A1. Panel A and B present the results of the contractual relation with the supplier and the customer, respectively. *, **, and *** indicate significance at 1%, 5% and 10%.

Panel A. Supplier Contract

	(1) Contract Num (Supplier)	(2) Contract Num (Private Supplier)	(3) Contract Num (New Supplier)	(4) Contract Duration (Supplier)
FX Vol (Exposure Weighted)	-0.64**	0.48***	0.60**	-4.84***
	(-2.74)	(3.36)	(2.62)	(-5.83)
Expired Contract Num	0.64***	0.11***	0.08**	-0.32***
	(13.46)	(3.94)	(2.81)	(-6.17)
FX Rate Change	0.09**	0.02	0.05	0.11
	(2.22)	(1.18)	(1.53)	(0.66)
Foreign Income	-0.00	0.00	-0.01	0.04
	(-0.08)	(0.00)	(-0.53)	(0.72)
TobinQ	-0.19	-0.14*	-0.15	-0.48
	(-1.03)	(-1.86)	(-0.93)	(-1.00)
Tangibility	0.50	2.91	1.82	-1.52
	(0.17)	(1.47)	(0.87)	(-0.21)
Leverage	-0.84	-1.83***	-1.04	-0.88
	(-0.82)	(-3.25)	(-0.94)	(-0.24)
Pretax Income	0.34	0.11	1.15	-2.86
	(0.16)	(0.10)	(0.48)	(-0.64)
Pretax Income Vol	2.83	-0.49	0.26	9.24
	(0.55)	(-0.16)	(0.05)	(1.50)
Size	0.75	0.29	0.90*	-0.72
	(1.32)	(0.71)	(1.86)	(-0.60)
Firm Age	-2.94	1.98	-0.34	-6.99
	(-1.40)	(1.24)	(-0.21)	(-1.06)
Constant	Yes	Yes	Yes	Yes
Market×Year FE	Yes	Yes	Yes	Yes
Industry×Year FE	Yes	Yes	Yes	Yes
Firm FE	Yes	Yes	Yes	Yes
Cluster	Market	Market	Market	Market
Observations	4,352	4,352	4,352	4,352
R-squared	0.97	0.82	0.87	0.58

Panel B. Customer Contract

	(1) Contract Num (Customer)	(2) Contract Num (Private Customer)	(3) Contract Num (New Customer)	(4) Contract Duration (Customer)
FX Vol (Exposure Weighted)	0.26	0.30	-1.07**	0.42
	(0.49)	(0.45)	(-2.72)	(0.50)
Expired Contract Num	0.60***	0.23***	0.05**	-0.22***
	(29.70)	(16.22)	(2.81)	(-10.92)
FX Rate Change	-0.08	-0.03	-0.07	0.14
	(-1.25)	(-0.68)	(-1.24)	(0.91)
Foreign Income	0.02	0.01	0.04	0.07***
	(0.63)	(0.66)	(1.52)	(2.86)
TobinQ	-0.01	-0.06	0.09	0.02
	(-0.01)	(-0.28)	(0.36)	(0.09)
Tangibility	3.33	1.54	3.69	-2.60
	(0.71)	(0.93)	(0.99)	(-0.49)
Leverage	-2.78	-1.90	-2.02	-5.50**
	(-0.65)	(-1.00)	(-0.69)	(-2.61)
Pretax Income	4.98	1.13	2.03	0.10
	(1.01)	(0.33)	(0.75)	(0.03)
Pretax Income Vol	-5.55	-7.24	-1.73	4.90
	(-0.41)	(-1.03)	(-0.15)	(0.45)
Size	1.95	0.31	1.86*	1.08
	(1.42)	(0.25)	(1.98)	(1.24)
Firm Age	-3.60	-0.49	-1.72	-10.65**
	(-0.74)	(-0.23)	(-0.48)	(-2.28)
Constant	Yes	Yes	Yes	Yes
Market×Year FE	Yes	Yes	Yes	Yes
Industry×Year FE	Yes	Yes	Yes	Yes
Firm FE	Yes	Yes	Yes	Yes
Observations	4,888	4,888	4,888	4,888
R-squared	0.89	0.85	0.69	0.60

Table 9. Cost of Switching Suppliers

This table presents the OLS regression results for Equation (17). The dependent variables are the firm's scope 1 and 3 carbon intensity and measures of contractual relationships with suppliers in the next year (year $t+1$). The key independent variables are the firm-specific FX volatility and its interaction terms with accounts payable to sales ratio (*AccountPayable*) in year t. Industry×Year fixed effects, Market×Year fixed effects, firm fixed effects and firm-year controls including *Expired Contract Num, FX Rate Change, Foreign Income, TobinQ, Tangibility, Leverage, Pretax Income, Pretax Income Vol, Size and Firm Age*, are included in all regressions. Standard errors are clustered at the market level, and t-statistics are in parentheses. Variables are defined in Internet Appendix Table A1. *, **, and *** indicate significance at 1%, 5% and 10%.

	(1) Scope 1	(2) Scope 3 (Up)	(3) Contract Num (Supplier)	(4) Contract Num (Private Supplier)	(5) Contract Num (New Supplier)	(6) Contract Duration
FX Vol (Exposure Weighted) × AccountPayable	51.40**	28.69***	-2.98**	4.39***	4.41***	-18.65**
	(2.71)	(2.91)	(-2.79)	(2.94)	(2.94)	(-2.77)
FX Vol (Exposure Weighted)	6.91**	2.64**	-0.61**	0.47***	0.71**	-3.27**
	(2.59)	(2.61)	(-2.76)	(3.52)	(2.76)	(-2.80)
AccountPayable	-0.18	-89.14***	-0.51	-1.59	-1.85	-0.49
	(-0.00)	(-2.92)	(-0.17)	(-1.33)	(-0.78)	(-0.07)
Expired Contract Num			0.65***	0.11***	0.10***	-0.34***
			(13.66)	(3.91)	(3.52)	(-6.58)
Constant	Yes	Yes	Yes	Yes	Yes	Yes
Firm-Year Control	Yes	Yes	Yes	Yes	Yes	Yes
Market×Year FE	Yes	Yes	Yes	Yes	Yes	Yes
Industry×Year FE	Yes	Yes	Yes	Yes	Yes	Yes
Firm FE	Yes	Yes	Yes	Yes	Yes	Yes
Cluster	Market	Market	Market	Market	Market	Market
Observations	10,608	10,608	3,933	3,933	3,933	3,933
R-squared	0.95	0.97	0.97	0.85	0.89	0.63

Table 10. Financial Constraint

This table presents the OLS regression results for Equation (18). The dependent variables are the firm's scope 1 and 3 carbon intensity and measures of contractual relationships with suppliers in the next year (year $t + 1$). The key independent variables are the firm-specific FX volatility and its interaction terms with financial constraint index (*KZ* and *WW*) in year t. Industry×Year fixed effects, Market×Year fixed effects, firm fixed effects and firm-year controls including *Expired Contract Num, FX Rate Change, Foreign Income, TobinQ, Tangibility, Leverage, Pretax Income, Pretax Income Vol, Size and Firm Age*, are included in all regressions. Standard errors are clustered at the market level, and t-statistics are in parentheses. Variables are defined in Internet Appendix Table A1. Panel A and B present the results using *KZ* and *WW* as proxies for financial constraints, respectively. *, **, and *** indicate significance at 1%, 5% and 10%.

Panel A. KZ Index

	(1) Scope 1	(2) Scope 3 (Up)	(3) Environmental Expense / Capex	(4) log (Environmental Expense)	(5) Contract Num (Supplier)	(6) Contract Num (Private Supplier)	(7) Contract Num (New Supplier)	(8) Contract Duration (Supplier)
FX Vol (Exposure Weighted) × KZ	1.08***	0.66***	-0.01***	-0.20***	-0.18**	0.20***	0.07***	-0.95***
	(3.70)	(4.16)	(-2.82)	(-2.97)	(-2.78)	(8.29)	(2.90)	(-4.02)
FX Vol (Exposure Weighted)	10.33**	3.85***	-0.06***	-1.19***	-1.09**	1.24***	1.40***	-6.52***
	(2.72)	(3.37)	(-3.61)	(-2.83)	(-2.77)	(3.45)	(3.46)	(-2.98)
KZ	-0.72**	-0.34	0.01**	0.06***	0.02	-0.03	0.00	-0.09
	(-2.31)	(-1.30)	(2.41)	(2.77)	(0.61)	(-1.56)	(0.03)	(-1.08)
Expired Contract Num					0.66***	0.10***	0.06**	-0.35***
					(19.10)	(3.38)	(2.10)	(-6.72)
Constant	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Firm-Year Control	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Market×Year FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Industry×Year FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Firm FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Cluster	Market	Market	Market	Market	Market	Market	Market	Market
Observations	9,775	9,775	2,044	2,044	3,546	3,546	3,546	3,546
R-squared	0.96	0.97	0.90	0.92	0.98	0.87	0.91	0.65

Panel B. WW Index

	(1) Scope 1	(2) Scope 3 (Up)	(3) Environmental Expense / Capex	(4) log (Environmental Expense)	(5) Contract Num (Supplier)	(6) Contract Num (Private Supplier)	(7) Contract Num (New Supplier)	(8) Contract Duration (Supplier)
FX Vol (Exposure Weighted) × WW	82.25***	25.11***	-0.56***	-4.94***	-8.93**	6.80***	5.10***	-45.16***
	(3.14)	(2.90)	(-2.90)	(-3.08)	(-2.75)	(3.30)	(2.89)	(-3.41)
FX Vol (Exposure Weighted)	90.16***	27.98***	-0.65***	-5.50***	-9.09***	7.02***	5.27**	-49.18***
	(3.10)	(3.22)	(-3.02)	(-3.10)	(-2.90)	(3.41)	(2.82)	(-3.87)
WW	31.03	-81.64**	-0.19	-1.17	-2.88	-0.05	-2.80	-4.82
	(0.52)	(-2.27)	(-0.67)	(-0.45)	(-0.51)	(-0.03)	(-0.64)	(-0.39)
Expired Contract Num					0.67***	0.11***	0.09***	-0.40***
					(16.47)	(5.19)	(3.50)	(-8.55)
Constant	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Firm-Year Control	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Market×Year FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Industry×Year FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Firm FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Cluster	Market	Market	Market	Market	Market	Market	Market	Market
Observations	10,171	10,171	2,069	2,069	3,735	3,735	3,735	3,735
R-squared	0.95	0.96	0.88	0.92	0.98	0.88	0.91	0.63

Table 11. Foreign Exchange Derivative Usage

This table presents the OLS regression results for Equation (19). The dependent variables are the firm's scope 1 and 3 carbon intensity and measures of contractual relationships with suppliers in the next year (year $t+1$). The key independent variables are the the the firm-specific FX volatility and its interaction terms with foreign exchange derivative usage (*FX Derivative*) in year t. Industry×Year fixed effects, Market×Year fixed effects, firm fixed effects and firm-year controls including *Expired Contract Num, FX Rate Change, Foreign Income, TobinQ, Tangibility, Leverage, Pretax Income, Pretax Income Vol, Size and Firm Age*, are included in all regressions. Standard errors are clustered at the market level, and t-statistics are in parentheses. Variables are defined in Internet Appendix Table A1. *, **, and *** indicate significance at 1%, 5% and 10%.

	(1) Scope 1	(2) Scope 3 (Up)	(3) Contract Num (Supplier)	(4) Contract Num (Private Supplier)	(5) Contract Num (New Supplier)	(6) Contract Duration (Supplier)
FX Vol (Exposure Weighted) × FX Derivative	-20.33***	-11.23**	1.88***	-1.85***	-2.44***	12.77**
	(-5.03)	(-2.67)	(3.10)	(-3.39)	(-3.09)	(2.94)
FX Vol (Exposure Weighted)	16.44**	6.45***	-2.97**	3.14***	3.05***	-16.63***
	(2.46)	(3.42)	(-2.74)	(5.90)	(3.38)	(-4.53)
FX Derivative	7.77	5.44*	0.81	0.64*	1.23**	-0.86
	(1.30)	(1.95)	(1.42)	(2.09)	(2.59)	(-0.71)
Expired Contract Num			0.65***	0.12***	0.12***	-0.25***
			(13.08)	(6.06)	(3.34)	(-3.62)
Constant	Yes	Yes	Yes	Yes	Yes	Yes
Firm-Year Control	Yes	Yes	Yes	Yes	Yes	Yes
Market×Year FE	Yes	Yes	Yes	Yes	Yes	Yes
Industry×Year FE	Yes	Yes	Yes	Yes	Yes	Yes
Firm FE	Yes	Yes	Yes	Yes	Yes	Yes
Cluster	Market	Market	Market	Market	Market	Market
Observations	4,075	4,075	1,277	1,277	1,277	1,277
R-squared	0.97	0.97	0.99	0.92	0.94	0.77

Table 12. Carbon Tax

This table presents the OLS regression results for Equation (20). The dependent variables are the firm's scope 1 and 3 carbon intensity in the next year (year $t + 1$). The key independent variables are the firm-specific FX volatility and its interaction terms with firm-specific carbon tax risk (*Carbon Tax* and *Carbon Tax (Customer)*) in year t. Industry×Year fixed effects, Market×Year fixed effects, firm fixed effects and firm-year controls including *FX Rate Change, Foreign Income, TobinQ, Tangibility, Leverage, Pretax Income, Pretax Income Vol, Size and Firm Age*, are included in all regressions. Standard errors are clustered at the market level, and t-statistics are in parentheses. Variables are defined in Internet Appendix Table A1. *, **, and *** indicate significance at 1%, 5% and 10%.

	(1)	(2)	(3)	(4)
	Scope 1		Scope 3 (Up)	
FX Vol (Exposure Weighted) × Carbon Tax	-0.20***		-0.13***	
	(-3.69)		(-4.11)	
FX Vol (Exposure Weighted) × Carbon Tax (Customer)		-0.30**		-0.26***
		(-2.65)		(-4.39)
FX Vol (Exposure Weighted)	7.35***	6.97***	4.48***	4.65***
	(3.51)	(2.99)	(5.35)	(4.68)
Carbon Tax	-0.12	-0.01	0.21	0.23
	(-0.68)	(-0.04)	(0.90)	(1.39)
FX Rate Change	-0.96*	-0.88*	-0.26	-0.24
	(-1.91)	(-1.77)	(-1.28)	(-1.19)
Foreign Income	-0.09	-0.08	0.00	0.03
	(-0.88)	(-0.69)	(0.03)	(0.31)
TobinQ	0.36	0.40	-1.64*	-1.62*
	(0.29)	(0.32)	(-1.83)	(-1.79)
Tangibility	-81.08	-81.58	52.56*	52.32*
	(-1.35)	(-1.37)	(2.07)	(2.04)
Leverage	26.60	25.70	-11.90	-11.35
	(0.78)	(0.74)	(-0.92)	(-0.84)
Pretax Income	-32.04	-30.78	-22.11	-20.90
	(-1.14)	(-1.11)	(-0.75)	(-0.71)
Pretax Income Vol	178.00*	182.02*	48.96*	49.60
	(1.90)	(1.94)	(1.77)	(1.71)
Size	-22.03**	-21.88**	-4.50	-4.60
	(-2.30)	(-2.30)	(-0.83)	(-0.83)
Firm Age	6.79	6.03	-14.57	-14.21
	(0.19)	(0.17)	(-1.11)	(-1.10)
Market×Year FE	Yes	Yes	Yes	Yes
Industry×Year FE	Yes	Yes	Yes	Yes
Firm FE	Yes	Yes	Yes	Yes
Constant	Yes	Yes	Yes	Yes
Cluster	Market	Market	Market	Market
Observations	11,323	11,323	11,323	11,323
R-squared	0.95	0.95	0.96	0.96

Internet Appendix

Table A1. Variable Definition

Variable	*Definition*	*Source*
Dependent Variables		
Scope 1	Greenhouse gas emissions from sources that are owned or controlled by the company divided by the company's revenue. (tCO2e/$M)	*Trucost*
Scope 2	Greenhouse gas emissions from consumption of purchased electricity, heat or steam by the company divided by the company's revenue. (tCO2e/$M)	*Trucost*
Scope 3 (Up)	Greenhouse gas emissions from other upstream activities not covered in Scope 2 divided by the company's revenue. (tCO2e/$M)	*Trucost*
Scope 3 (Down)	Downstream indirect greenhouse gas emissions associated with the use of sold goods and services divided by the company's revenue. (tCO2e/$M)	*Trucost*
Environmental	Weighted average of environmental scores. Calculated as: 32.35%∗Resource Use + 35.29%∗Emission + 32.35%∗Environmental Innovation. The weights are provided by Asset4 database.	*Asset4 ESG*
Resource Use	Reflects a company's performance and capacity to reduce the use of materials, energy, or water, and to find more eco-efficient solutions by improving supply chain management.	*Asset4 ESG*
Emission Reduction	Measures a company's commitment and effectiveness towards reducing environmental emissions in the production and operational processes.	*Asset4 ESG*
Environmental Innovation	Reflects a company's capacity to reduce the environmental costs and burdens for its customers, and thereby creating new market opportunities through new environmental technologies and processes or eco-designed products.	*Asset4 ESG*
Environmental Expense / Capex	All environmental investment expenditures for environmental protection or to prevent, reduce, control environmental aspects, impacts, and hazards scaled by Capital Expenditure.	*Refinitv, Worldscope*
log(Environmental Expense)	Natural logarithm of all environmental investment expenditures in US$ for environmental protection or to prevent, reduce, control environmental aspects, impacts, and hazards.	*Refinitv*
Events	The number of negative environmental news events, classified by the United Nations Global Compact (UNGC).	*Reprisk*
Events (Severity)	The total number of negative environmental news events weighted by severity score. Calculated as: [$\sum$ Event∗Severity], where Severity ranges from 1 to 3, with 3 indicating the highest severity.	*Reprisk*

Continued on next page

Table A1. Variable Definition - Continued

Events (Severity-Novelty)	The total number of negative environmental news events weighted by severity and novelty scores. Calculated as: [$\sum$ Event$*$Severity$*$Novelty], where Severity ranges from 1 to 3, with 3 indicating the highest severity, and Novelty ranges from 1 to 2, with 2 indicating the highest novelty.	*Reprisk*
Events (Severity-Reach)	The total number of negative environmental news events weighted by severity and reach scores. Calculated as: [$\sum$ Event$*$Severity$*$Reach], where Severity ranges from 1 to 3, with 3 indicating the highest severity, and Reach ranges from 1 to 3, with 2 indicating the level of public awareness.	*Reprisk*
Events (Severity-Novelty-Reach)	The total number of negative environmental news events weighted by severity and reach scores. Calculated as: [$\sum$ Event$*$Severity$*$Novelty$*$Reach], where Severity ranges from 1 to 3, with 3 indicating the highest severity, Novelty ranges from 1 to 2, with 2 indicating the highest novelty, and Reach ranges from 1 to 3, with 3 indicating the level of public awareness.	*Reprisk*
Contract Num	Number of newly initiated contracts with suppliers (customers).	*FactSet*
Contract Num (Private)	Number of newly initiated contracts with private suppliers (customers), where suppliers (customers) are identified as private if their "entity_type" in FactSet is not "PUB" .	*FactSet*
Contract Num (New)	Number of newly initiated contracts with suppliers (customers) that have no contract commenced in the past.	*FactSet*
Contract Duration	The average duration of newly initiated contracts with suppliers (customers) in months.	*FactSet*
Independent Variables		
FX Vol (Exposure Weighted)	Geographic revenue weighted average of realized volatility, where realized variance-covariance matrix is calculated as the standard deviation of daily pairwise foreign exchange rate over the year and weight is calculated as the percentage of revenue from each foreign market to total revenue.	*Datastream, FactSet*
FX GarchVol (Exposure Weighted)	Geographic revenue weighted average of realized volatility, where realized variance-covariance matrix is calculated based on GARCH model and weight is calculated as the percentage of revenue from each foreign market to total revenue.	*Datastream, FactSet*
CME Derivative (Exposure Weighted)	Geographic revenue weighted average of the availability of CME FX Derivatives, where "CME FX Derivative availability" is a binary variable that is set to one if the currency of a foreign or domestic market has at least one derivative listed on CME and weight is calculated as the percentage of revenue from that market to total revenue.	*Chicago Mercantile Exchange*
FixedToFloat (Exposure Weighted)	Geographic revenue weighted average of FX regime change, where regime change is a dummy variable which equals to one if currency changes from a floating to fixed regime and weight is calculated as the percentage of revenue from each foreign market to total revenue. The classification of the FX regime is determined according to Ilzetzki, Reinhart, and Rogoff (2019).	*FactSet*

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Table A1. Variable Definition - Continued

FixedToFloat (Exposure Weighted)	Geographic revenue weighted average of FX regime change, where regime change is a dummy variable which equals to one if currency changes from a fixed to floating regime and weight is calculated as the percentage of revenue from each foreign market to total revenue. The classification of the FX regime is determined according to Ilzetzki, Reinhart, and Rogoff (2019).	*FactSet*
AccountPayable	Accounts Payable / Total Assets.	*Worldscope*
KZ	Financial constraint index by Kaplan and Zingales (1997), calculated as: [-1.001∗(Cash Flow / PPENT) + 0.2823∗Tobin's Q + 3.139∗(Debt / Total Capital) - 39.368∗(Dividends / PPENT) - 1.315∗(Cash / PPENT)]	*Worldscope*
WW	Financial constraint index by Whited and Wu (2006), calculated as: -0.091∗(Cash Flow / Total Assets) - 0.062∗**1**(Dividend) + 0.021∗(Long Term Debt / Total Assets) - 0.044∗Ln(Total Assets) + 0.102∗(Industry Sales Growth) - 0.035∗Sales Growth. Industry Sales Growth is the average sales growth by two-digit SIC and year.	*Worldscope*
FX Derivative	Dummy variable equals to one if we find "futures", "swap", "derivative", "option", "hedge" and "foreign exchange", "exchange rate" or "currency" in the same paragraph of a firm's annual report.	*Reuters Eikon*
Carbon Tax	The percentage of revenue from domestic market subject to a carbon tax. The carbon tax data are sourced from Dolphin and Xiahou (2022).	*FactSet*
Carbon Tax (Customer)	The percentage of revenue from foreign market subject to a carbon tax. The carbon tax data are sourced from Dolphin and Xiahou (2022).	*FactSet*
Control Variables		
Expired Contract Num	Number of expired contracts with suppliers (customers).	*FactSet*
FX Rate Change	Geographic revenue weighted average of exchange rate change, where exchange rate change is the annualized log return and weight is calculated as the percentage of revenue from each foreign market to total revenue.	*Datastream, FactSet*
Foreign Income	The percentage of revenue from foreign market to total revenue.	*FactSet*
TobinQ	Tobin's Q, calculated as: [(Total Assets + Market Capitalization - Stockholders Equity) / Total Assets].	*Worldscope*
Tangibility	Property, Plant and Equipment / Total Assets.	*Worldscope*
Leverage	(Long-Tern Debt + Debt in Current Liabilities) / Total Assets.	*Worldscope*
Pretax Income	Pretax Income / Total Assets.	*Worldscope.*
Pretax Income Vol	Standard deviation of (Pretax Income / Total Assets) over the last five years .	*Worldscope*
Size	Natural logarithm of Total Assets in US-Dollar.	*Worldscope*
Firm Age	Natural logarithm of firm age in years.	*Worldscope*

Table A2. Carbon Tax Implementation in Sample Countries

Country Name	Country Code	Effective Periods	Description
Finland	FIN	1991-Ongoing	Finland introduced a carbon tax of EUR 1.12 (USD1.41)/tCO2e in 1990, based on the carbon content of the fossil fuel.
Norway	NOR	1991-Ongoing	The initial carbon tax rate was introduced at NOK 437.87 (USD 39.98) and NOK 186.3 (USD 17.01) in 1991, and has since risen to an estimate of NOK 1176 (USD 112.35)/tCO2e for 2024.
Sweden	SWE	1991-Ongoing	The carbon tax was introduced in 1991 at a rate corresponding to SEK 250 (EUR 22)/tCO2e and has gradually been increased since then.
Denmark	DNK	1992-Ongoing	On 15th May 1992, Denmark introduced a carbon tax on energy products. The objective of this tax was to reduce both energy consumption and CO2 emissions. The tax is DKK 100 per ton of CO2 emitted (equivalent to about 57 USD/ton of carbon). Initially,the tax only applied to households and small enterprises which are not VAT-registered. However, as of 1st January 1993, the tax is also being levied on the energy use of VAT-registered enterprises, albeit at the lower rate of 50 DKK/tCO2e.
Australia	AUS	2012-2013	Australia implemented carbon tax during the 2012-2013 financial year, the carbon price is AUD 23/tCO2e. The carbon price will be AUD 24.15/tCO2e in 2013-14.
Japan	JPN	2012-Ongoing	The Japan Environmental Agency, the predecessor of the Ministry of the Environment, proposed introducing a carbon tax in 1998. Subsequent discussions, mainly led by the Environmental Agency (Ministry of the Environment), resulted in the introduction of the "Global Warming Countermeasures Tax" in 2012, with a carbon tax of YEN 289/tCO2e being imposed after the phase of gradual increase.
United Kingdom	GBR	2013-Ongoing	The UK has a domestic carbon tax in the power sector, known as the Carbon Price Support, introduced to augment the low carbon price signal UK power emitters would have had to pay under the EU ETS. The Carbon Price Support was introduced in 2013 at a rate of GBP 16 (EUR 18.05) /tCO2e, and was set to increase to GBP 30 (EUR 33.85) by 2020.

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Table A2. Carbon Tax Implementation in Sample Countries - Continued

France	FRA	2014-Ongoing	The French carbon tax (Contribution Climat-Énergie or CCE) is attached to the domestic excise taxes on energy consumption, increasing their overall rate. These excise taxes are added to the final price of petrol, diesel, heating oil or natural gas, so are paid by individuals and businesses. The carbon tax scheme serves as a complementary policy measure to the EU ETS.
Singapore	SGP	2019-Ongoing	Singapore implemented a carbon tax, the first carbon pricing scheme in Southeast Asia, on 1 January 2019. The carbon tax level was set at SGD 5/tCO2e for the first five years from 2019 to 2023 to provide a transitional period for emitters to adjust.
South Africa	ZAF	2019-Ongoing	South Africa's Carbon Tax Act (CBT) 15 of 2019, enacted in May 2019 and implemented on June 1, 2019, established a tax on greenhouse gas (GHG) emissions. The CBT is a new tax in response to climate change, which is aimed at reducing greenhouse gas (GHG) emissions in a sustainable, cost effective and affordable manner. Carbon Tax gives effect to the polluter-pays-principle and helps to ensure that firms and consumers take the negative adverse costs (externalities) of climate change into account in their future production, consumption and investment decisions.
Netherlands	NLD	2021-Ongoing	In 2021, the Netherlands implemented a national carbon tax to supplement the EU Emissions Trading System (ETS), starting at a minimum price of EUR 30/tCO2e for industrial emissions and gradually increasing to EUR 125 per tonne by 2030.

Table A3. Robustness Check - Carbon Emissions: Cluster Standard Errors at the Firm Level

This table presents the OLS regression results for Section 3.1. The dependent variables are the firm's carbon intensity in different scopes in the next year (year $t + 1$). The key independent variable is the firm-specific FX volatility in year t. Industry×Year fixed effects, Market×Year fixed effects, firm fixed effects and firm-year controls including *FX Rate Change, Foreign Income, TobinQ, Tangibility, Leverage, Pretax Income, Pretax Income Vol, Size and Firm Age*, are included in all regressions. Standard errors are clustered at the firm level, and t-statistics are in parentheses. Variable definitions are provided in Internet Appendix Table A1. *, **, and *** indicate significance at 1%, 5% and 10%.

	(1) Scope 1	(2) Scope 2	(3) Scope 3 (Up)	(4) Scope 3 (Down)
FX Vol (Exposure Weighted)	5.01*	-0.68	2.87***	-11.46
	(1.79)	(-0.59)	(2.67)	(-0.34)
FX Rate Change	-0.85	0.06	-0.19	0.06
	(-1.38)	(0.24)	(-0.82)	(0.01)
Foreign Income	-0.12	0.06	0.01	-0.28
	(-0.77)	(0.76)	(0.14)	(-0.17)
TobinQ	0.41	-0.60	-1.65*	18.89
	(0.22)	(-0.82)	(-1.66)	(1.32)
Tangibility	-80.96	-7.16	51.98**	369.19
	(-1.42)	(-0.45)	(2.19)	(1.03)
Leverage	25.96	1.70	-11.91	-252.21
	(0.83)	(0.17)	(-1.04)	(-1.15)
Pretax Income	-31.16	-27.63**	-20.82	-174.62
	(-1.11)	(-2.10)	(-1.21)	(-0.69)
Pretax Income Vol	178.49	6.51	48.92	886.60
	(1.59)	(0.25)	(1.63)	(1.56)
Size	-21.91***	-4.79	-5.01	151.08**
	(-2.76)	(-1.61)	(-1.02)	(2.05)
Firm Age	5.48	31.45**	-14.06	-290.39
	(0.16)	(2.57)	(-1.03)	(-0.69)
Constant	Yes	Yes	Yes	Yes
Market×Year FE	Yes	Yes	Yes	Yes
Industry×Year FE	Yes	Yes	Yes	Yes
Firm FE	Yes	Yes	Yes	Yes
Cluster	Firm	Firm	Firm	Firm
Observations	11,323	11,323	11,323	5,741
R-squared	0.95	0.86	0.96	0.91

Table A4. Robustness Check - Carbon Emissions: Excluding Energy Firms

This table presents the OLS regression results for Section 3.1, excluding firms in the gas, oil, and utility industries. The dependent variables are the firm's carbon intensity in different scopes in the next year (year $t + 1$). The key independent variable is the firm-specific FX volatility in year t. Industry×Year fixed effects, Market×Year fixed effects, firm fixed effects and firm-year controls including *FX Rate Change, Foreign Income, TobinQ, Tangibility, Leverage, Pretax Income, Pretax Income Vol, Size and Firm Age*, are included in all regressions. Standard errors are clustered at the market level, and t-statistics are in parentheses. Variables are defined in Internet Appendix Table A1. *, **, and *** indicate significance at 1%, 5% and 10%.

	(1) Scope 1	(2) Scope 2	(3) Scope 3 (Up)	(4) Scope 3 (Down)
FX Vol (Exposure Weighted)	4.74***	-0.69	3.16***	-8.27
	(2.85)	(-0.47)	(3.67)	(-0.25)
FX Rate Change	-0.79	0.03	-0.22	0.51
	(-1.60)	(0.13)	(-1.00)	(0.08)
Foreign Income	-0.13	0.06	0.01	-0.04
	(-1.09)	(1.13)	(0.15)	(-0.02)
TobinQ	0.11	-0.43	-1.50	17.48
	(0.10)	(-0.75)	(-1.65)	(1.26)
Tangibility	-61.48	-11.48	54.50**	355.15
	(-1.12)	(-0.68)	(2.14)	(0.83)
Leverage	41.54	-1.00	-14.01	-259.11
	(1.42)	(-0.08)	(-1.07)	(-1.20)
Pretax Income	-33.50	-26.77***	-22.32	-88.95
	(-1.14)	(-2.90)	(-0.76)	(-0.33)
Pretax Income Vol	173.35*	7.62	48.15	909.57*
	(1.80)	(0.38)	(1.72)	(1.76)
Size	-22.59**	-4.84	-3.70	148.03**
	(-2.32)	(-1.63)	(-0.63)	(2.09)
Firm Age	2.29	32.58**	-14.95	-258.03
	(0.07)	(2.32)	(-1.17)	(-0.63)
Constant	Yes	Yes	Yes	Yes
Market×Year FE	Yes	Yes	Yes	Yes
Industry×Year FE	Yes	Yes	Yes	Yes
Firm FE	Yes	Yes	Yes	Yes
Cluster	Market	Market	Market	Market
Observations	11,169	11,169	11,169	5,686
R-squared	0.95	0.86	0.96	0.90

Table A5. Robustness Check - Carbon Emissions: GARCH Model Volatility

This table presents the OLS regression results for Section 3.1. The dependent variables are the firm's carbon emissions in different scopes in the next year (year $t + 1$). The key independent variable is the firm-specific FX volatility based on GARCH model in year t. Industry×Year fixed effects, Market×Year fixed effects, firm fixed effects and firm-year controls including *FX Rate Change, Foreign Income, TobinQ, Tangibility, Leverage, Pretax Income, Pretax Income Vol, Size and Firm Age*, are included in all regressions. Standard errors are clustered at market level, and t-statistics are in parentheses. Variable definitions are provided in Internet Appendix Table A1. *, **, and *** indicate significance at 1%, 5% and 10%.

	(1) Scope 1	(2) Scope 2	(3) Scope 3 (Up)	(4) Scope 3 (Down)
FX GarchVol (Exposure Weighted)	5.15**	0.22	2.34***	-11.09
	(2.52)	(0.29)	(3.63)	(-0.64)
FX Rate Change	-0.88	-0.01	-0.16	0.31
	(-1.68)	(-0.04)	(-0.86)	(0.05)
Foreign Income	-0.25**	0.04	-0.04	-0.03
	(-2.15)	(0.67)	(-0.47)	(-0.01)
TobinQ	0.46	-0.59	-1.63*	18.73
	(0.36)	(-1.02)	(-1.86)	(1.30)
Tangibility	-81.67	-7.22	51.67*	367.86
	(-1.38)	(-0.40)	(2.07)	(0.87)
Leverage	26.81	1.70	-11.50	-256.84
	(0.78)	(0.16)	(-0.88)	(-1.15)
Pretax Income	-30.42	-27.57**	-20.50	-176.80
	(-1.09)	(-2.80)	(-0.69)	(-0.65)
Pretax Income Vol	178.89*	6.54	49.09*	891.40
	(1.93)	(0.32)	(1.78)	(1.71)
Size	-21.89**	-4.77	-5.01	151.53**
	(-2.30)	(-1.62)	(-0.86)	(2.20)
Firm Age	5.68	31.43**	-13.95	-293.04
	(0.16)	(2.22)	(-1.10)	(-0.74)
Constant	Yes	Yes	Yes	Yes
Market×Year FE	Yes	Yes	Yes	Yes
Industry×Year FE	Yes	Yes	Yes	Yes
Firm FE	Yes	Yes	Yes	Yes
Cluster	Market	Market	Market	Market
Observations	11,323	11,323	11,323	5,741
R-squared	0.95	0.86	0.96	0.91

Table A6. Robustness Check - Total Carbon Emissions

This table presents the OLS regression results for Section 3.1. The dependent variables are the natural logarithms of the firm's carbon emissions in different scopes in the next year (year $t + 1$). The key independent variable is the firm-specific FX volatility in year t. Industry×Year fixed effects, Market×Year fixed effects, firm fixed effects and firm-year controls including *FX Rate Change, Foreign Income, TobinQ, Tangibility, Leverage, Pretax Income, Pretax Income Vol, Size and Firm Age*, are included in all regressions. Standard errors are clustered at the market level, and t-statistics are in parentheses. Variables are defined in Internet Appendix Table A1. *, **, and *** indicate significance at 1%, 5% and 10%.

	(1)	(3)	(2)	(4)
	log(Scope 1 Absolute)		log(Scope 3 (Up) Absolute)	
FX Vol (Exposure Weighted)	0.05***		0.02**	
	(3.13)		(2.11)	
FX GarchVol (Exposure Weighted)		0.03**		0.01**
		(2.70)		(2.29)
FX Rate Change	-0.01**	-0.01	-0.01	-0.01
	(-2.24)	(-1.33)	(-0.83)	(-0.76)
Foreign Income	-0.01	-0.01	0.01	-0.01
	(-0.13)	(-0.50)	(0.35)	(-0.25)
TobinQ	0.02	0.02	0.03***	0.03***
	(0.84)	(0.86)	(7.48)	(7.55)
Tangibility	0.69**	0.69**	0.42***	0.42***
	(2.28)	(2.27)	(4.16)	(4.13)
Leverage	-0.07	-0.07	-0.33***	-0.33***
	(-0.48)	(-0.44)	(-4.49)	(-4.44)
Pretax Income	0.67**	0.67**	0.61***	0.62***
	(2.69)	(2.69)	(5.45)	(5.46)
Pretax Income Vol	0.44	0.44	-0.08	-0.08
	(0.97)	(0.97)	(-0.37)	(-0.37)
Size	0.60***	0.60***	0.78***	0.78***
	(13.14)	(13.18)	(17.17)	(17.18)
Firm Age	0.06	0.06	-0.03	-0.03
	(0.39)	(0.39)	(-0.38)	(-0.37)
Constant	Yes	Yes	Yes	Yes
Market×Year FE	Yes	Yes	Yes	Yes
Industry×Year FE	Yes	Yes	Yes	Yes
Firm FE	Yes	Yes	Yes	Yes
Cluster	Market	Market	Market	Market
Observations	11,323	11,323	11,323	11,323
R-squared	0.97	0.97	0.99	0.99

Table A7. Carbon Emissions: Placebo Test

This table presents the OLS regression results for Section 3.1. The dependent variables are the firm's carbon intensity in different scopes in the previous years (year $t-1$ to $t-3$). The key independent variable is the firm-specific FX volatility in year t. Industry×Year fixed effects, Market×Year fixed effects, firm fixed effects and firm-year controls including *FX Rate Change, Foreign Income, TobinQ, Tangibility, Leverage, Pretax Income, Pretax Income Vol, Size and Firm Age*, are included in all regressions. Standard errors are clustered at the market level, and t-statistics are in parentheses. Variable definitions are provided in Internet Appendix Table A1. *, **, and *** indicate significance at 1%, 5% and 10%.

	(1)	(2)	(3)	(4)	(5)	(6)
		Scope 1			Scope 3 (Up)	
	$t-1$	$t-2$	$t-3$	$t-1$	$t-2$	$t-3$
FX Vol (Exposure Weighted)	1.20	-2.72	-0.37	2.91	3.42	4.38
	(0.34)	(-0.71)	(-0.17)	(1.37)	(1.55)	(0.95)
FX Rate Change	-0.84	0.44	0.70	-0.67	-1.21**	-0.78*
	(-0.96)	(0.46)	(0.88)	(-1.08)	(-2.77)	(-1.74)
Foreign Income	0.26	0.54	0.70*	-0.15	0.03	0.08
	(0.61)	(1.27)	(1.86)	(-1.49)	(0.38)	(0.74)
TobinQ	4.58**	2.75	4.06	-1.99	-1.49	-0.76
	(2.39)	(1.09)	(1.03)	(-1.24)	(-0.98)	(-0.49)
Tangibility	-62.65*	-39.17	-69.86	-17.76	-18.16	-27.02
	(-1.91)	(-0.99)	(-1.32)	(-0.65)	(-0.82)	(-1.16)
Leverage	-7.37	-18.37	10.94	22.59	21.02	25.65*
	(-0.26)	(-0.61)	(0.39)	(1.35)	(1.11)	(1.82)
Pretax Income	-13.90	-26.39	8.87	-34.06*	-47.40***	-1.81
	(-0.59)	(-0.96)	(0.30)	(-1.74)	(-2.93)	(-0.11)
Pretax Income Vol	-43.11	-24.87	118.75	72.61	39.03	28.44
	(-0.40)	(-0.29)	(1.10)	(1.38)	(0.91)	(0.56)
Size	-1.21	-0.63	0.28	-4.94	-7.89	-11.47
	(-0.12)	(-0.06)	(0.03)	(-0.67)	(-1.05)	(-1.65)
Firm Age	-2.86	-37.24	-55.23	9.88	21.32	29.20
	(-0.05)	(-0.46)	(-0.50)	(0.48)	(0.89)	(0.96)
Constant	Yes	Yes	Yes	Yes	Yes	Yes
Market×Year FE	Yes	Yes	Yes	Yes	Yes	Yes
Industry×Year FE	Yes	Yes	Yes	Yes	Yes	Yes
Firm FE	Yes	Yes	Yes	Yes	Yes	Yes
Cluster	Market	Market	Market	Market	Market	Market
Observations	7,341	5,809	4,563	7,341	5,809	4,563
R-squared	0.95	0.96	0.96	0.96	0.96	0.96

Table A8. Robustness Check - ESG Rating: Cluster Standard Errors at the Firm Level

This table presents the OLS regression results for Equation (10). The dependent variables are the firm's ASSET4 environmental rating scores in the next year (year $t+1$). The key independent variable is firm-specific FX volatility in year t. Industry×Year fixed effects, Market×Year fixed effects, firm fixed effects and firm-year controls including *FX Rate Change, Foreign Income, TobinQ, Tangibility, Leverage, Pretax Income, Pretax Income Vol, Size and Firm Age*, are included in all regressions. Standard errors are clustered at the firm level, and t-statistics are in parentheses. Variable definitions are provided in Internet Appendix Table A1. *, **, and *** indicate significance at 1%, 5% and 10%.

	(1) Environmental	(2) Resource Use	(3) Emission Reduction	(4) Environmental Innovation
FX Vol (Exposure Weighted)	-1.44***	-1.03*	-1.89***	-1.19
	(-4.24)	(-1.92)	(-3.46)	(-1.57)
FX Rate Change	0.26***	0.08	0.31***	0.38***
	(3.42)	(0.80)	(2.79)	(2.77)
Foreign Income	-0.02	0.00	-0.05	-0.01
	(-0.47)	(0.04)	(-1.04)	(-0.11)
TobinQ	1.00*	0.65	1.41	0.95
	(1.71)	(0.89)	(1.53)	(1.11)
Tangibility	-6.39	-18.16*	-7.73	5.25
	(-0.87)	(-1.87)	(-0.73)	(0.56)
Leverage	-1.06	2.28	-0.75	-4.51
	(-0.22)	(0.35)	(-0.11)	(-0.64)
Pretax Income	-7.10	-9.97*	-0.82	-10.61
	(-1.51)	(-1.72)	(-0.13)	(-1.36)
Pretax Income Vol	-22.91**	-39.31***	-21.20	-7.89
	(-2.01)	(-2.70)	(-1.28)	(-0.37)
Size	2.90**	3.32*	4.72***	0.59
	(2.13)	(1.76)	(2.60)	(0.28)
Firm Age	14.57**	12.21	2.97	29.00***
	(2.56)	(1.60)	(0.40)	(2.85)
Constant	Yes	Yes	Yes	Yes
Market×Year FE	Yes	Yes	Yes	Yes
Industry×Year FE	Yes	Yes	Yes	Yes
Firm FE	Yes	Yes	Yes	Yes
Cluster	Firm	Firm	Firm	Firm
Observations	5,187	5,187	5,187	5,187
R-squared	0.88	0.86	0.86	0.81

Table A9. Robustness Check - ESG Rating: GARCH Model Volatility

This table presents the OLS regression results for Equation (10). The dependent variables are the firm's ASSET4 environmental rating scores in the next year (year $t + 1$). The key independent variable is the firm-specific FX volatility based on GARCH model in year t. Industry×Year fixed effects, Market×Year fixed effects, firm fixed effects and firm-year controls including *FX Rate Change, Foreign Income, TobinQ, Tangibility, Leverage, Pretax Income, Pretax Income Vol, Size and Firm Age*, are included in all regressions. Standard errors are clustered at the market level, and t-statistics are in parentheses. Variable definitions are provided in Internet Appendix Table A1. *, **, and *** indicate significance at 1%, 5% and 10%.

	(1) Environmental	(2) Resource Use	(3) Emission	(4) Environmental Innovation
FX GarchVol (Exposure Weighted)	-1.10***	-0.79***	-1.14***	-1.32***
	(-6.16)	(-4.15)	(-3.00)	(-3.48)
FX Rate Change	0.22**	0.05	0.24**	0.37**
	(2.67)	(0.65)	(2.62)	(2.19)
Foreign Income	0.01	0.02	-0.03	0.03
	(0.48)	(0.52)	(-1.06)	(0.98)
TobinQ	1.00**	0.65	1.41**	0.95
	(2.47)	(0.74)	(2.22)	(1.19)
Tangibility	-6.08	-17.94**	-7.33	5.52
	(-0.97)	(-2.11)	(-0.58)	(0.75)
Leverage	-1.24	2.15	-0.93	-4.72
	(-0.20)	(0.48)	(-0.12)	(-0.55)
Pretax Income	-7.37	-10.17	-1.10	-10.95
	(-1.27)	(-1.38)	(-0.16)	(-1.71)
Pretax Income Vol	-22.84*	-39.26***	-20.94	-8.07
	(-1.76)	(-3.60)	(-1.10)	(-0.37)
Size	2.91*	3.32*	4.75***	0.58
	(2.06)	(1.84)	(4.44)	(0.19)
Firm Age	14.73*	12.32	3.12	29.19**
	(1.96)	(1.67)	(0.35)	(2.70)
Constant	Yes	Yes	Yes	Yes
Market×Year FE	Yes	Yes	Yes	Yes
Industry×Year FE	Yes	Yes	Yes	Yes
Firm FE	Yes	Yes	Yes	Yes
Cluster	Market	Market	Market	Market
Observations	5,187	5,187	5,187	5,187
R-squared	0.88	0.86	0.86	0.81

Table A10. Robustness Check - Pollution News Events: Cluster Standard Errors at the Firm Level

This table presents the Possion regression results for Equation (11). The dependent variables are the number of firm's pollution news events weighted with different schemes in the next year (year $t + 1$). The key independent variable is the firm-specific FX volatility in year t. Industry×Year fixed effects, Market×Year fixed effects, firm fixed effects and firm-year controls including *FX Rate Change, Foreign Income, TobinQ, Tangibility, Leverage, Pretax Income, Pretax Income Vol, Size and Firm Age*, are included in all regressions. Standard errors are clustered at the firm level, and t-statistics are in parentheses. Variables are defined in Internet Appendix Table A1. *, **, and *** indicate significance at 1%, 5% and 10%.

	(1)	(2)	(3)	(4)	(5)
	Number of Pollution News Events				
	Events	Events (Severity)	Events (Severity-Novelty)	Events (Severity-Reach)	Events (Severity-Novelty-Reach)
FX Vol (Exposure Weighted)	0.19***	0.20***	0.21***	0.21***	0.21***
	(3.90)	(3.80)	(3.99)	(3.99)	(3.99)
FX Rate Change	-0.01	-0.02	-0.03*	-0.03*	-0.03*
	(-0.93)	(-1.47)	(-1.66)	(-1.66)	(-1.71)
Foreign Income	-0.01**	-0.01*	-0.01	-0.01	-0.01
	(-1.98)	(-1.68)	(-1.56)	(-1.56)	(-1.45)
TobinQ	0.12	0.13	0.14*	0.14*	0.14*
	(1.61)	(1.62)	(1.70)	(1.70)	(1.71)
Tangibility	-0.88	-1.41**	-1.46**	-1.46**	-1.55**
	(-1.35)	(-2.04)	(-2.11)	(-2.11)	(-2.18)
Leverage	-1.06*	-1.28**	-1.12*	-1.12*	-1.02*
	(-1.89)	(-2.09)	(-1.84)	(-1.84)	(-1.66)
Pretax Income	0.19	0.12	0.28	0.28	0.35
	(0.28)	(0.17)	(0.41)	(0.41)	(0.49)
Pretax Income Vol	0.68	0.72	1.16	1.16	1.48
	(0.46)	(0.46)	(0.69)	(0.69)	(0.82)
Size	0.91***	0.95***	0.94***	0.94***	0.95***
	(4.34)	(4.49)	(4.60)	(4.60)	(4.66)
Firm Age	0.33	0.26	0.06	0.06	-0.09
	(0.52)	(0.38)	(0.09)	(0.09)	(-0.13)
Constant	Yes	Yes	Yes	Yes	Yes
Market×Year FE	Yes	Yes	Yes	Yes	Yes
Industry×Year FE	Yes	Yes	Yes	Yes	Yes
Firm FE	Yes	Yes	Yes	Yes	Yes
Cluster	Firm	Firm	Firm	Firm	Firm
Observations	4,630	4,630	4,630	4,630	4,630

Table A11. Robustness Check - Pollution News Events: GARCH Model Volatility

This table presents the Possion regression results for Equation (11). The dependent variables are the number of firm's pollution news events weighted with different schemes in the next year (year $t+1$). The key independent variable is the firm-specific FX volatility based on GARCH model in year t. Industry×Year fixed effects, Market×Year fixed effects, firm fixed effects and firm-year controls including *FX Rate Change, Foreign Income, TobinQ, Tangibility, Leverage, Pretax Income, Pretax Income Vol, Size and Firm Age*, are included in all regressions. Standard errors are clustered at the market level, and t-statistics are in parentheses. Variables are defined in Internet Appendix Table A1. *, **, and *** indicate significance at 1%, 5% and 10%.

	(1)	(2)	(3)	(4)	(5)
	Number of Pollution News Events				
	Events	Severity	Severity-Novelty	Severity-Reach	Severity-Novelty-Reach
FX GarchVol (Exposure Weighted)	0.19***	0.20***	0.21***	0.21***	0.21***
	(3.12)	(2.92)	(3.03)	(3.03)	(3.07)
FX Rate Change	-0.01	-0.02	-0.03	-0.03	-0.03
	(-0.86)	(-1.28)	(-1.38)	(-1.38)	(-1.40)
Foreign Income	-0.01*	-0.01*	-0.01	-0.01	-0.01
	(-1.83)	(-1.80)	(-1.55)	(-1.55)	(-1.39)
TobinQ	0.12**	0.13**	0.14**	0.14**	0.14**
	(2.20)	(2.04)	(2.30)	(2.30)	(2.38)
Tangibility	-0.88	-1.41	-1.46	-1.46	-1.55
	(-1.06)	(-1.51)	(-1.54)	(-1.54)	(-1.60)
Leverage	-1.06	-1.28	-1.12	-1.12	-1.02
	(-1.41)	(-1.64)	(-1.40)	(-1.40)	(-1.25)
Pretax Income	0.19	0.12	0.28	0.28	0.35
	(0.24)	(0.14)	(0.36)	(0.36)	(0.43)
Pretax Income Vol	0.68	0.72	1.16	1.16	1.48
	(0.59)	(0.53)	(0.71)	(0.71)	(0.78)
Size	0.91***	0.95***	0.94***	0.94***	0.95***
	(5.24)	(4.96)	(4.80)	(4.80)	(4.63)
Firm Age	0.33	0.26	0.06	0.06	-0.09
	(0.43)	(0.27)	(0.06)	(0.06)	(-0.10)
Constant	Yes	Yes	Yes	Yes	Yes
Market×Year FE	Yes	Yes	Yes	Yes	Yes
Industry×Year FE	Yes	Yes	Yes	Yes	Yes
Firm FE	Yes	Yes	Yes	Yes	Yes
Cluster	Market	Market	Market	Market	Market
Observations	4,630	4,630	4,630	4,630	4,630