Global Currency Risk and Corporate Carbon Emissions

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Abstract

We collect global firms' greenhouse gas (GHG) emissions, foreign exchange (FX) exposures, supply chain relations, and accounting information to construct an international sample of 2,159 GHG-reporting firms across 21 markets from 2003 to 2020. We first show that firms with higher FX risk (their exposures multiplied by FX volatility) release more GHG emissions in their own and upstream operations. This relation has a causal interpretation based on our identification tests that exploit the introductions of new FX derivatives in the Chicago Mercantile Exchange and the shifts in foreign exchange regime. FX risk also weakens corporate environmental performance. We further examine the mechanisms underlying the effect by looking into firms' decisions. Affected firms adjust their suppliers, such as switching to new and short-term ones, to offset their FX risk. The FX risk effect is more pronounced for firms with lower supplier-switching costs and with more financial constraints. On the other hand, firms that utilize FX derivatives more are less affected by FX risk. This paper highlights the real effect of FX volatility from the perspective of environmental externalities.

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

JEL Code**:** F31, G30, M14

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1. Introduction

Externalities of economic activities have been a key issue in economic analyses of corporate decisions and managerial incentives. Among all the externalities resulting from corporate operations, carbon emissions appear to be one of the most pressing issues given the increasing public attention to climate change and potential economic damage.[1] On the other hand, the globalization of supply chains and production networks over the past few decades allowed firms to offshore not only their production and procurement, but also their pollution and GHG emission (Li and Zhou, 2017; Shapiro and Walker, 2018; Berry, Kaul, and Lee, 2021; Bartram, Hou, and Kim, 2022; Choi et al., 2025). All of these suggest an important role of FX risk in corporate operations, especially in environmental engagement.[2]

In this paper, we propose that FX risk influences corporate carbon emissions through FX hedging, financial constraints, and operational adjustment. If a firm can perfectly predict the amount of foreign currency revenue it will generate, it can hedge the risk with a forward contract for that specific amount (Kerkvliet and Moffett, 1991), thereby maintaining a stable operational performance. However, if the foreign revenues are uncertain, no ex ante financial contracts can completely hedge the risk, the firm is subject to uncertain financial constraint and may choose to cut back investment in emission reductions (Fang, Hsu, and Tsou, 2024). Another choice for the firm is to seek cheaper overseas sources (Chowdhry and Howe, 1999).[3] Such offshoring can produce even more carbon emissions due to the lower environmental standard of cheaper suppliers and increased transportation needs for global sourcing (Ugarte, Golden, and Dooley, 2016).

To empirically examine the effect of FX risk on corporate emissions, we first construct the pairwise FX rates to calculate the variance-covariance matrix of different currencies. Then, we calculate the firm-level FX risk by multiplying a vector representing the revenues of the firm from different markets

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

[2]While researchers have exerted great efforts to analyze the determinants of corporate carbon emissions, most of prior studies focus on *microeconomic* factors, such as cost of capital (Sharfman and Fernando, 2008; Levine et al., 2018; Flammer, 2021), reputation concerns (Matsumura, Prakash, and Vera-Muñoz, 2014; Li, Xu, and Zhu, 2025), and pollution regulation (Ramadorai and Zeni, 2024).

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

with the variance-covariance matrix of different currencies.[4] Since the foreign revenues of a firm vary across different years, this metric can be considered as an incomplete Bartik-style instrument (Borusyak, Hull, and Jaravel, 2022).

We collect the firm carbon emission data form 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). We also collect the environmental scores from the Refinitiv ASSET4 ESG database for alternative indicators of firm performance in emission abatement.

Our baseline empirical results show that firm-level FX risk is associated with increased scope 1 carbon intensity and scope 3 upstream carbon intensity in the next year, after controlling for firm, industry-year, and market-year fixed effects, as well as an extensive list of firm characteristics. The effects are economically sizable as a 1% increase in FX risk leads to a 4.3% increase in scope 1 carbon intensity and a 1.3% increase in scope 3 upstream carbon intensity. The positive relation with the scop 3 upstream supports the operational mechanism – affected firms choose to offshore emissions or seek cheaper suppliers of lower environmental standards.[5] The results are similar if we use the GARCH model to calculate the FX risk. In addition, we also find that firms' FX risk is negatively related to their ASSET4 scores, suggesting weakened environmental performance.

To establish a causal interpretation of the positive relation between FX risk and carbon intensity, we employ two historical shocks in foreign exchange market as quasi-natural experiments. We first examine the introduction of new currency derivative products by the Chicago Mercantile Exchange (CME). As documented by Hoberg and Moon (2017), the launch of these new products provides liquid tools for international firms to hedge their FX risk, even for those heavily relying on OTC contracts. We

[4]This approach differs from existing studies that assume the impacts of currency movements to be marginal (Deng, 2020; Taylor, Wang, and Xu, 2021; Hsu et al., 2022), we include the co-movements among different currencies to have a more accurate proxy.

[5]Empirical literature has docoumented 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.

observe that firms subject to this shock exhibit reduce future carbon intensity in comparison to unaffected firms. Our second shock is the exchange rate regime changes by Ilzetzki, Reinhart, and Rogoff (2019). Transitioning from floating to fixed (fixed to floating) FX rate systems makes firms encounter reduced (increased) uncertainty with regard to exchange rates. We observe that firms in markets transitioning from floating to fixed (fixed to floating) exchange rate regimes reduce (increase) their future carbon intensity. Both identification tests support a causal effect of FX risk on corporate emissions.

Many countries or regions, such as European Union, have implemented carbon tax for domestic (and even foreign) production to mitigate carbon emissions. We thus examine if the FX risk effect is mitigated by carbon tax. This conjecture receives empirical evidence: the positive relation between FX risk and carbon emissions is reduced for firms located or having customers in markets with a carbon tax.

We then examine the operational adjustment mechanism. We gather firm contract data from both suppliers and customers to construct proxies for various contract-related metrics, including the number of current contracts, newly established contracts, contracts with private suppliers or customers, and the average contract duration in months. We find that when FX risk hits, firms tend to have more short-term contracts with private suppliers but the contracts with customer are largely unaffected. Firms benefit from such operational adjustments that increase their flexibility to allocate production, especially under uncertain FX rates. However, private suppliers typically exhibit poorer environmental performance compared to their public counterparts, which lead to increased carbon emissions to downstream (Hörisch, Johnson, and Schaltegger, 2015). The effects are amplified for firms with lower switching cost in the supply chain.

We next investigate the mechanisms related to firms' FX hedging and financial constraints. The usage of FX derivatives reduces firms' incentives to adopt operational adjustments which may lead to higher emission levels. Our empirical results show that usage of FX derivatives can effectively shield firms and mitigate the effects of FX risk. Existing research has highlighted the significance of financially constrained firms when implementing environmental regulations (Bartram, Hou, and Kim, 2022; Xu and Kim, 2022). Since financially constrained firms face difficulties in obtaining external financing, the marginal cost of emission abatement rises. We find that the impact of FX volatility is more pronounced for firms that are more financially constrained.

We contribute to the existing literature on firms' operational adjustments and FX hedging from a new perspective – corporate carbon emissions. Our tests for the operational adjustment mechanism highlight the potential environmental externalities of firms' flexible supply contracts to diminish its FX risk (Huchzermeier and Cohen, 1996; Kamrad and Siddique, 2004; Kazaz, Dada, and Moskowitz, 2005). To maintain operational flexibility when FX rates are more volatile, firms may increase the frequency of transportation and further increase the carbon intensity of downstream customers (Ugarte, Golden, and Dooley, 2016).[6] On the other hand, prior studies on FX hedging focus on benefits to corporate production and profit (Géczy, Minton, and Schrand, 1997; Allayannis and Weston, 2001; Allayannis, Lel, and Miller, 2012) but neglect its non-pecuniary effects. We show that FX hedging helps mitigate firms' financial uncertainty and thus facilitates their long-term investments including emission abatement.

Our paper also adds to the literature on the real effects of FX volatility on corporate decisions. Previous studies (Taylor, Wang, and Xu, 2021; Hsu et al., 2022) investigate the financial activities and performance such as capital investment and innovation but ignore the non-financial performance, such as environmental externalities. Different from prior studies that explore the determinants of industry- or firm-level pollution in a single market (e.g. Hettige, Mani, and Wheeler, 2000; Doonan, Lanoie, and Laplante, 2005; Clarkson et al., 2011; Jiang, Lin, and Lin, 2014), we focus on the role of an important macroeconomic factor – FX volatility – in international firms' emission decisions. Our mechanism tests based on supply chain data also provide direct evidence for such an influence.

The remainder of the paper is organized as follows. Section 2 describes the data source and variables construction. Section 3 presents the main empirical test results between FX risk and corporate carbon emissions. Section 4 further investigates the underlying economic mechanisms that explain the connection between FX risk and corporate carbon emissions. Section 5 summarizes the paper.

[6]On average, the logistics and transport carbon emissions are 5% to 15% of product 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.

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.[7] An increase in the exchange rate indicates an appreciation of the foreign currency against USD. The 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:

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

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:

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

where $var(\cdot)$ and $cov(\cdot)$ is the annualized variance and covariance function, respectively; $\mathbf{r}_{i,j,t}$ =

[7] The 48 currencies are from the markets below: Australia, Austria, Belgium, Brazil, Bulgaria, Canada, Croatia, Cyprus, Czech Republic, Denmark, Egypt, European Union, 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, United Kingdom.

$[r_{i,j,1}, \cdots, r_{i,j,k}]$ 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.[8] As a robustness check, we consider an alternative measure of exchange rate variance-covariance using the generalized autoregressive conditional heteroskedasticity (GARCH) model of Bollerslev (1986).

2.1.1. Firm-Level Foreign Exchange Rate Volatility

To proxy a firm's exposure on exchange rate volatility, we obtain the firm's annual revenue from different markets via the FactSet Geographic Revenue Exposure database. 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 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, and the currency volatility of domestic revenue is defined as zero.

The we calculate the firm-specific FX volatility as follows:

$$Vol_{f,t} = \sqrt{\mathbf{w_{f,t}} \cdot \Sigma_{i,t} \cdot \mathbf{w}'_{f,t}}, \tag{4}$$

where $Vol_{f,t}$ is the specific 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 intuition is that if a firm has more revenue from a specific foreign market, the bilateral exchange rate volatility 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. Our firm-specific FX risk takes into account the co-movement of multiple currencies, differing from existing studies that suggest the impact of this correlation is marginal

[8] 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.

(e.g, Deng, 2020; Taylor, Wang, and Xu, 2021; Hsu et al., 2022). Our method aligns with the Bartik instrument proposed by Bartik (1991), which interacts the industry employment shares (exposure) with the national industry employment growth rate (common shock). The aggregated volatility can be decomposed as the product of revenue-based exposure vector and the currency variance-covariance matrix.

2.1.2. Exogenous Shocks on Foreign Exchange Market

Although the revenue across different markets are outcome of firm policies, it is unlikely for a single firm to influence market-level exchange rates. Therefore, we have less concern regarding the reverse causality. To mitigate the influence of omitted confounding factors and establish the causal effect of FX volatility on corporate environmental performance, we employ two exogenous shocks on foreign exchange market as quasi-natural experiments: 1) the launch of new currency derivative products by Chicago Mercantile Exchange (CME); 2) the change of exchange rate regime from fixed to floating or from floating to fixed.

CME Currency Derivative Launch We collect the historical first trade dates of FX derivative products from the CME.[9] The introduction of new FX products is staggered over time and only certain markets are 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 derivatives 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:

$$CME\ Deriative_{f,t} = \sum_{j,j\neq i} w_{f,i,j,t} \cdot \max(\mathbb{1}_{i,t}, \mathbb{1}_{j,t}) \tag{5}$$

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; 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

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

domestic currency or foreign currency.

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. Then we construct two dummy variables: $\mathbb{1}_{\text{floating},t}$ equals one if the exchange rate regime is floating in year t, and $\mathbb{1}_{\text{fixed},t}$ equals one if the exchange rate regime is fixed in year t. Similar to the aforementioned, the firm's foreign revenue affected by the exchange rate regime change shock can be calculated as:

$$Fixed2Float_{f,t} = \sum_{j,j\neq i} w_{f,i,j,t} \cdot \mathbb{1}_{\text{fixed},t-1} \cdot \mathbb{1}_{\text{floating},t} \tag{6}$$

and exchange rate regime change from floating to fixed is calculated as:

$$Float2Fixed_{f,t} = \sum_{j,j\neq i} w_{f,i,j,t} \cdot \mathbb{1}_{\text{floating},t-1} \cdot \mathbb{1}_{\text{fixed},t} \tag{7}$$

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 $\mathbb{1}_{\text{fixed},t-1} \cdot \mathbb{1}_{\text{floating},t}$ ($\mathbb{1}_{\text{floating},t-1} \cdot \mathbb{1}_{\text{fixed},t}$) indicates the transition of exchange rate regime from floating to fixed (fixed to floating).

2.2. Corporate Environmental Performance

We collect the 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 [10]. Trucost also estimates the carbon emissions of firms without publicly available disclosure using the environmental profiling model 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 other five major data vendors.

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

We analyze the 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. We construct four main dependent variables : *Scope 1, Scope 2, Scope 3 (Up), Scope 3 (Down)*, which are the firm's carbon intensity from different sources. We use the carbon intensity, defined as the ratio between a firm's carbon emissions (tonnes of CO2 equivalent) to its revenue (million USD), 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.

Besides the corporate emission data, we obtain the firm's overall environmental and subcategory performance scores (*Environmental, Resource Use, Emission, Environmental Innovation*) by rating agency from the Refinitiv ASSET4 ESG database following Dyck et al. (2019). The ASSET4 ESG data have been widely used in academic research, but recent study has raised concerns about the reliability of the scores (Berg, Fabisik, and Sautner, 2021). Thus, we utilize the data as an alternative measure and base our main analysis on corporate carbon intensity.

2.3. The Usage 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 the firm derivative usage data from their annual reports sourced from the Reuters Eikon. We construct a dummy variable *FX Derivative* that equals one if firms report the usage of FX derivatives in their annual report. We confirm a firm's FX derivative usage 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 usage is smaller than that of the main results due to the limited availability of annual reports through Reuters Eikon.

2.4. Firm-level Supply Chain Relation

To proxy the firm's operational shift policy, we collect the contractual relationships between customers and suppliers from the Factset Revere database. The database provides supply chain relation details 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 (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 company's operational adjustments regarding the upstream and downstream.

2.5. Firm Fundamentals

We collect the international firms' 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. 2) *Foreign Income* denotes the proportion of foreign income. 3) *TobinQ* is the 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 that covers 123,353 firm-year observations from the year 2002 to 2021. Then we merge the sample with the FactSet Geographic Revenue Exposure and keep 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 Datastream database to construct the firm-level FX volatility and keep the observations with available foreign exchange 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 controls' observations. After removing the markets with 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. 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 in OLS:

$$Carbon_{f,t+1} = \alpha + \beta \cdot Vol_{f,t} + \mathbf{X}_{f,t} + \Phi_f + \Phi_{market,t} + \Phi_{ind,t} + \epsilon_{f,t}, \tag{8}$$

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; $Vol_{f,t}$ is the geographic revenue weighted FX volatility of firm f 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 at Internet Appendix Table A1. We include the firm fixed effects Φ_f to absorb all firm-specific omitted variables, market-year fixed effects $\Phi_{market,t}$ to incorporate all market-specific time-varying factors, and industry-year fixed effects $\Phi_{ind,t}$ to adjust for the industry-level time trend of all variables. $\epsilon_{f,t}$ is the normally distributed error term with a zero mean. Our industry classification is based on two-digit SIC code and 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.[11]

Table 3 presents the results of Equation (8). As shown in column (1) of Table 3, more volatile exchange rate is associated with higher scope 1 carbon intensity and in the following year. The results are not only statistically significant but also economically meaningful. A standard deviation increase of firm-specific FX volatility leads to a 2.2% increase in scope 1 carbon intensity.[12] The result of scope 2 carbon intensity in column (2) is insignificant, indicating that FX risk does not lead to more intensive energy consumption. Results in columns (3) and (4) show that FX risk increases the scope 3 carbon intensity related to upstream activities but does not affect downstream carbon emissions. The baseline results suggest that firms implement varying operational strategies in response to fluctuating exchange rates. Our findings remain robust when using an alternative volatility measure by the GARCH model, as presented in Internet Appendix Table A2.

[Place Table 3 Here]

To eliminate concerns of reverse causality that firms in a country experiencing growing trade with foreign markets, leading to a more stable currency, may gradually decrease their carbon emissions, we run a placebo test using the carbon intensity from year $t-3$ to $t-1$ as the dependent variables. The remaining specifications of our placebo test align with the baseline regressions. Internet Appendix Table A3 presents the results of our placebo test, and suggests no significant relation between lagged emission levels and FX risk, contrary to the reverse causality conjecture.

3.2. Environmental Ratings

Our baseline findings indicate that firms' carbon intensity levels increase with their FX risk. To reexamine this relation, we use the ASSET4 ESG scores as an alternative measure of firm environmental

[11] The results are robust if we cluster the standard errors at the firm level.

[12] 2.2% is calculated as: 5.01 (coefficient) × 0.53 (standard deviation) / 119.81 (mean of scope 1 carbon intensity) × 100%.

performance and re-estimate our baseline model:

$$Env_{f,t+1} = \alpha + \beta \cdot Vol_{f,t} + \mathbf{X}_{f,t} + \Phi_f + \Phi_{market,t} + \Phi_{ind,t} + \epsilon_{f,t}, \tag{9}$$

where $Env_{f,t+1}$ is the overall (*Environmental*) or subcategory (*Resource Use, Emission, Environmental Innovation*) scores of firm f in year $t+1$. The remaining specifications are the same as our baseline model outlined in Equation (8).

Table 4 reports the results of Equation (9). 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 are reflected in lower environmental scores. Poor performance in subcategories suggests that, when exchange rates become volatile, the firm may postpone irreversible environmental-related projects, such as the adoption of green technology and investment in eco-efficient supply chains. The results are similar if we use volatility based on the GARCH model and are presented in Internet Appendix Table A4.

[Place Table 4 Here]

3.3. Identification Strategy

In the baseline analysis, we observe a positive relation between FX risk and carbon intensity levels of firms. A common concern is that, as both foreign revenue and carbon intensity are outcomes of endogenous decisions made by firms, there could exist omitted variables that influence both outcomes. To establish the causal interpretation of the FX risk effect on firm carbon intensity, we use two shocks to firms' FX risk: the launch of new FX products by CME and the exchange regime change, as quasi-natural experiments. The idea is that although the exposure are endogenous, common shocks are as-good-as-randomly assigned to mitigate concerns about omitted variables. Unlike the conventional Bartik instrument that assumes that the sum of exposure shares equals one, in our setting, firm's foreign revenue does not necessarily sum to a constant value. Borusyak, Hull, and Jaravel (2022) show that the incomplete share methods, after controlling for the sum of exposure shares, remain valid under the conditional shock exogeneity assumption.

3.3.1. Launch of new currency products

Our first shock is the CME launches of new FX derivative products, which are staggered in time and only affect firms located in or traded with specific markets. During our sample periods, 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, we expect that post their introduction, firms could take advantage of liquid products to protect themselves against uncertain FX rates.

We estimate the following empirical model:

$$Carbon_{f,t+1} = \alpha + \beta \cdot CME\ Deriative_{f,t} + \mathbf{X}_{f,t} + \Phi_f + \Phi_{market,t} + \Phi_{ind,t} + \epsilon_{f,t}, \tag{10}$$

where $Carbon_{f,t+1}$ is the scope 1 or scope 3 carbon intensity from upstream operations for firm f in year t; $CME\ Deriative_{f,t}$ is the percentage of foreign revenue affected by the CME launch of new currency products 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 5 Here]

Table 5 presents the results of Equation (10). We find that post the CME shocks, firms affected more by the shock tend to decrease their carbon emissions compared to firms affected less. Our findings are consistent with previous studies document that firms reduce operational hedging when more liquid FX instruments are available (Hoberg and Moon, 2017).

To validate the absence of any pre-existing trends before the events, we conduct a dynamic events 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 CME introduced new currency products for home market of firm f or foreign markets that firm f traded in. In particular, we estimate the following regressions:

$$Carbon_{f,t+1} = \alpha + \sum_{y=-5, y\neq 0}^{+5} \beta_y \cdot D_{f,e-1} \cdot Event_{f,e+y} + \mathbf{X}_{f,t} + \Phi_f + \Phi_{market,t} + \Phi_{ind,t} + \epsilon_{f,t}, \tag{11}$$

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: Panel 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 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 persistent FX volatility effects post the shock, confirming the causal effect of FX risk.

[Place Figure 1 Here]

3.3.2. Changes in exchange rate regime

Our second shock is the exchange rate regime change. If an economy shifts its exchange rate system from a fixed regime to a floating one, firms will encounter increased FX risk. For instance, the global exchange rate volatility increased dramatically following the collapse of the Bretton Woods system (Smith Jr, Smithson, and Wilford, 1989). The timing of the changes is largely exogenous and 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 $CME\ Deriative_{f,t}$ in Equation (10) by firm-specific exchange regime changes and estimate the following regression:

$$Carbon_{f,t+1} = \alpha + \beta_1 \cdot Fixed2Float_{f,t} + \beta_2 \cdot Float2Fixed_{f,t} + \mathbf{X}_{f,t} + \Phi_f + \Phi_{market,t} + \Phi_{ind,t} + \epsilon_{f,t}, \quad (12)$$

where $Fixed2Float_{f,t}$ and $Float2Fixed_{f,t}$ denote the percentage of firm revenue affected by the floating-to-fixed and fixed-to-floating shock, respectively. The construction of $Fixed2Float_{f,t}$ and $Float2Fixed_{f,t}$ has been detailed in Section 2.1.2. The remaining specifications are the same as our baseline model outlined in Equation (8).

Table 6 reports the results of Equation (12). As shown in Table 6, the estimated effects of fixed-to-float transitions are negative and statistically significant for firm carbon emissions. The estimated effects of float-to-fixed transitions hold the opposite sign. The results not only confirm our baseline findings, but also support a causal effect of FX fluctuations in FX rates on increased carbon emissions.

[Place Table 6 Here]

4. Corporate Incentives and Decisions

4.1. Carbon Tax

Many countries or subnational jurisdictions have implemented carbon tax systems. For example, the European Union has carbon emission regulations that require importers of carbon-intensive goods have to pay a charge. We expect that the FX risk effect on corporate 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:

$$\begin{aligned} Carbon_{f,t+1} = \ & \alpha + \beta \cdot Vol_{f,t} \cdot CarbonTax_{f,t} + Vol_{f,t} + CarbonTax_{f,t} + \\ & \mathbf{X}_{f,t} + \Phi_f + \Phi_{market,t} + \Phi_{ind,t} + \epsilon_{f,t} \end{aligned} \tag{13}$$

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 $CarbonTax\ (Customer)_{f,t}$ 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 is obtained from the global carbon pricing databases by Dolphin and Xiahou (2022). The remaining specifications are the same as our baseline model.

Table 7 presents the results of Equation (13). As shown in Table 7, the coefficients of interaction terms are negative and statistically significant. Both the carbon tax imposed by home country or customers' countries matters, aligning with studies suggesting that firm carbon abatement policies are determined by current or anticipated future carbon regulations (Ramadorai and Zeni, 2024). These results confirm our prediction that as the marginal cost of carbon outputs increases, firms are less likely to raise carbon emissions in response to FX risks.

[Place Table 7 Here]

4.2. Operational Adjustment

4.2.1. Supply chain restructuring

As shown in our baseline results, FX risk leads to higher carbon intensity associated with upstream rather than downstream. To further empirically estimate the effects of FX volatility on firm contractual relations with suppliers and customers, we estimate the following regression:

$$Contract_{f,t+1} = \alpha + \beta \cdot Vol_{f,t} + Expired_{f,t} + \mathbf{X}_{f,t} + \Phi_f + \Phi_{market,t} + \Phi_{ind,t} + \epsilon_{f,t}, \tag{14}$$

where the $Contract_{f,t+1}$ denotes measures for the firm's contractual relations with suppliers (customers) in year $t+1$, which includes *Contract Num*, *Contract Num*, *Contract Num*, and *Contract Duration* for suppliers or customers. $Expired_{f,t}$ is 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 results of Equation (14). As shown in Panel A of Table 8 for contracts with suppliers, FX volatility reduces the number and the average duration of newly initiated contracts in the following year. More importantly, FX volatility increases the number of contracts with new suppliers and private suppliers. In Panel B for contracts with customers, we find no significant results when using contracts with customers as the dependent variables. These findings confirm our initial results that firms increase carbon intensity in connection to their upstream operations. 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). 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 emission. Reduced supplier duration and the implementation of just-in-time inventory management lead to a higher frequency of transportation as large shipping packages are split to small ones, resulting in increased greenhouse gas emissions within the supply chain. Moreover, compared to large public suppliers, small private ones have fewer sustainability management tools and resources to reduce the emission levels (Hörisch, Johnson, and Schaltegger, 2015). The results provide empirical evidence that firms adopt operational policies to mitigate the influence of FX rate uncertainty, which increases supply chain carbon emissions due to more frequent orders to private suppliers. Internet Appendix Table A5 presents the results using the GARCH model to calculate the volatility, which shows consistent results.

[Place Table 8 Here]

4.2.2. Costs to switch 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 supply patterns to new ones is less costly, then the option to allocate production to particular markets until uncertain exchange rates stabilize is more appealing (Ding, Dong, and Kouvelis, 2007). To empirically test the hypothesis, we estimate the following model:

$$\begin{aligned} Y_{f,t+1} = \; & \alpha + \beta \cdot Vol_{f,t} \cdot AP_{f,t} + Vol_{f,t} + AP_{f,t} + \\ & \mathbf{X}_{f,t} + \Phi_f + \Phi_{market,t} + \Phi_{ind,t} + \epsilon_{f,t} \end{aligned} \tag{15}$$

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

Table 9 presents the results of Equation (15). As shown in Columns (1) and (2), the interaction terms are positive and significant for carbon intensity, which suggests that firms tend to increase pollution levels when they can easily switch suppliers. In Columns (3) to (6), the interaction terms hold the same signs as the FX risk in Equation (14), indicating that firms reduce the number of new contracts while initiate more short-term contracts with private suppliers. The results suggest that firms' operational flexibility actually amplifies the effects of FX volatility, which unfortunately results in more emissions.

[Place Table 9 Here]

4.3. Currency Derivative Usage

Firms exposed to FX rate uncertainty may use currency derivatives to hedge the FX risk. Therefore, we expect that the usage of currency derivatives will weaken the effects of FX risk. To empirically test our prediction, we estimate the following model:

$$
\begin{aligned}
Y_{f,t+1} =& \alpha + \beta_1 \cdot Vol_{f,t} \cdot FX\ Derivative_{f,t} + \beta_2 \cdot Vol_{f,t} + \beta_3 \cdot FX\ Derivative_{f,t} + \\
& \mathbf{X}_{f,t} + \Phi_f + \Phi_{market,t} + \Phi_{ind,t} + \epsilon_{f,t},
\end{aligned} \tag{16}
$$

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 usage in its annual report of year t and zero otherwise. The remaining specifications are the same as our baseline model.

[Place Table 10 Here]

Table 10 presents the results of regression Equation (16). The interaction terms are statistically significant and hold the opposite signs to $Vol_{f,t}$. The results support our conjecture that currency derivative usage can efficiently mitigate the risk of uncertain FX rates and reduce firms' operational adjustments (such as switching to new suppliers or using more short-term contracts). The usage of currency derivatives is also economically meaningful: it mitigates the marginal effect of FX risk on scope 1 emission intensity by 34%.[13] Similarly, these firms have less incentive to take more short-term orders with suppliers.

4.4. Financial Constraint

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

[13] 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 FX volatility in our sample.

the long-term value of a firm, yet it may lead to a short-term boost in financial performance (Maeckle, 2024). When foreign revenues are uncertain, financially constrained firms tend to increase their emission levels to maintain their financial performance. We empirically examine if the effects of FX volatility is more pronounced for financially constrained firms by estimating the following model:

$$\begin{aligned} Y_{f,t+1} = {} & \alpha + \beta \cdot Vol_{f,t} \cdot FinConstraint_{f,t} + Vol_{f,t} + FinConstraint_{f,t} + \\ & \mathbf{X}_{f,t} + \Phi_f + \Phi_{market,t} + \Phi_{ind,t} + \epsilon_{f,t}, \end{aligned} \tag{17}$$

where $Y_{f,t+1}$ is the carbon intensity 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 for both indices indicates a higher degree of financial constraints. The remaining specifications are the same as our baseline model.

Table 11 presents the results of Equation (17), where Panel A (B) presents the results using *KZ* (*WW*) index as the proxy for financial constraint, respectively. The coefficients of interaction terms are all significant and share the same direction as that of FX volatility, suggesting that the effects of FX volatility are more pronounced for firms with more financial constraints that increase their marginal cost of carbon emission abatement (Fang, Hsu, and Tsou, 2024).

[Place Table 11 Here]

5. Conclusion

In this paper, we empirically investigate whether firms' greenhouse gas emissions are influenced by their foreign exchange risk. Using panel data with the firm-specific measure of emissions and FX risk, we find that uncertain FX rates increase a firm's carbon intensity in its own and upstream operations. Moreover, the overall and sub-categorical environmental scores assigned by the external rating agency also decrease with FX volatility. We then implement identification tests based on the introductions of FX derivatives and FX regime changes to support a causal interpretation. Our empirical evidence collectively indicates that FX volatility has an adverse impact on a firm's environmental performance.

We further examine the channels underlying such a relation by focusing on firms' incentives. The higher emission levels are results of multinational firms' operational adjustment. When foreign exchange rates become uncertain, companies tend to reduce the quantity of contracts with suppliers but increase the usage of short-term contracts with private suppliers, who typically exhibit lower environmental performance. Firms prefer to maintain adaptable production processes that rely on frequent, cost-effective short-term orders, resulting in higher carbon emissions. The effects are stronger for firms with lowering switching cost in the global supply chain. On the contrary, companies use financial derivatives to mitigate FX risk are under lower pressure to modify their operational strategies, thereby diminishing the effects of FX risk on carbon emissions. Moreover, financially constrained firms are more impacted by FX risk due to higher costs of external financing, which in turn raises the marginal cost of implementing emission abatement measures.

The paper provides firm-level evidence of how a critical macroeconomic risk (FX volatility) can factor in microeconomic environmental performance (firm-level carbon emissions). We present novel evidence on increased environmental externalities of corporate operations due to uncertainty, and highlight the necessity for policies to internalize the social costs in corporate decisions. We acknowledge that this research only focuses on the environmental dimension and does not speak to the overall effects of foreign exchange risk on the dynamics in global supply chains.

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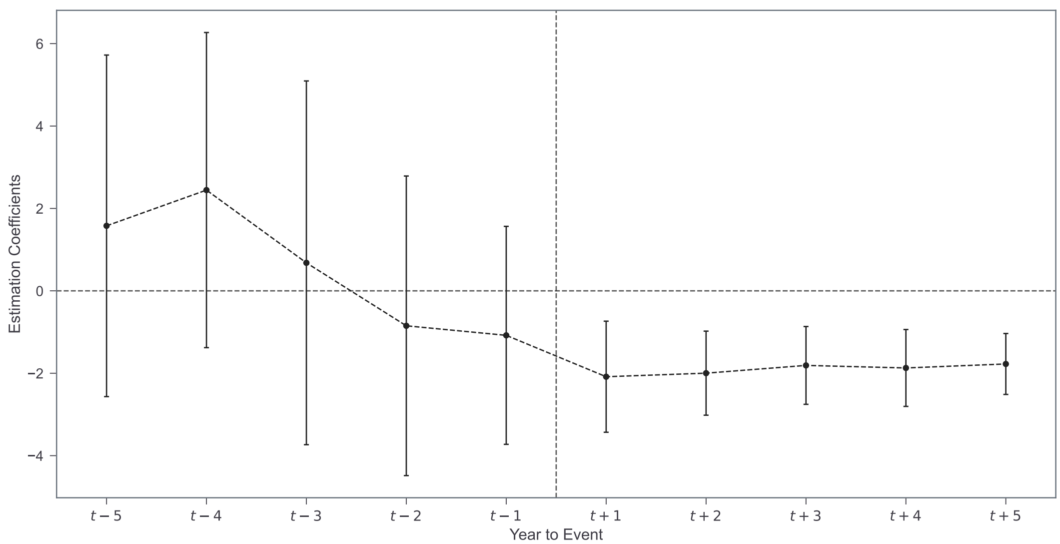
Tables and Figures

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. The event year t serves as the reference year and is omitted from the regression analysis. The vertical lines denote the 90 confidence intervals. 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

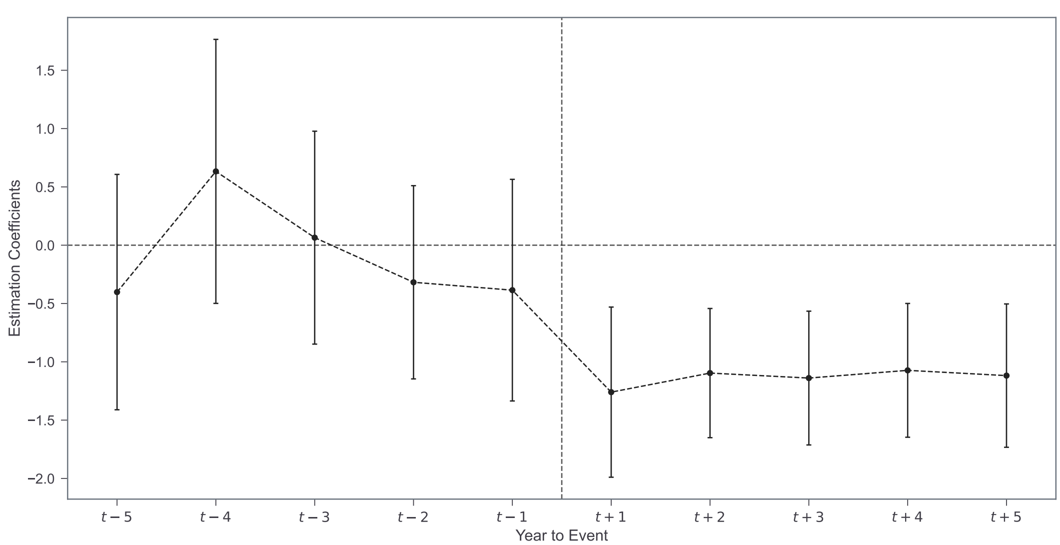


Table 1. Summary Statistics

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
Inventory (Total)	10,975	0.15	0.11	0.08	0.14	0.20
Inventory (Raw Materials)	10,975	0.04	0.04	0.01	0.04	0.06
Inventory (Finished Goods)	10,975	0.07	0.07	0.01	0.06	0.10
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	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
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 Volatility	11,323	0.21	0.53	0.04	0.09	0.21
FX Volatility (Garch)	11,323	0.64	0.96	0.19	0.36	0.72
CME Derivative	11,323	18.26	25.90	3.74	6.77	14.96
Fixed2Float	11,323	0.18	3.59	0.00	0.00	0.00
Float2Fixed	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
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
AP	10,608	0.11	0.07	0.07	0.10	0.15
FX Debt	3,480	1.18	1.06	0.35	0.98	1.67
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

Continued on next page

Table 1. Summary Statistics - Continued

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 markets of the sample firms in the main analyses, including the number of 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 with fixed effects. The dependent variables are the firm's carbon intensity in different scopes in the next year (year $t+1$). The independent variable is the firm-specific FX volatility. 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. Variables are defined in Table A1. Robust t-statistics are in parentheses. *, **, and *** indicate significance at 1%, 5% and 10%.

	(1) Scope 1	(2) Scope 2	(3) Scope 3 (Up)	(4) Scope 3 (Down)
FX Volatility	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
Country×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

This table presents the OLS regression results with fixed effects. The dependent variables are the firm's ASSET4 environmental rating scores in the next year (year $t + 1$). The independent variable is firm-specific FX Volatility. 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. Variables are defined in Table A1. Robust t-statistics are in parentheses. *, **, and *** indicate significance at 1%, 5% and 10%.

	(1) Environment	(2) Resource Use	(3) Emission	(4) Environmental Innovation
FX Volatility	-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
Country×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 5. CME FX Derivatives

This table presents the OLS regression results with fixed effects. The dependent variables are the firm's scope 1 and 3 carbon intensity in the next year (year $t+1$). The independent variable is the interaction of firm-specific exposure and CME currency product launch events (*CME Derivative*). 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. Variables are defined in Table A1. Robust t-statistics are in parentheses. *, **, and *** indicate significance at 1%, 5% and 10%.

	(1) Scope 1	(2) Scope 3 (Up)
CME Derivative	-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
Country×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. FX Regime Change

This table presents the OLS regression results with fixed effects. The dependent variables are the firm's scope 1 and 3 carbon intensity in the next year (year $t+1$). The independent variables are the interactions of firm-specific exposure and FX rate regime change events (*FixedToFloat* or *FloatToFixed*) . 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. Variables are defined in Table A1. Robust t-statistics are in parentheses. *, **, and *** indicate significance at 1%, 5% and 10%.

	(1) Scope 1	(2) Scope 3 (Up)
FixedToFloat	0.94**	0.54***
	(2.60)	(3.29)
FloatToFixed	-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
Country×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. Carbon Tax

This table presents the OLS regression results with fixed effects. The dependent variables are the firm's scope 1 and 3 carbon intensity in the next year (year $t + 1$). The independent variables are the the the firm-specific FX Volatility and its interaction terms with firm-specific carbon tax risk (*Carbon Tax* and *Carbon Tax (Customer)*). 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. Variables are defined in Table A1. Robust t-statistics are in parentheses. *, **, and *** indicate significance at 1%, 5% and 10%.

	(1)	(2)	(3)	(4)
	Scope 1		Scope 3 (Up)	
FX Volatility × Carbon Tax	-0.20***		-0.13***	
	(-3.69)		(-4.11)	
FX Volatility × Carbon Tax (Customer)		-0.30**		-0.26***
		(-2.65)		(-4.39)
FX Volatility	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)
Country×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

Table 8. Supply Chain Contractual Relations

This table presents the OLS regression results with fixed effects. The dependent variables are the firm's contractual relation measures with supplier (customer) in the next year (year $t + 1$) and the independent variable is the firm-specific FX Volatility. 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. Variables are defined in Table A1. Panel A and B present the results of the contractual relation with the supplier and the customer, respectively. Robust t-statistics are in parentheses. *, **, 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 Volatility	-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
Country×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 Volatility	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
Country×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 with fixed effects. 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 independent variables are the firm-specific FX Volatility and its interaction terms with accounts payable to sales ratio (*AP*). 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. Variables are defined in Table A1. Robust t-statistics are in parentheses. *, **, 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 Volatility × AP	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 Volatility	6.91**	2.64**	-0.61**	0.47***	0.71**	-3.27**
	(2.59)	(2.61)	(-2.76)	(3.52)	(2.76)	(-2.80)
AP	-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
Country×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. Foreign Exchange Derivative Usage

This table presents the OLS regression results with fixed effects. 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 independent variables are the the the firm-specific FX Volatility and its interaction terms with foreign exchange derivative usage (*FX Derivative*). 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. Variables are defined in Table A1. Robust t-statistics are in parentheses. *, **, 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 Volatility × 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 Volatility	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
Country×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 11. Financial Constraint

This table presents the OLS regression results with fixed effects. 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 independent variables are the firm-specific FX Volatility and its interaction terms with financial constraint index (*KZ* and *WW*). 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. Panel A and B present the results using *KZ* and *WW* as proxies for financial constraints, respectively. Variables are defined in Table A1. Robust t-statistics are in parentheses. *, **, and *** indicate significance at 1%, 5% and 10%.

Panel A. KZ Index

	(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 Volatility × KZ	1.08***	0.66***	-0.18**	0.20***	0.07***	-0.95***
	(3.70)	(4.16)	(-2.78)	(8.29)	(2.90)	(-4.02)
FX Volatility	10.33**	3.85***	-1.09**	1.24***	1.40***	-6.52***
	(2.72)	(3.37)	(-2.77)	(3.45)	(3.46)	(-2.98)
KZ	-0.72**	-0.34	0.02	-0.03	0.00	-0.09
	(-2.31)	(-1.30)	(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
Firm-Year Control	Yes	Yes	Yes	Yes	Yes	Yes
Country×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	9,775	9,775	3,546	3,546	3,546	3,546
R-squared	0.96	0.97	0.98	0.87	0.91	0.65

Panel B. WW Index

	(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 Volatility × WW	82.25***	25.11***	-8.93**	6.80***	5.10***	-45.16***
	(3.14)	(2.90)	(-2.75)	(3.30)	(2.89)	(-3.41)
FX Volatility	90.16***	27.98***	-9.09***	7.02***	5.27**	-49.18***
	(3.10)	(3.22)	(-2.90)	(3.41)	(2.82)	(-3.87)
WW	31.03	-81.64**	-2.88	-0.05	-2.80	-4.82
	(0.52)	(-2.27)	(-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
Firm-Year Control	Yes	Yes	Yes	Yes	Yes	Yes
Country×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	10,171	10,171	3,735	3,735	3,735	3,735
R-squared	0.95	0.96	0.98	0.88	0.91	0.63

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*
Inventory (Total)	Inventories - Total / Total Assets	*Compustat Global*
Inventory (Raw Materials)	Inventories - Raw Materials / Total Assets	*Compustat Global*
Inventory (Finished Goods)	Inventories - Finished Goods / Total Assets	*Compustat Global*
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	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*
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*

Continued on next page

Table A1. Variable Definition - Continued

Independent Variables		
FX Volatility	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 Volatility (Garch)	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	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*
Float2Fixed	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*
Fixed2Float	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*
AP	Accounts Payable / Total Assets.	*Compustat Global*
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)]	*Compustat Global*
WW	Financial constraint index by Whited and Wu (2006), calculated as: -0.091$*$(Cash Flow / Total Assets) - 0.062$*\mathbf{1}$(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.	*Compustat Global*
Foregin Debt	Foreign debt by Kalemli-Ozcan, Liu, and Shim (2021) / Total Assets.	*Compustat Global, Bank of International Settlements*
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*

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Table A1. Variable Definition - Continued

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].	*Compustat Global*
Tangibility	Property, Plant and Equipment / Total Assets.	*Compustat Global*
Leverage	(Long-Tern Debt + Debt in Current Liabilities) / Total Assets.	*Compustat Global*
Pretax Income	Pretax Income / Total Assets.	*Compustat Global.*
Pretax Income Vol	Standard deviation of (Pretax Income / Total Assets) over the last five years .	*Compustat Global*
Size	Natural logarithm of Total Assets in US-Dollar.	*Compustat Global*
Firm Age	Natural logarithm of firm age in years.	*Compustat Global*

Table A2. Robustness Check - Carbon Emissions

This table presents the OLS regression results with fixed effects. The dependent variables are the firm's carbon emissions in different scopes in the next year (year $t+1$). The independent variable is the firm-specific FX Volatility based on GARCH model. 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. Variables are defined in Table A1. Robust t-statistics are in parentheses. *, **, and *** indicate significance at 1%, 5% and 10%.

	(1) Scope 1	(2) Scope 2	(3) Scope 3 (Up)	(4) Scope 3 (Down)
FX Volatility (Garch)	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
Country×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 A3. Carbon Emissions: Placebo Test

This table presents the OLS regression results with fixed effects. The dependent variables are the firm's carbon intensity in different scopes in the previous years (year $t-1$ to $t-3$). The independent variable is the firm-specific FX volatility. 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. Variables are defined in Table A1. Robust t-statistics are in parentheses. *, **, 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 Volatility	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
Country×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 A4. Robustness Check - ESG Rating

This table presents the OLS regression results with fixed effects. The dependent variables are the firm's ASSET4 environmental rating scores in the next year (year $t+1$). The independent variable is the firm-specific FX Volatility based on GARCH model. 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. Variables are defined in Table A1. Robust t-statistics are in parentheses. *, **, and *** indicate significance at 1%, 5% and 10%.

	(1) Environmental	(2) Resource Use	(3) Emission	(4) Environmental Innovation
FX Volatility (GARCH)	-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
Country×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 A5. Robustness Check - Supply Chain Contractual Relations

This table presents the OLS regression results with fixed effects. The dependent variables are the firm's contractual relation measures with supplier (customer) in the next year (year $t+1$) and the independent variable is the firm-specific FX Volatility based on GARCH model. 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. Variables are defined in Table A1. Panel A and B present the results of the contract with the supplier and the customer, respectively. Robust t-statistics are in parentheses. *, **, 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 Volatility (Garch)	-0.56**	0.28**	0.35***	-2.95***
	(-2.78)	(2.81)	(3.00)	(-4.22)
Expired Contract Num	0.64***	0.11***	0.08**	-0.32***
	(13.44)	(3.94)	(2.81)	(-6.15)
FX Rate Change	0.09**	0.02	0.05	0.10
	(2.30)	(1.11)	(1.61)	(0.49)
Foreign Income	0.01	-0.00	-0.01	0.09
	(0.47)	(-0.37)	(-0.91)	(1.38)
TobinQ	-0.19	-0.14*	-0.15	-0.50
	(-1.05)	(-1.81)	(-0.90)	(-1.05)
Tangibility	0.47	2.90	1.82	-1.51
	(0.16)	(1.47)	(0.86)	(-0.21)
Leverage	-0.78	-1.85***	-1.07	-0.66
	(-0.77)	(-3.29)	(-0.96)	(-0.18)
Pretax Income	0.50	0.02	1.04	-1.90
	(0.24)	(0.02)	(0.42)	(-0.43)
Pretax Income Vol	2.84	-0.51	0.25	9.37
	(0.55)	(-0.16)	(0.05)	(1.49)
Size	0.72	0.31	0.92*	-0.89
	(1.28)	(0.76)	(1.91)	(-0.73)
Firm Age	-2.85	1.95	-0.38	-6.63
	(-1.36)	(1.20)	(-0.23)	(-1.02)
Constant	Yes	Yes	Yes	Yes
Country×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 Volatility (GARCH)	-0.18	-0.11	-0.77***	-0.43
	(-0.51)	(-0.41)	(-2.93)	(-0.50)
Expired Contract Num	0.60***	0.23***	0.05**	-0.22***
	(29.72)	(16.21)	(2.78)	(-10.83)
FX Rate Change	-0.08	-0.03	-0.07	0.14
	(-1.21)	(-0.66)	(-1.39)	(0.93)
Foreign Income	0.02	0.02	0.05*	0.09***
	(0.85)	(0.96)	(1.86)	(2.92)
TobinQ	-0.01	-0.07	0.09	0.02
	(-0.02)	(-0.28)	(0.33)	(0.07)
Tangibility	3.19	1.41	3.81	-2.87
	(0.68)	(0.83)	(1.03)	(-0.53)
Leverage	-2.80	-1.92	-2.07	-5.54**
	(-0.65)	(-1.00)	(-0.70)	(-2.54)
Pretax Income	4.92	1.07	2.12	-0.02
	(1.00)	(0.32)	(0.79)	(-0.00)
Pretax Income Vol	-5.67	-7.37	-1.51	4.67
	(-0.42)	(-1.03)	(-0.13)	(0.42)
Size	1.95	0.31	1.89*	1.08
	(1.42)	(0.24)	(2.02)	(1.24)
Firm Age	-3.60	-0.48	-1.71	-10.64**
	(-0.73)	(-0.23)	(-0.49)	(-2.28)
Constant	Yes	Yes	Yes	Yes
Country×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	4,888	4,888	4,888	4,888
R-squared	0.89	0.85	0.69	0.60