Global Currency Risk and Corporate Carbon Emissions

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Outline

Motivation

- Globalization and Offshoring are two important operation issues over the past few decades → foreign exchange (FX) risk arises.
- Globalization created bigger markets, production scale, and more transportation → all leading to more carbon emissions
- Outsourcing reduced production costs and enabled firms to bypass environmental regulation → shifting pollution and carbon emissions to regions with 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).

Given that FX risk factors in firms' globalization dynamics, it may influence their carbon emissions.

Motivation: Mechanisms

How would FX risk influence firms' emissions?

Firms use hedging and operational adjustment to mitigate FX uncertainty

- **FX hedging**: firms can perfectly hedge their FX risk with a forward contract if their foreign revenues are predictable (Kerkvliet and Moffett, 1991).

- However, when foreign revenues are uncertain, financial hedging becomes incomplete (Chowdhry and Howe, 1999), increasing financial constraints and limiting firms' ability to invest in emissions reduction (Xu and Kim, 2022; Fang, Hsu, and Tsou, 2024).

- **Operational adjustment**: alternatively, firms may respond to FX volatility by sourcing from local suppliers (Chowdhry and Howe, 1999). Such outsourcing may create more emissions due to emerging markets' lower environmental standard, etc.

Data Sources

We focus on global firms with exposures to foreign currencies

1. Firm annual revenue from different markets via the FactSet Geographic Revenue Exposure database.
2. USD-denominated exchange rates of 48 currencies from the WMR/Reuters database.
3. Contractual relationships between customers and suppliers from the Factset Revere database.
4. Firm carbon emission data from the S&P Trucost database.
5. Firm environmental expenses and their ratings and from Refinitv database.
6. Firm environmental news from RepRisk database.
7. Firms' financial fundamentals from the Worldscope database.

Example - Factset vs. Compustat Segment

We use Factset Geographic Revenue instead of Compustat Segment for two reasons: (1) Factset has international coverage; and (2) Factset is more comprehensive as it estimates the revenue when self-disclosed values are unavailable.

This is a US firm's supplier data from Compustat (upper) and Revere (lower)

		conm	ctype	gareac	salecs
cusip	**year**				
88162G103	2020	TETRA TECH INC	MARKET	USA	674.605

		conf	est_percent	iso_alpha_3
cusip	**year**			
88162G103	2020	0.988782	8.469500	CAN
	2020	1.000000	70.206220	USA
	2020	0.988208	7.273626	AUS
	2020	0.989520	14.050654	GBR

Notes: About 90% of the revenue is estimated by the data vendor, and "conf" indicates the confidence level of the algorithm, with 1 meaning the value is

Main Variable - Firm-level FX Risk

We measure firm-level FX risk using their exposure weights:
Exposure ($w_{f,i,j,t}$) of 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:

$$w_{f,i,j,t} = \frac{revenue_{f,j,t}}{\sum_m revenue_{f,m,t}}, \tag{1}$$

- $revenue_{f,j,t}$: the firm f's revenue denominated by foreign currency j in year t
- $\sum_m revenue_{f,m,t}$, denotes the firm f's total revenue in year t.

We then calculate firm-level exposure-weighted FX volatility as follows:

$$FX\ Vol\ (Exposure\ Weighted)_{f,t} = \sqrt{\mathbf{w_{f,t}} \cdot \Sigma_{i,t} \cdot \mathbf{w'}_{f,t}}, \tag{2}$$

$\Sigma_{i,t}$ denotes the variance-covariance matrix of currencies, and the currency volatility of domestic revenue is defined as zero.

Example for Exposure-weighted FX Volatility

For example, firm f is headquartered in Hong Kong and has foreign incomes from Europe, Japan, and Hong Kong:

$$\text{FXVol(ExposureWeighted)}_{f,hk} = \sqrt{\begin{pmatrix} w_{f,euro} & w_{f,jpy} & w_{f,hkd} \end{pmatrix} \begin{pmatrix} \sigma^2_{euro} & \text{Cov}_{euro,jpy} & 0 \\ \text{Cov}_{euro,jpy} & \sigma^2_{jpy} & 0 \\ 0 & 0 & 0 \end{pmatrix} \begin{pmatrix} w_{f,euro} \\ w_{f,jpy} \\ w_{f,hkd} \end{pmatrix}}$$

where σ^2_{euro} and σ^2_{jpy} denote the variances of the Euro and Japanese Yen, respectively, both denominated in Hong Kong dollars. The volatility of domestic income are 0.

Final Sample Distribution

We focus on firms with foreign revenues of known currencies (FactSet Geographic Revenue Exposure).

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

Baseline Regression

We estimate the following firm-year level regression model:

$$Carbon_{f,t+1} = \alpha + \beta \cdot FX\ Vol\ (Exposure\ Weighted)_{f,t} + \mathbf{X}_{f,t} + \Phi_f + \Phi_{market,t} + \Phi_{ind,t} + \epsilon_{f,t} \quad (3)$$

- $Carbon_{f,t+1}$: the carbon intensity (*Scope 1* to *Scope 3*) of firm f in year $t+1$.
- $FXVol(ExposureWeighted)_{f,t}$: FX risk for firm f in year t.
- $\mathbf{X}_{f,t}$: 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*.
- Φ: the fixed effects at different levels.
  - Φ_f: firm fixed effects.
  - $\Phi_{market,t}$: firm f's market/country-year fixed effects (All market-specific factors, including local FX volatility, are absorbed)
  - $\Phi_{ind,t}$: industry-year fixed effects, where the industry classification is based on two-digits SIC codes.
    $\rightarrow$ with all these FEs, we rule out many omitted variables and confounding factors

Baseline Results - Emissions

	(1) Scope 1	(2) Scope 2	(3) Scope 3 (Upstream)	(4) Scope 3 (Down-stream)
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)
Control	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

Notes: 1% ⇑ in firm-level FX risk ⇒ 4.2% ⇑ in scope 1 and 1.3% ⇑ in scope 3 carbon intensity.

Firm Environmental Expense

We then examine firms' environmental expense:

$$Expense_{f,t+1} = \alpha + \beta \cdot FX\ Vol\ (Exposure\ Weighted)_{f,t} + \mathbf{X}_{f,t} + \Phi_f + \Phi_{market,t} + \Phi_{ind,t} + \epsilon_{f,t} \quad (4)$$

	(1) Environmental Expense / Capex	(2) log (Environmental Expense)
FX Vol (Exposure Weighted)	-0.06***	-1.19*
	(-3.11)	(-1.91)
Control	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

(1) Firms' environmental expense decreases with FX risk.
(2) FX risk reduces environmental expense more than capital expenditure.
→ The effect of FX risk on environmental investment is different from regular investment

Summary of Findings

Firms' exposure-weighted FX risk leads

- ↑ scope 1 and scope 3 (upstream) emissions
- ↓ environmental expenses
- ↓ environmental ratings
- ↑ pollution incidents

Shocks to firms' FX volatility

To establish a causal interpretation of the effect of FX risk on firm carbon intensity, we examine how two "shocks" to firms' FX volatility:

1. Shifts in exchange rate regimes.
   - 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 floating and as fixed otherwise.
   - Fixed To Float: MYS (2006), IND (2009), SWE (2009)
   - Float to Fixed: IND (2013)
2. Introduction of specific currencies' derivatives by the Chicago Mercantile Exchange (CME) (Hoberg and Moon, 2017).
   - 2004 (Polish Zloty, Hungarian Forint, Czech Koruna), 2006 (Korean Won, Israeli Shekel), and 2013 (Indian Rupee).

While some firms expect those events with a probability p, but the event probability changes from p to 1 is still a shock.

Exchange Regime Changes

We replace the FX Vol (Exposure Weighted) in our baseline model by firm-specific exchange regime changes and estimate the following regression:

$$\begin{aligned} Carbon_{f,t+1} = \; & \alpha + \beta_1 \cdot (FixedToFloat(ExposureWeighted))_{f,t} \\ & + \beta_2 \cdot (FloatToFixed(ExposureWeighted))_{f,t} \\ & + \mathbf{X}_{f,t} + \Phi_f + \Phi_{market,t} + \Phi_{ind,t} + \epsilon_{f,t} \end{aligned} \tag{7}$$

- $FixedToFloat(ExposureWeighted)_{f,t} = \Sigma_c \; FixedToFloat_{c,t} \times FX\ Expo_{f,c,t}$
- $FixedToFloat_{c,t}$: indicator equal to one if exchange rate regime of market c shift from fixed to floating in year t.
- $FX\ Expo_{f,c,t}$: firm exposure is defined as the revenue from a specific market c divided by total revenue in year t.
- $FloatToFixed(ExposureWeighted)_{f,t} = \Sigma_c \; FloatToFixed_{c,t} \times FX\ Expo_{f,c,t}$
- $FloatToFixed_{c,t}$: indicator equal to one if exchange rate regime of market c shift from floating to fixed in year t.

Empirical Results - Exchange Regime Changes

	(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)
Control	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

(1) When a firm increases its FX risk due to FX regime changes from fixed to floating, its emissions increase.
(2) When a firm decreases its FX risk due to FX regime changes from floating to fixed, its emissions reduce.

Launch of CME Products

We replace the FX Vol (Exposure Weighted) in our baseline model by firm-specific exchange regime changes and estimate the following regression:

$$Carbon_{f,t+1} = \alpha + \beta \cdot CME\ Deriative(Exposure\ Weighted)_{f,t} + \mathbf{X}_{f,t} + \Phi_f + \Phi_{market,t} + \Phi_{ind,t} + \epsilon_{f,t}, \tag{8}$$

- $CME\ Deriative(ExposureWeighted) = \Sigma_c\ CME\ Deriative_{c,t} \times FX\ Expo_{f,c,t}$
- $CME\ Deriative_{c,t}$: indicator equal one if CME has listed future products for currency c in year t.
- $FX\ Expo_{f,c,t}$: firm exposure is defined as the revenue from a specific market c divided by total revenue in year t.

Empirical Results - Launch of CME Products

	(1) Scope 1	(2) Scope 3 (Up)
CME Derivative (Exposure Weighted)	-0.99** (-2.53)	-0.33** (-2.51)
Control	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

The exogenous launch of FX derivatives support a causal interpretation.

Financial Hedge - Usage of FX Derivative

Firms' use of FX derivatives mitigates the effect of FX risk on:
– emissions
– environmental expenses
– switch suppliers with shorter contracts
→ Our finding is specific to FX

	(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) × FX Derivative	-20.33***	-11.23**	0.25**	8.21**	1.88***	-1.85***	-2.44***	12.77**
	(-5.03)	(-2.67)	(2.58)	(2.21)	(3.10)	(-3.39)	(-3.09)	(2.94)
FX Vol (Exposure Weighted)	16.44**	6.45***	-0.20*	-4.82	-2.97**	3.14***	3.05***	-16.63***
	(2.46)	(3.42)	(-1.83)	(-1.42)	(-2.74)	(5.90)	(3.38)	(-4.53)
FX Derivative	7.77	5.44*	-0.02	-0.52	-0.52	0.64*	1.23**	-0.86
	(1.30)	(1.95)	(-0.99)	(-1.06)	(-1.06)	(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	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	4,075	4,075	707	707	1,277	1,277	1,277	1,277
R-squared	0.97	0.97	0.96	0.96	0.99	0.92	0.94	0.77

Financial Constraint- KZ Index

Financial constraints amplifies the effect of FX risk on:
– emissions
– environmental expenses
– switch suppliers with shorter contracts

	(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

Operational Hedge

We use a firm's accounts payable to sales ratio reflects its bargaining power against its suppliers and thus negatively relates to its cost to switch suppliers (Dass, Kale, and Nanda, 2015).

Firms' bargaining power amplifies the effect of FX on emissions, environmental expenses, switching suppliers and using shorter contracts

	(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) × Account Payable	51.40**	28.69***	-0.70***	-8.66***	-2.98**	4.39***	4.41***	-18.65**
	(2.71)	(2.91)	(-3.28)	(-2.87)	(-2.79)	(2.94)	(2.94)	(-2.77)
FX Vol (Exposure Weighted)	6.91**	2.64**	-0.02	-0.60	-0.61**	0.47***	0.71**	-3.27**
	(2.59)	(2.61)	(-0.86)	(-1.35)	(-2.76)	(3.52)	(2.76)	(-2.80)
Account Payable	-0.18	-89.14***	0.16	2.41	-0.51	-1.59	-1.85	-0.49
	(-0.00)	(-2.92)	(1.13)	(1.47)	(-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	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	10,608	10,608	2,074	2,074	3,933	3,933	3,933	3,933
R-squared	0.95	0.97	0.88	0.92	0.97	0.85	0.89	0.63

Carbon Tax

Carbon tax mitigates the effect of FX risk on emissions

	(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)
Market×Year FE	Yes	Yes	Yes	Yes
Industry×Year FE	Yes	Yes	Yes	Yes
Firm FE	Yes	Yes	Yes	Yes
Control	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

Contracts with Supplier

Increased FX risk reduces the number of suppliers, use more new suppliers, and use the average duration of new contracts.

	(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)
Control	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

Contracts with Customer

Increased FX risk does not affect firms' contracts with customers.

	(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)
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

Conclusion

1. FX volatility leads to a rise in firms' carbon intensity in both their direct operations (scope 1) and upstream activities (scope 3).
2. This relation is further supported by (i) lower environmental expenses; (ii) lower environmental rating; and (iii) increased environmental controversies.
3. A causal interpretation is supported by Bartik-like instruments based on two classes of shocks: (i) FX regime switches and (ii) currency derivatives in CME
4. Our tests for three mechanisms underlying the FX risk effect:
   - *Financial Hedge*: firms' use of FX derivatives mitigate the effect of FX risk on emissions.
   - *Financial Constraint*: financial constraint amplifies the effect of FX risk on emissions.
   - *Operational Adjustment*: FX risk makes firms to switch suppliers and use short-term agreements. Firms' bargining power against supplier amplifies the effect of FX risk on emissions.

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