Climate Risks and FDI

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Research Question

- Climate-related risks have increased in recent decades in terms of
  - Frequency of extreme weather events (physical risk)
  - Implementation of green house gas abatement policy (transition risk)
- Research questions:
  - Do climate risks affect FDI flows and MNE affiliate location?
  - If so, to what extent and how is the impact affected by emission productivity and firm exposure to the climate risks?
- Methodology:
  - Build a partial equilibrium model to provide intuition
  - Conduct country, bilateral, industry, firm-level analyses, with interactions of country/industry emission productivity and firm climate risk exposure/awareness

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Contributions and Results

- Little research about the effect of climate change on FDI
  - Barua et al. (2020, country-level), Doytch (2020, country-level), Pankratz and Schiller (2021, global supply chain), Kato and Okubo (2022, input-output linkage model, country-level empirical)
    Our paper provides: Multi-aggregation-level and firm-level analyses with interactions, and model intuitions of both climate risks and interactions
- **Model Predictions**: Target-country physical risk and transition risk directly reduce FDI inflows and MNE affiliates; emission productivity increases them
- Emission productivity can dampen or amplify the impact of climate risks
- **Empirical Findings**: Few statistically significant effects (those significant bear the model-predicted signs) indicate limited attention to climate risks
- At firm-level, higher exposure/attention to climate risks associated with more response to them, thus likely to increase the effects going forward

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Outline

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Environment

- Our model explains:
  1. How many affiliates MNE locates and how much FDI flows to a target country
  2. How the above measures change with physical and transition risks
  3. What is the interaction effect with emission productivity

- Two-country partial-equilibrium model: Horizontal FDI (Helpman, Melitz, and Yeaple, 2004), without goods trade
- Each country: one MNE and N other firms (domestic firms/foreign affiliates)
- Entry mode: M&A with bargained price between MNE and local owners and MNE cost advantage, to calculate FDI inflow (Razin et al, 2007)
- Each affiliate/local firm produces one product variety, monopolistic competition in the product market, standard CES utility function
- Timing: MNE decides to purchase an affiliate or not before disaster state realizes

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MNE, Affiliate n, and Climate Risks in Country i

- Each prospective affiliate's production function: $q_{in} = z_{in} k_{in}$
  where z_{in} is a known idiosyncratic output-per-unit-emission (emission productivity), k_{in} is emission

- Conditional on producing, an affiliate n's problem is:
  $\max_{k_{in}} \quad E(\Pi_{in}) = \beta[p_{in} q_{in} - r_i k_{in} - E(f_i)] \geq 0$
  where r_i (transition risk): affected by input costs and i's current climate policy
  $E(f_i) = \pi f_{id} + (1 - \pi) f_{in}$ (physical risk): disaster probability $0 < \pi < 1$ and $f_{id} > f_{in} > 0$, and f_i is overhead cost only during production, affected by i's extreme weather state, is repeated and not fixed over time

- There exists an emission productivity threshold $\bar{z}$ such that potential affiliates with $z_{in} \geq \bar{z}$ are acquired by the MNE

- Assume $z_{in} \sim Pareto$ with scale parameter b_i (lower bound) and shape parameter v_i (dispersion), and $\bar{z} > b_i$ (Helpman, Melitz, and Yeaple, 2004; Bloom et al, 2010; Boyd, 2017)

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Propositions

Proposition 1. Physical risk *When a target country's physical climate risk increases such that the affiliate's expected overhead cost $E(f_i)$ increases, or when a disaster actually happens, it reduces the number of affiliates in the target country.*

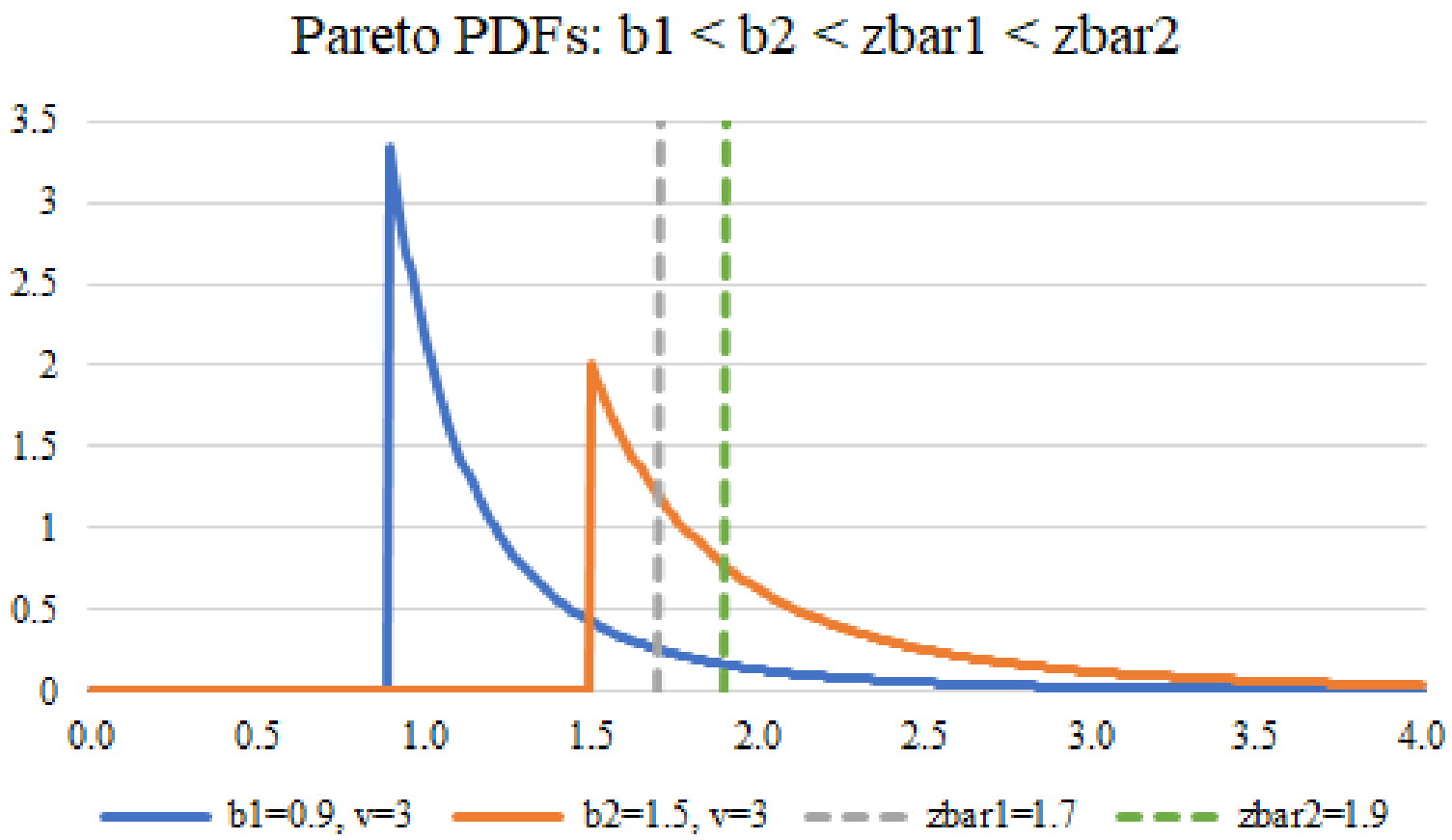
Proposition 2. Transition risk *When climate policies increase emission unit cost r_i, the number of MNE's affiliates in the target country decreases; and the policies **dampen** the effect of physical risk from Proposition 1.*

Proposition 3. Emission Productivity *When technology becomes greener which increases the emission productivity distribution's lower bound b_i (i.e., shifting distribution right and increasing the emission productivity mean), the number of MNE's affiliates in the target country increases; and in this case higher emission productivity **amplifies** the effect of climate risks from Propositions 1 and 2 (**Better Loses**).*

Similar propositions for FDI flows: FDI value calculated from bargained M&A price assuming MNE cost advantage over local owners

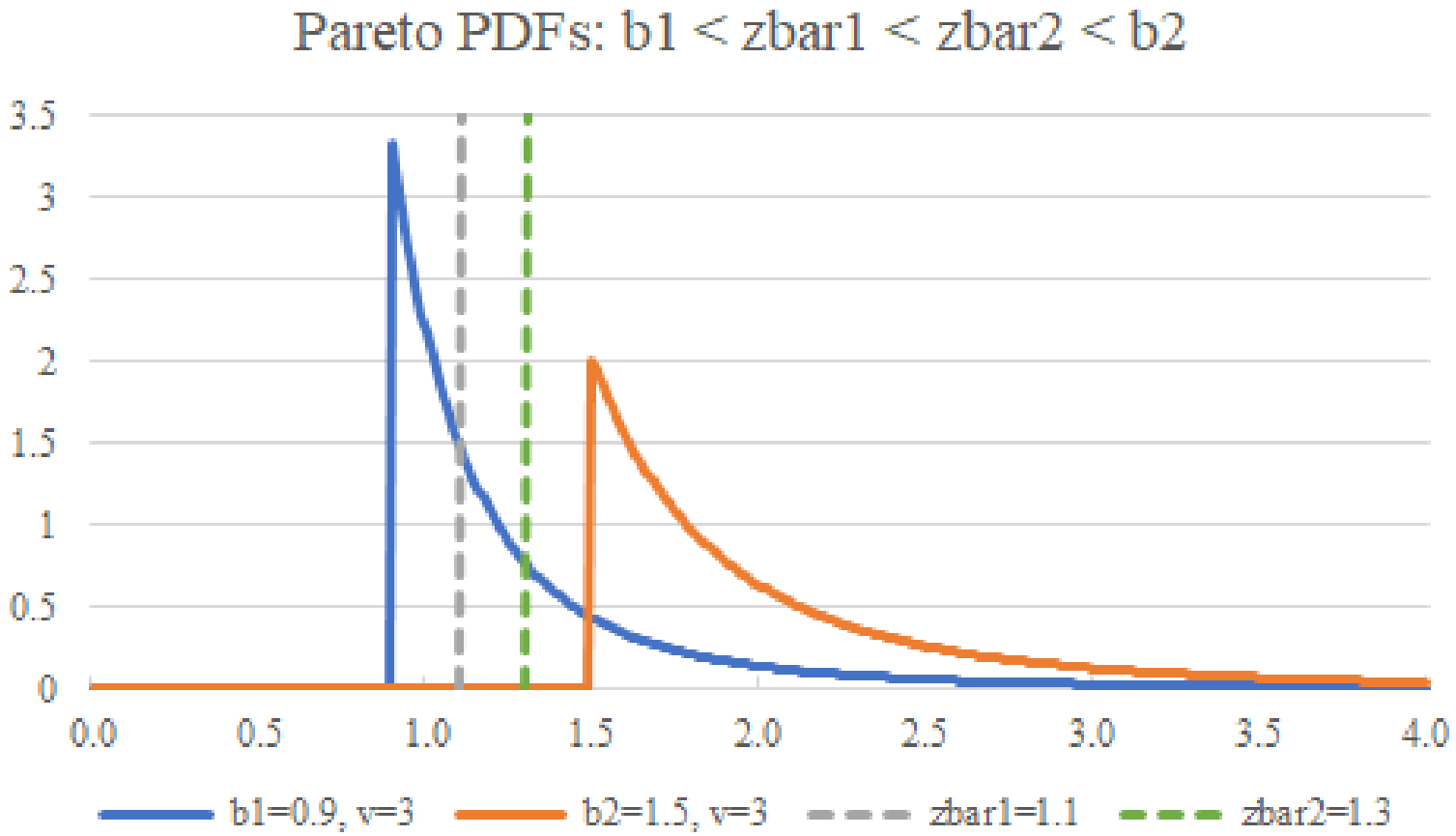
Emission Productivity Interaction: Better Loses

So far we assume that $\bar{z} > b_i$ always holds: More emission-productive industries/target-countries have more exits or FDI reduction due to rising climate risks



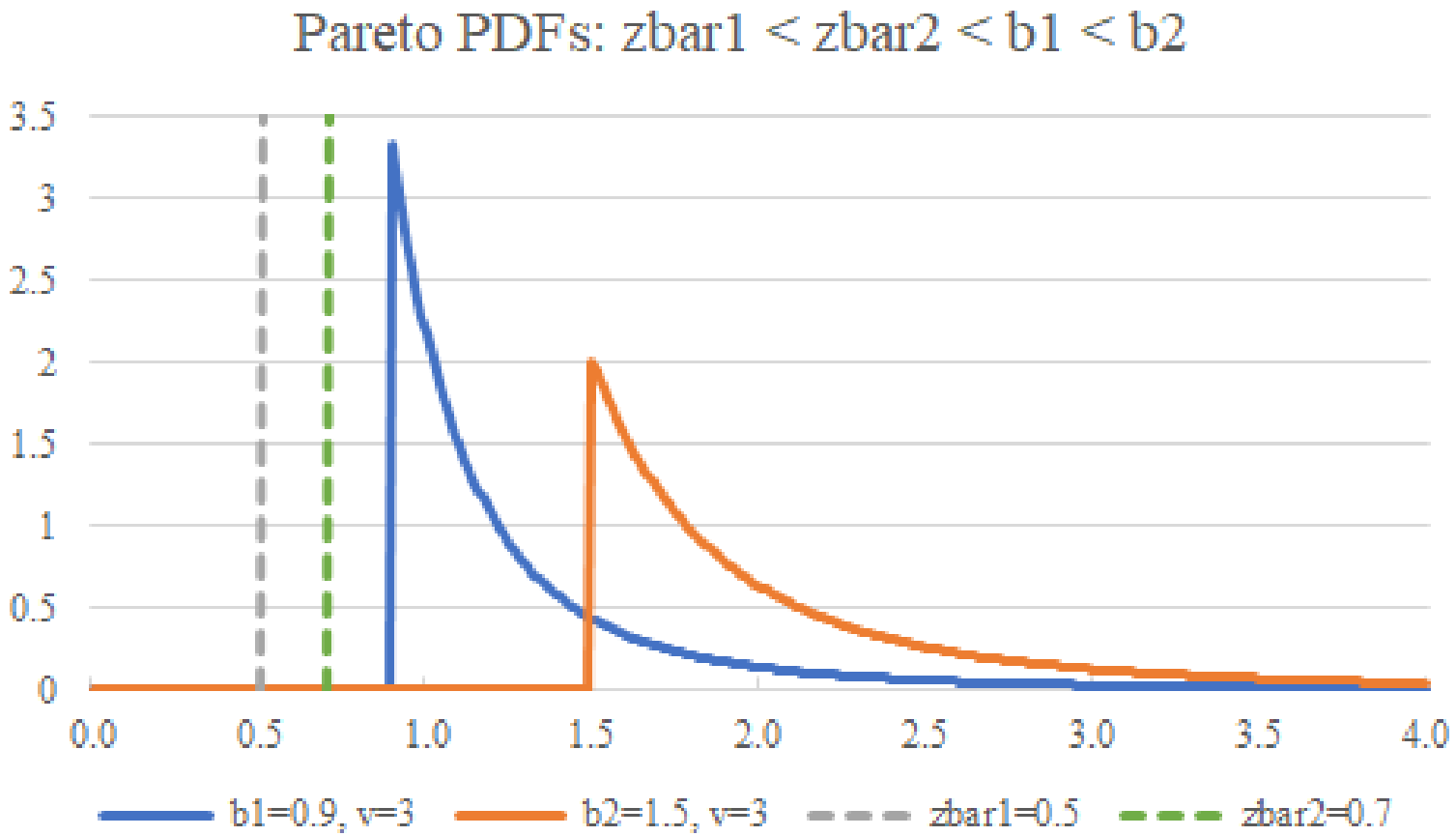
Emission Productivity Interaction: Better Wins

More emission-productive industries/target-countries have fewer exits or less FDI reduction due to rising climate risks



Emission Productivity Interaction: No Effect

$\bar{z}$ is so low (e.g., due to a low r_i or a high market size, or highly emission-efficient industries) that emission-productivity does not matter to the impact of climate risks on FDI



Model Result Summary

- Physical risk ↑, or Transition risk ↑, or actual disaster realizes
  → FDI ↓ (intensive and extensive margins)
- Transition risk may dampen the negative impact of physical risk
- Emission productivity can amplify (*Proposition 3, or Better Loses*) or dampen (*Better Wins*) the impact of climate risks on FDI, depending on the relative position of $\bar{z}$ and b_i ...
- ... with amplification (*Proposition 3, or Better Loses*) being a more likely empirically as on average $b_{AE} > b_{EME}$ *slightly* and both close to 0 in data [Histogram]

Outline

Empirical Strategy

- Target country(i) level, clustered at region level:
  $(FDI/GDP)_{igt} = Phy'_{it-1}\Gamma_1 + Tran'_{it-1}\Gamma_2 + \gamma_3 z_{it-1} + Macro'_{it-1}\Gamma_3 + \alpha_i + \beta_t + \delta_{gt} + \epsilon_{it}$,
  where g is country group (AE/EME/LIC)
  - Interaction with z_{it-1}: $\ldots + (z_{it-1}Phy_{it-1})'\Gamma_4 + (z_{it-1}Tran_{it-1})'\Gamma_5$,
  - Also interaction with $Post_{COP21}$ (2016 onward), and cross sectional analysis
- Target Country(i)-industry(k) level, clustered at country-industry level:
  $(FDI/VA)_{ikt} = Phy'_{it-1}\Gamma_1 + Tran'_{it-1}\Gamma_2 + \gamma_3 z_{ikt-1} + Macro_{it-1}\Gamma_4 + \alpha_{ik} + \delta_{kt} + \epsilon_{ikt}$
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- Firm(f) level, headquartered in country j, clustered at firm-country (i) level:
  $\triangle NAffShare_{fjikt} = Phy'_{it-1}\Gamma_1 + Tran'_{it-1}\Gamma_2 + \gamma_3 z_{it-1} + Phy'_{jt-1}\Gamma_4 + Tran'_{jt-1}\Gamma_5 + \gamma_6 z_{jt-1} + \gamma_7 CCR_{ft-1} + Macro_{it-1}\Gamma_3 + \alpha_f + \beta_i + \delta_{ik} + e_t + \epsilon_{fjikt}$
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Outline

Climate Disaster Data for Physical Risk

- The Emergency Events Database (EM-DAT) from the Centre for Research on the Epidemiology of Disasters (CRED), U of Louvain
- Worldwide extreme weather events from 1900 to present:
  - 10+ human deaths; or 100+ people injured or left homeless;
  - Declaration by the country of a state of emergency and/or an appeal for international assistance
- For us only climate-related disaster events:
  - Climatological (wildfire and drought);
  - Meteorological (extreme temperatures and storms);
  - Hydrological (flood)
- Monthly number of events, deaths, number of people affected, and economic losses in USD, we aggregate data to country-year level

Climate Policy Data for Transition Risk

- OECD Environmental Policy Stringency (EPS):
  - Computed by scoring and aggregating environmental policy instruments, including emission taxes, trading schemes, renewable and R&D subsidies, and emission limits
  - Hypothesis: Countries with stricter environmental regulations are more likely to be more aggressive on climate change mitigation
- CO2 tax:
  - Interpret: Higher existing CO2 tax as higher transition risk
  - Dummy (1/0) for having CO2 tax or not
- Notre Dame-Global Adaptation Index (ND-GAIN)'s Climate Vulnerability Index:
  - Reflect climate change exposure, sensitivity and adaptive capacity, as well as economic, governance and social components
  - Used alone

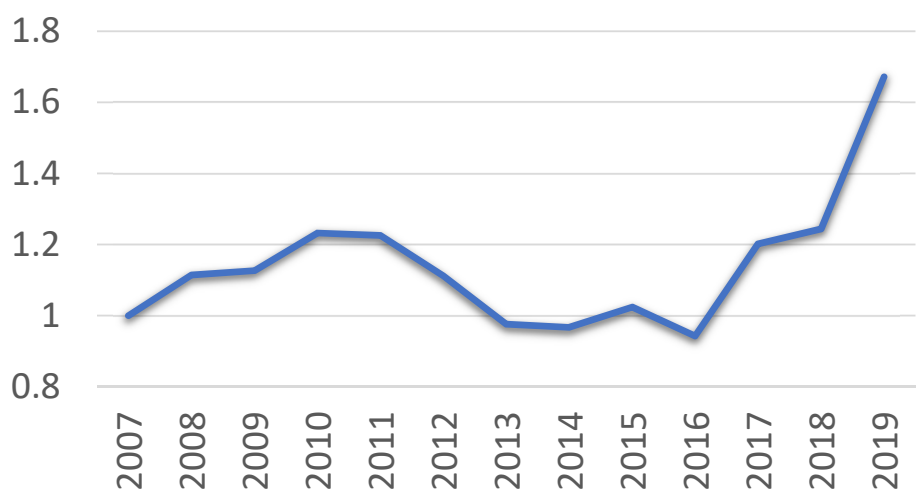
Country-industry Emission Data

- World Input-Output Database (v2016)'s environmental accounts (2000-2016) (Timmer et. al., 2015)
- Emission = *emission relevant total energy use* (*in Terajoule*) − *emission relevant energy use from nuclear and renewables* (*in Terajoule*)
- Country-industry emission productivity $z_{ikt} = Real\ VA_{ikt} / Emission_{ikt}$
- Country emission productivity $z_{it} = RGDP_{it} / \sum_k Emission_{ikt}$

Firm Exposure/Awareness Data

- Climate change exposure index for publicly traded firms, with ISIN numbers (2002-2019) from Sautner et. al. (2021)
- Based on textual analysis of firm conference calls, we use their “risk" measure

Figure: Climate change risk index



- Hypothesis: More exposed firms are more reactive to climate risks
- Dummy (1/0) for higher/lower than median climate change exposure index

FDI Data: Aggregate Levels*

- Country level: WDI (1970-2019, 94 countries), divided by GDP
- Bilateral: IMF CDIS (2009-2019, 125 countries), calculated target-country's received FDI share in source-country' total outflow position
- Country-industry: OECD International Direct Investment Statistics Yearbook (2005-2019, 49 industries), classified by ISIC4 codes (2-digit level), manually merged with WIOD industries to be divided by industry value added
- Extensive margins (inflow/outflow) = An indicator (1/0) of whether the inflow is positive (or negative for outflow)

FDI Data: Firm level

- ORBIS (2007-2019), restricted to firms with total assets in excess of 1 billion USD for a given year and excluding OFCs as target countries (but keep firms with headquarters in OFCs)
- For each firm f, Collect information on firm headquarter country j and its industry k, aggregate information on affiliates by target country i and year t
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Result Roadmap

- Summarize the coefficients' significance and signs
- Use a heatmap to compare coefficients' magnitudes: Most climate variables between 0 and 1
  - Disasters Only
  - Main effects of climate disasters and policies
  - Interaction effects of emission productivity
- Examine the role of firm-level climate exposure: On average MNEs do not fully take into account the effects of climate risks; so perhaps firm-level climate change risk (CCR) matters. We expect most exposured firms react more

Signs and Significance

- Count of significantly + coef. / Count of significantly − coef. / Total number of specifications available

- Robust results: Green/blue: Half+ results consistent with model predictions; Red: Half+ results contradicting model predictions

	Main effects				Interactions with emission productivity			
	Model	All	AEs	EMEs	Model	All	AEs	EMEs
Effect on FDI (intensive margin)								
Target:								
Climatological	< 0	2 / 3 /12	1 / 3 /12	1 / 2 /12	< 0 or > 0	1 / 0 / 4	1 / 0 / 4	0 / 0 / 4
Meteorological	< 0	1 / 2 / 9	2 / 1 / 9	0 / 2 / 9	< 0 or > 0	1 / 0 / 4	1 / 1 / 4	2 / 0 / 4
Hydrological	< 0	2 / 1 /12	1 / 2 /12	2 / 0 / 12	< 0 or > 0	1 / 0 / 4	1 / 0 / 4	1 / 0 / 4
EPS	< 0	1 / 0 / 4	0 / 0 / 4	1 / 0 / 4	< 0 or > 0	0 / 1 / 4	0 / 2 / 4	1 / 0 / 4
CO2 Tax	< 0	0 / 1 / 3	0 / 1 / 3	0 / 2 / 3	< 0 or > 0	0 / 1 / 3	1 / 1 / 3	1 / 0 / 3
Emission Productivity	> 0	0 / 1 / 4	0 / 0 / 4	0 / 0 / 4	> 0	1 / 0 / 4	2 / 0 / 4	0 / 1 / 4

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	Main effects				Interactions with emission productivity			
	Model	All	AEs	EMEs	Model	All	AEs	EMEs
Effect on FDI (intensive margin)								
Target:								
Climatological	< 0	2 / 3 /12	1 / 3 /12	1 / 2 /12	< 0 or > 0	1 / 0 / 4	1 / 0 / 4	0 / 0 / 4
Meteorological	< 0	1 / 2 / 9	2 / 1 / 9	0 / 2 / 9	< 0 or > 0	1 / 0 / 4	1 / 1 / 4	2 / 0 / 4
Hydrological	< 0	2 / 1 /12	1 / 2 /12	2 / 0 / 12	< 0 or > 0	1 / 0 / 4	1 / 0 / 4	1 / 0 / 4
EPS	< 0	1 / 0 / 4	0 / 0 / 4	1 / 0 / 4	< 0 or > 0	0 / 1 / 4	0 / 2 / 4	1 / 0 / 4
CO2 Tax	< 0	0 / 1 / 3	0 / 1 / 3	0 / 2 / 3	< 0 or > 0	0 / 1 / 3	1 / 1 / 3	1 / 0 / 3
Emission Productivity	> 0	0 / 1 / 4	0 / 0 / 4	0 / 0 / 4	> 0	1 / 0 / 4	2 / 0 / 4	0 / 1 / 4

- Also did for extensive margins
- Few significant effects, robust coefs consistent with model predictions
- No robust results contradicting model predictions (no red cell)

Magnitude: Disasters Only and Post-2016

- Heatmap: Red for most − coefficients of the block, blue for most +

Aggregation level:	X-section TC			X-section Bilateral			X-section bilateral PPML			Target country		
	Full	AE	EME	Full	AE	EME	Full	AE	EME	Full	AE	EME
Sample years	pre/post 2015 aggregate			pre/post 2015 aggregate			pre/post 2015 aggregate			1970(96)-2019		
FEs	Country group			TC, SC			TC, SC			TC, Year, CG*Year		
LHS	TC inflow/GDP			D.FDI / Total FDI from SC			D.FDI / Total FDI from SC			TC inflow/GDP		
Effect on FDI (intensive margin)												
reg1												
Climatological	**0.029**	**0.043**	-0.016	0.011	0.104	**-0.003**	**0.046**	**-0.073**	**-0.050**	**-0.309**	-0.334	-0.094
Meteorological										0.013	0.007	0.009
Hydrological	-0.007	-0.030	0.000	-0.002	-0.033	0.000	**0.023**	**0.034**	**0.044**	**-0.112**	**-0.311**	-0.085
Post*C	0.249	0.195	-0.148	0.014	0.103	-0.001	**-0.064**	-0.018	-0.027	**0.979**	1.444	-0.121
Post*M										**-0.108**	-0.337	-0.064
Post*H	0.015	0.060	0.023	-0.001	-0.042	0.000	**0.036**	**-0.057**	**0.046**	**0.167**	0.858	**0.172**
reg2												
Vulnerability	**-3.674**	17.55	-3.509	4.42	16.23	**0.89**	9.29	-42.35	-10.49	-23.8	4.8	-34.5
Post*Vulnerability	**12.38**	-16.10	**5.713**	0.54	2.07	**0.09**	**5.98**	**13.04**	6.29	6.0	-15.1	**15.7**

- Also did for bilateral (OLS/PPML), country-industry, and firm analysis
- Post-COP21: FDI has not become uniformly more sensitive to climate risk
- Effects are small: e.g., for country panel, 2019 median FDI/GDP share is 2.18% (EME) - 2.51% (AE)

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- Effects are small: e.g., for country panel, 2019 median FDI/GDP share is 2.18% (EME) - 2.51% (AE)

Magnitude: Main Effects: Intensive Margin*

- Heatmap: Red for most − coefficients of the block, green for most +

Aggregation level:	**Target Country**			**Bilateral-PPML**			**Target Country-industry**			**Firm**		
	Full	AE	EME	Full	AE	EME	Full	AE	EME	Full	AE	EME
Sample years	2001-2016			2010-2016			2006-2014		2009-13	2008-2016		
FEs	TC, Year, CG*Year			TC*SC, Year			TC*TI, TI*Year			Firm*Year, TC, TI		
LHS	TC inflow/GDP			D.FDI / Total FDI from SC			TC Inflow/VA			D.Aff in TC/Total aff		
Effect on FDI (intensive margin)												
Source:												
Climatological				**-0.26**	**-0.30**	**-0.24**				-0.003	**-0.004**	-0.002
Meteorological				0.00	0.03	-0.03				0.000	0.000	-0.001
Hydrological				0.03	0.00	**0.10**				0.000	-0.001	0.000
EPS				-0.20	-0.33	0.17				0.002	0.001	0.004
CO2 Tax				-0.31	0.22	-0.89				0.009	0.021	**-0.007**
Emissions				**-7.72**	**-9.72**	-1.57				0.069	0.071	0.058
Climate risk										-0.002	-0.002	0.000
Target:												
Climatological	0.00	-0.04	0.16	**-0.23**	-0.13	0.12	0.004	0.119	-1.879	**-0.011**	**-0.016**	0.001
Meteorological	0.09	0.08	0.05	**0.09**	**-0.04**	0.05	-0.009	-0.002	0.977	0.001	0.001	**-0.002**
Hydrological	-0.16	**-0.32**	-0.14	0.08	**-0.12**	**0.14**	-0.006	-0.039	-0.268	-0.001	-0.002	0.000
EPS	0.16	0.12	1.09	**0.31**	0.00	**1.86**	-0.026	-0.142	17.340	-0.006	-0.006	-0.006
CO2 Tax	0.03	-0.93	2.01	**-1.18**	**-1.09**	**-1.86**				0.009	0.021	**-0.007**
Emissions	-15.46	-31.99	23.55	-6.59	-0.69	6.27	-0.340	-2.440	45.670	**-0.239**	-0.120	-0.054

- Also did for extensive margins, small effects except for emission productivity
- Transition risk has a slightly larger impact than physical risk
- Transition risk has a more − impact on AE than on EME (*Prop 3, Better Loses*)
- Source country variables has less impact than target country variables

Magnitude: Emission-Productivity Interactions

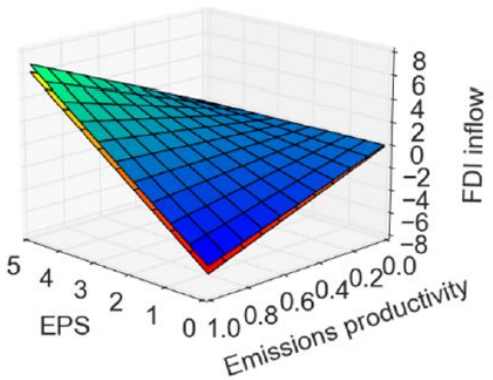
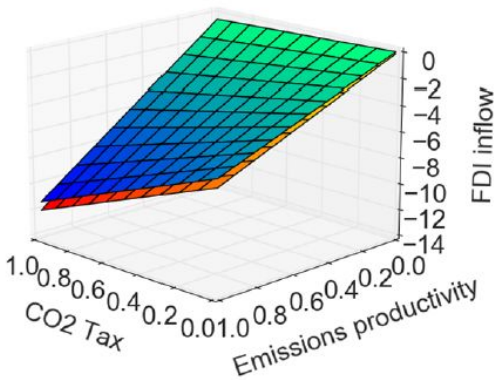
- Heatmap: Red for most − coefficients of the block, green for most +

Aggregation level:	**Target Country**			**Bilateral-PPML**			**Target Country-industry**			**Firm**		
	Full	AE	EME	Full	AE	EME	Full	AE	EME	Full	AE	EME
Sample years	2001-2016			2010-2016			2006-2014		2009-13	2008-2016		
FEs	TC, Year, CG*Year			TC*SC, Year			TC*TI, TI*Year, TC*Year			Firm*Year, TC, TI		
LHS	TC inflow/GDP			D.FDI / Total FDI from SC			TC Inflow/VA			D.Aff in TC/Total aff		
Effect on FDI (intensive margin)												
Source:												
Climatological				1.34	**1.84**	**0.55**				**-0.014**	-0.016	**-0.014**
Meteorological				**-1.39**	**-1.65**	**-1.15**				**0.002**	0.003	**0.002**
Hydrological				**0.45**	**0.42**	0.47				-0.002	-0.006	-0.002
EPS				-0.99	**-2.37**	0.47				0.000	0.001	0.000
CO2 Tax				**-7.91**	**-8.39**	-5.57				**-0.043**	**-0.060**	**-0.043**
Emissions				**-44.43**	-40.58	-6.05				**0.061**	**0.087**	**0.061**
Climate risk										**-0.019**	**-0.025**	**-0.019**
Target:												
Climatological	-3.47	0.65	-5.69	-0.52	**6.76**	6.03	**2.22**	6.24	-22.16	-0.015	0.088	-0.015
Meteorological	-3.29	**-7.88**	-0.96	0.54	1.06	**6.04**	-0.17	-0.72	-5.96	**0.017**	**0.026**	**0.017**
Hydrological	0.50	-0.32	4.83	**0.76**	**2.95**	**3.00**	-0.91	-2.08	-3.59	-0.003	0.002	-0.003
EPS	**-12.07**	**-14.16**	-7.43	2.60	**-3.61**	**26.96**	-2.20	-2.41	-122.80	-0.025	0.008	-0.025
CO2 Tax	-4.02	**40.87**	-1.49	-5.33	**-68.52**	49.24				0.030	0.021	**0.030**
Emissions	**21.22**	**26.31**	6.74	-5.69	**13.58**	**-37.35**	2.05	0.63	293.80	-0.128	-0.242	-0.128

- Also did for extensive margins
- Emission productivity dampens or amplifies the climate risk impact

Magnitude: Bilateral PPML, Full Sample*

- The effects of source countries, control variables, and FEs are set to zero
- Blue layer is when disasters are set zero, red layer when climatological disasters are included

	EPS	CO2 Tax
Climatological		

- Also did for other disasters and AE/EME
- Climatological disasters ↑→ FDI ↓ **slightly** (red plane below the blue one)
- Low-polluting countries (high z_{it}), EPS ↑→ FDI ↑, CO2 tax ↑→ FDI ↓ (*Prop 3, Better Loses*); High-polluting countries (low z_{it}), no effect of EPS or CO2 tax

Firm-Level Climate Change Risk Exposure (CCR)

- $RelEPS = Target\ EPS_{it-1} - Source\ EPS_{jt-1}$
- $CO_2\ Tax_i$ = Dummy for only target country having CO2 tax in year $t-1$
- $CO_2\ Tax_{both}$ = Dummy for both countries having CO2 tax in year $t-1$
- FEs: firm-target country, firm-year, target country-year, and target industry

	Full sample			Target in AE			Target in EME		
		Extensive			Extensive			Extensive	
	Intensive	Inflow	Outflow	Intensive	Inflow	Outflow	Intensive	Inflow	Outflow
$CCR * Climat$	-0.00034	-0.000016	0.00063	0.00376	-0.00148	0.00051	-0.00096	-0.00678	0.00347*
$CCR * Meteo$	0.000321	0.0004	-0.000004	-0.00147	-0.00050	-0.00125	-0.000350	0.00562**	-0.00096**
$CCR * Hydro$	-0.00008	-0.00065	0.000031	0.00171	0.000751	0.00172	0.000640	-0.00560	-0.000143
$CCR * RelEPS$	-0.00038	-0.00294	0.00071	0.00668	-0.000182	-0.00789	-0.00346	-0.0250	0.00292**
$CCR * CO_2\ Tax_i$	0.00450	0.00651*	0.000963	0.00307	0.00180	0.0136**	-0.0244	-0.0659**	-0.00035
$CCR * CO_2\ Tax_{both}$	-0.00571**	-0.00816***	-0.00470	-0.0122*	0.0674***	0.0556*	0.0515	0.0724*	0.0220*
Observations	80941	52959	26438	2823	123517	82191	38993	4757	108545
R^2	0.490	0.500	0.583	0.541	0.725	0.755	0.746	0.822	0.765

- Full and AE: More exposed firms do not react differently to disasters and EPS
- AE: More exposed firms are more likely to close affiliates after CO2 tax
- EME: More exposed firms are more likely to reduce inflow or close affiliates after climatological disasters or tightening of EPS and CO2 tax

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Outline

Conclusion

- Do MNEs incorporate climate risks into their FDI decisions? "Not yet."
- Key contributions:
  - One of the first few papers to study the FDI effect of both climate risks
  - At country-, bilateral-, industry- and firm-level, and with interactions with emission-productivity and firm-exposure to climate risk
  - The interaction results are not always intuitive but guided by model predictions
- Main takeaways:
  - Most statistically robust effects are consistent with model predictions, but few significant results and small in magnitude
  - But exposure/attention of MNEs to climate risks are rising and more exposed firms react more to transition risk $\rightarrow$ Future large and abrupt FDI changes are coming as climate risks intensify

Outline

Timing

- An MNE decides whether to purchase a prospective affiliate in the target country h, its production, and price of output
- The target country's extreme weather state (disaster or no disaster) realizes
- If a disaster realizes, the MNE can terminate some affiliates in the target country; otherwise, they continue to operate.

Affiliate Operating Threshold

- Expected operating profit of a potential affiliate:
  $E(\Pi_{in}) = \beta[\frac{A_i z_{in}^{\sigma-1}(1-\frac{1}{\sigma})^{\sigma-1}}{\sigma r_i^{\sigma-1}} - E(f_i)] \geq 0$
  where A_i is exogenous market size and $\sigma > 1$ is the elasticity of substitution between product varieties in a standard CES utility function

- There exists an emission productivity threshold: $\bar{z} = [\frac{E(f_i)\sigma r_i^{\sigma-1}}{A_i(1-\frac{1}{\sigma})^{\sigma-1}}]^{\frac{1}{\sigma-1}}$ such that potential affiliates with $z_{in} \geq \bar{z}$ are acquired by the MNE

- Assume $z_{in} \sim Pareto$ with scale parameter b_i (lower bound) and shape parameter v_i (dispersion), and $\bar{z} > b_i$ (Helpman, Melitz, and Yeaple, 2004; Bloom et al, 2010; Boyd, 2017)

- The number of MNE's affiliates in target country i:
  $M_i = \rho N[1 - F(\bar{z})] = \rho N(\frac{b_i}{\bar{z}})^{v_i} = \rho N b_i{}^{v_i}[\frac{A_i(1-\frac{1}{\sigma})^{\sigma-1}}{E(f_i)\sigma r_i{}^{\sigma-1}}]^{\frac{v_i}{\sigma-1}}$
  where $0 < \rho < 1$ and $v_i > 2$ to have a finite variance

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  where $0 < \rho < 1$ and $v_i > 2$ to have a finite variance

Potential Affiliate and Operating Threshold

- Optimal emission input: $k_{ih} = \frac{A_h z_{ih}^{\sigma-1}(1-\frac{1}{\sigma})^{\sigma}}{r_h^{\sigma}}$
  Optimal price: $p_{ih} = \frac{r_h}{z_{ih}(1-\frac{1}{\sigma})}$
  Optimal output: $q_{ih} = \frac{A_h z_{ih}^{\sigma}(1-\frac{1}{\sigma})^{\sigma}}{r_h^{\sigma}}$

- Expected operating profit: $E(\Pi_{ih}) = \beta[\frac{A_h z_{ih}^{\sigma-1}(1-\frac{1}{\sigma})^{\sigma-1}}{\sigma r_h^{\sigma-1}} - E(f_h)] \geq 0$

- There exists an emission productivity threshold: $\bar{z} = [\frac{E(f_h)\sigma r_h^{\sigma-1}}{A_h(1-\frac{1}{\sigma})^{\sigma-1}}]^{\frac{1}{\sigma-1}}$ such that potential affiliates with $z_{ih} \geq \bar{z}$ are acquired by the MNE

Consumer and Affiliate Operating Threshold

- Country i's consumer preferences across varieties j of products have the standard CES form, with an elasticity of substitution $\sigma > 1$ and share parameters α_{ij}, as in (Helpman, Melitz, and Yeaple, 2004)

- Demand function for each good=$A_i p_{ij}^{-\sigma}$,
  where $A_i = \frac{\alpha_{ij}^{\sigma} E_i}{P_i^{1-\sigma}}$ the total demand of the target country i,
  E_i =the total expenditure
  $P_i = (\sum_{j=1}^{N} \alpha_{ij}^{\sigma} p_{ij}^{1-\sigma})^{\frac{1}{1-\sigma}}$ = i's price index
  Individual firms view A_i as exogenous

- Expected operating profit of a potential affiliate:
  $E(\Pi_{in}) = \beta[\frac{A_i z_{in}^{\sigma-1}(1-\frac{1}{\sigma})^{\sigma-1}}{\sigma r_i^{\sigma-1}} - E(f_i)] \geq 0$

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Number of Foreign Affiliates in h

- A fixed number of potential affiliates (existing local firms) in i for the MNE to M&A: $N_i = \rho N$, where $0 < \rho < 1$
- Assume $z_{in} \sim$ *Pareto* with scale parameter b_i (lower bound) and shape parameter v_i (dispersion) (Helpman, Melitz, and Yeaple, 2004; Bloom et al, 2010; Boyd, 2017)
- The number of MNE's affiliates in i:
  $M_i = \rho N[1 - F(\bar{z})] = \rho N(\frac{b_i}{\bar{z}})^{v_i} = \rho N b_i^{v_i}[\frac{A_i(1-\frac{1}{\sigma})^{\sigma-1}}{E(f_i)\sigma r_i^{\sigma-1}}]^{\frac{v_i}{\sigma-1}}$,
  where $\bar{z} \geq b_i > 0$ and $v_i > 2$ to have a finite variance
- The number of affiliates $\uparrow$ if target country h has:
  lower physical risk $E(f_i)\downarrow$,
  lower emission cost $r_i \downarrow$,
  higher productivity mean $b_i \uparrow$,
  lower productivity dispersion $v_i \uparrow$,
  larger target market $A_i \uparrow$

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  larger target market $A_i \uparrow$

Propositions

Proposition 1. Physical risk *When a target country's physical climate risk increases such that the affiliate's expected overhead cost $E(f_i)$ increases, or when a disaster actually happens, it reduces the number of affiliates in the target country.*

Proposition 2. Transition risk *When climate policies increase emission unit cost r_i, the number of MNE's affiliates in the target country decreases; and the policies **dampen** the effect of physical risk from Proposition 1.*

Intuition:

A higher emission unit cost

$\rightarrow$ a smaller mass of affiliates, but those remaining are more productive;

When physical risk increases or a disaster strikes

$\rightarrow$ fewer productive affiliates will exit

Propositions

Proposition 3. Emission Productivity *When technology becomes greener which increases the emission productivity distribution's lower bound b_i (i.e., shifting distribution right and increasing the emission productivity mean), the number of MNE's affiliates in the target country increases; and in this case higher emission productivity* ***amplifies*** *the effect of climate risks from Propositions 1 and 2 (****Better Loses****).*

Intuition:

A higher b_i, z_{in} distribution shifts right (z_{in} mean $\uparrow$)

$\rightarrow$ a larger mass of affiliates be acquired;

When climate risks increase

$\rightarrow$ a larger mass of affiliates will exit

Similar propositions for FDI flows: FDI value calculated from bargained M&A price assuming MNE cost advantage over local owners

FDI Inflow Value

- M&A: FDI inflow value=Purchasing cost of foreign affiliates
- Assume: original owners run target-country firms with a larger overhead cost $E(f) > E(f_i)$
- Assume: original owners of target country firms hold all the bargaining power

- Each potential affiliate with $z_{in} > \bar{z}$ is purchased by the MNE at its expected profit to the MNE, which is the maximized $E(\Pi_{in})$
- $FDI_i = \int_{\bar{z}}^{\infty} \beta[\frac{A_i z_{in}^{\sigma-1}(1-\frac{1}{\sigma})^{\sigma-1}}{\sigma r_i^{\sigma-1}} - E(f_i)]f(z_{in})dz_{in}$,

  where $f(z) = \frac{v_i b_i^{v_i}}{z^{v+1}}$ is the emission productivity PDF

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Propositions

$$FDI_i = \beta \frac{b_i^{v_i}(\sigma-1)}{1-(\sigma-v_i)} \frac{1}{E(f_i)^{\frac{1-(\sigma-v_i)}{\sigma-1}}} \left[\frac{A_i(1-\frac{1}{\sigma})^{\sigma-1}}{\sigma r_i^{\sigma-1}}\right]^{\frac{v_i}{\sigma-1}}, \text{ assuming } \sigma - v_i < 1$$

- **Proposition 4. Physical risk.** *When a target country's physical climate risk increases such that the affiliate's expected overhead cost $E(f_i)$ increases, it reduces the FDI inflows to the target country.*

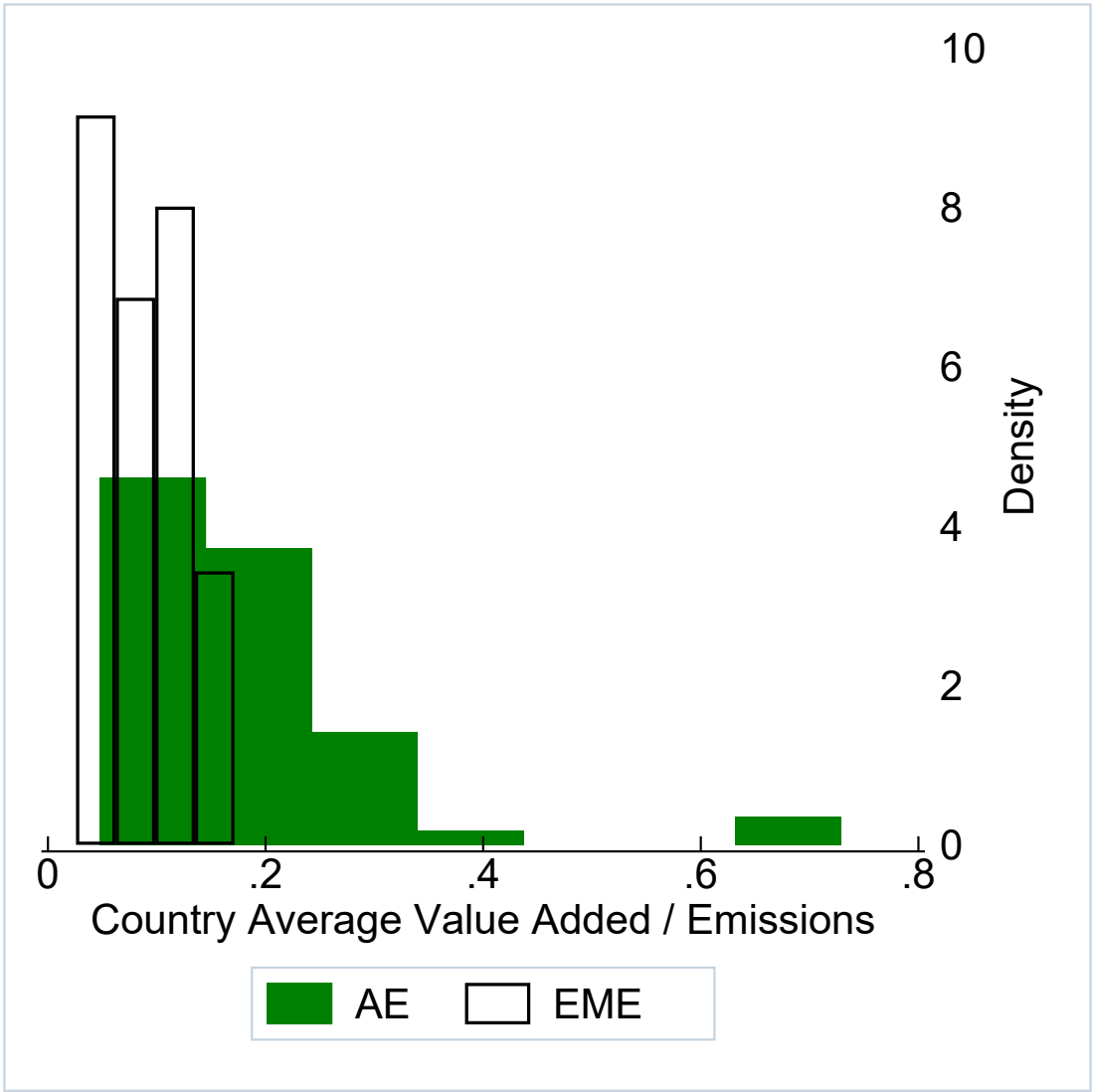
- **Proposition 5. Transition risk.** *When climate policies increase emission unit cost r_i, the FDI inflows to the target country decrease.*

  Proposition 6. Emission Productivity. *When technology becomes greener which increases the emission productivity distribution's lower bound b_i (i.e., increasing the emission productivity mean), the FDI inflows to the target country increase; and in this case higher emission productivity amplifies the effect of climate risks from Propositions 4 and 5.*

Model Result Summary

- Physical risk ↑, or Transition risk ↑, or actual disaster realizes
  → FDI ↓ (intensive and extensive margins)
- Transition risk may dampen the negative impact of physical risk
- Emission productivity can amplify (*Proposition 3, or Better Loses*) or dampen (*Better Wins*) the impact of climate risks on FDI, depending on the relative position of $\bar{z}$ and b_i with amplification (*Proposition 3, or Better Loses*) being a more likely empirically as on average $b_{AE} > b_{EME}$ *slightly* and both close to 0 in data [Histogram]
- Symmetrical source country affiliate location problem:
  Target country's climate risk relative to the source country's ↑
  → The *share* of total affiliates in the target country changes in the same direction

Figure: Histogram of Country Average Emission Productivity by Group



[Back to model]

Empirical Strategy

- Proxy physical risk: Data on past hydrological, meterological, and climatological disasters
- Proxy transition risk: Data on environmental policies
- Proxy exposure/awareness: Data on
  - Country emission productivity (RGDP/emission)
  - country-industry emission productivity (RVA/emission)
  - firm exposures/awareness (Sautner et al, 2021)

Climate Disaster Data

- Climate-related disaster events:
  - Climatological (wildfire and drought);
  - Meteorological (extreme temperatures and storms);
  - Hydrological (flood)

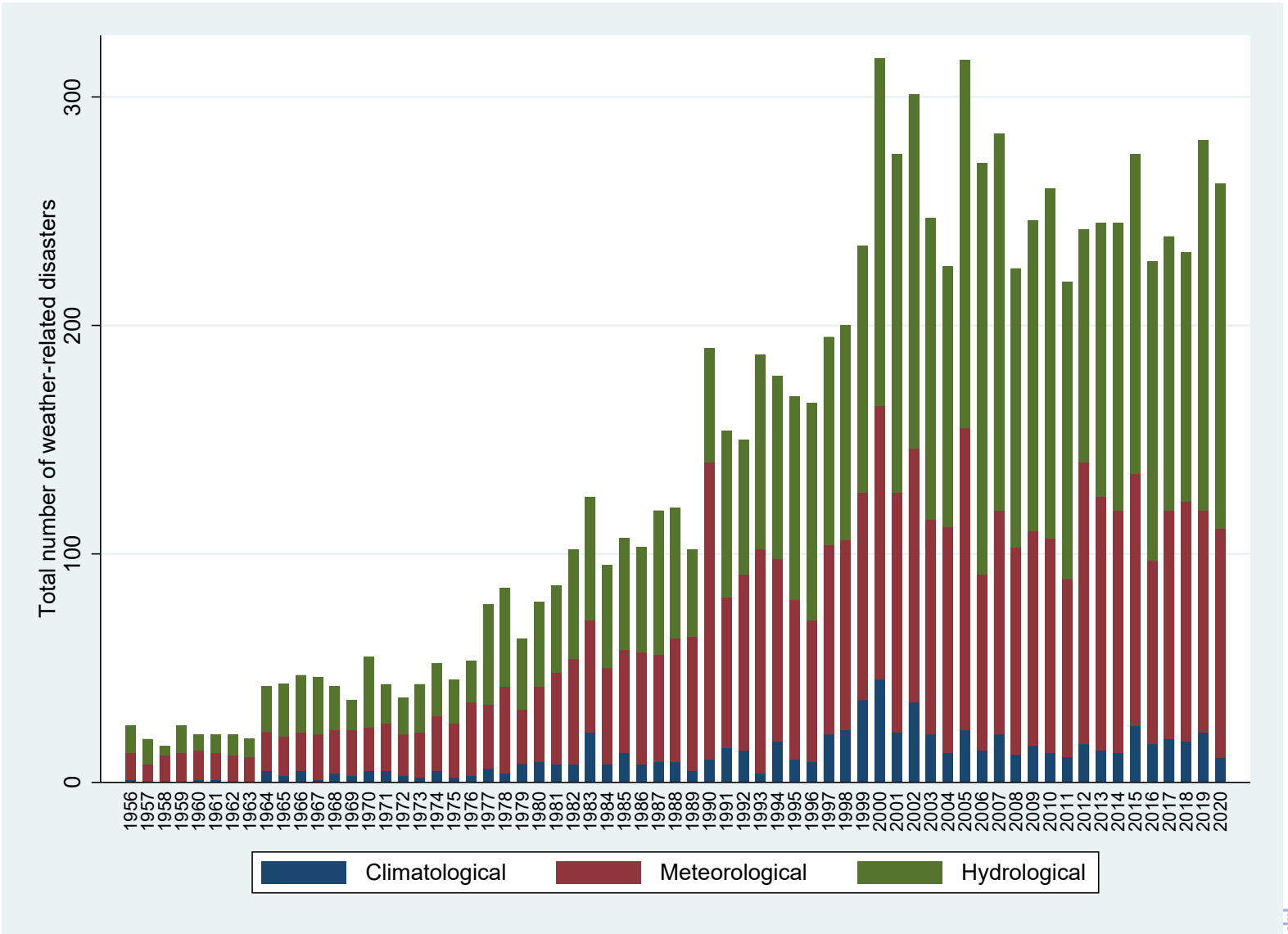
- Monthly number of events, deaths, number of people affected, and economic losses in USD

- Aggregate data to country-year level, and for country-years where no disasters are reported we assume that all indicators are zero — no events

- Economic losses in real USD, by dividing the amount by the U.S. CPI.

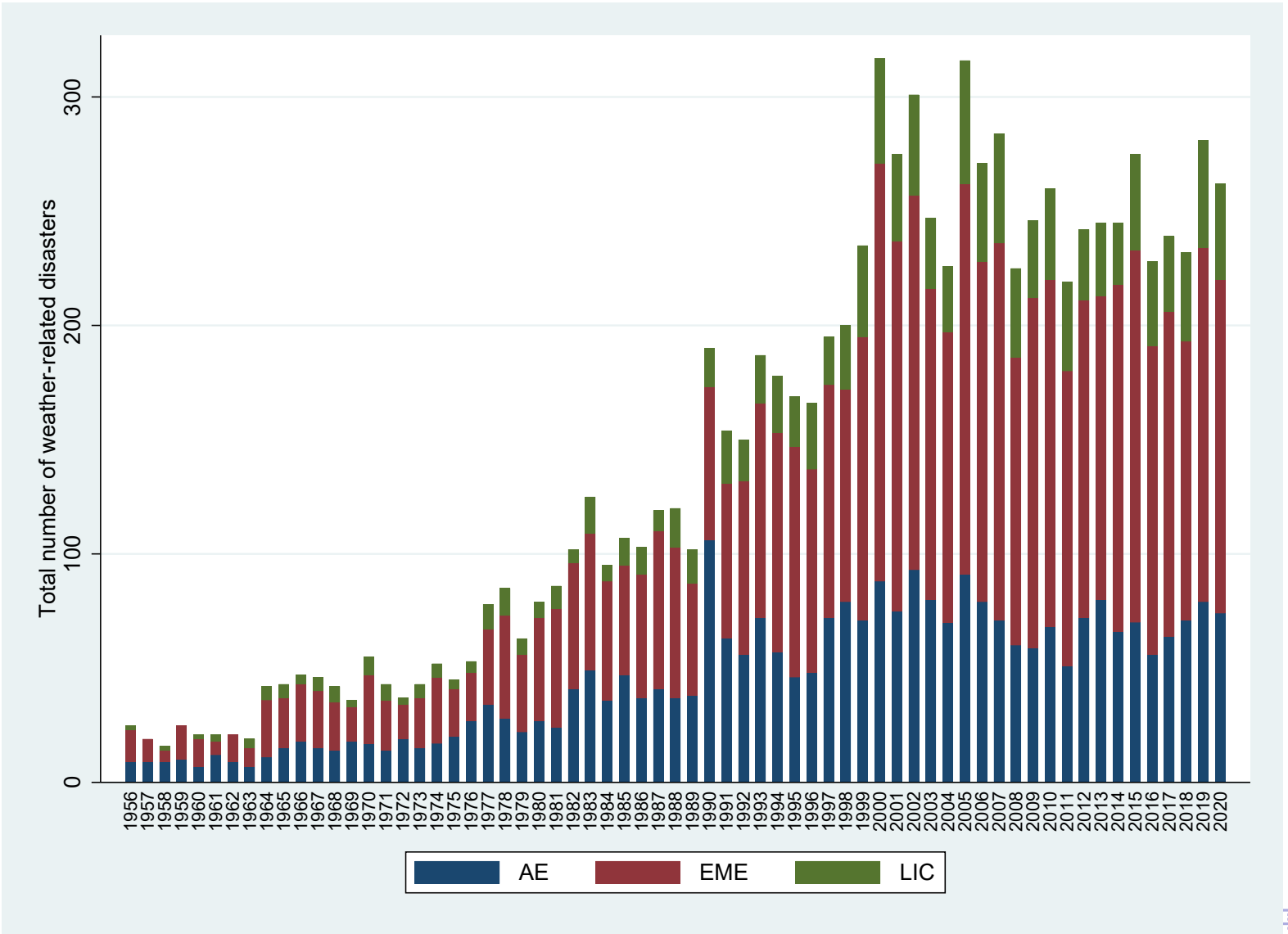
Climate Disaster Data

Figure: Climate-related disaster events by type



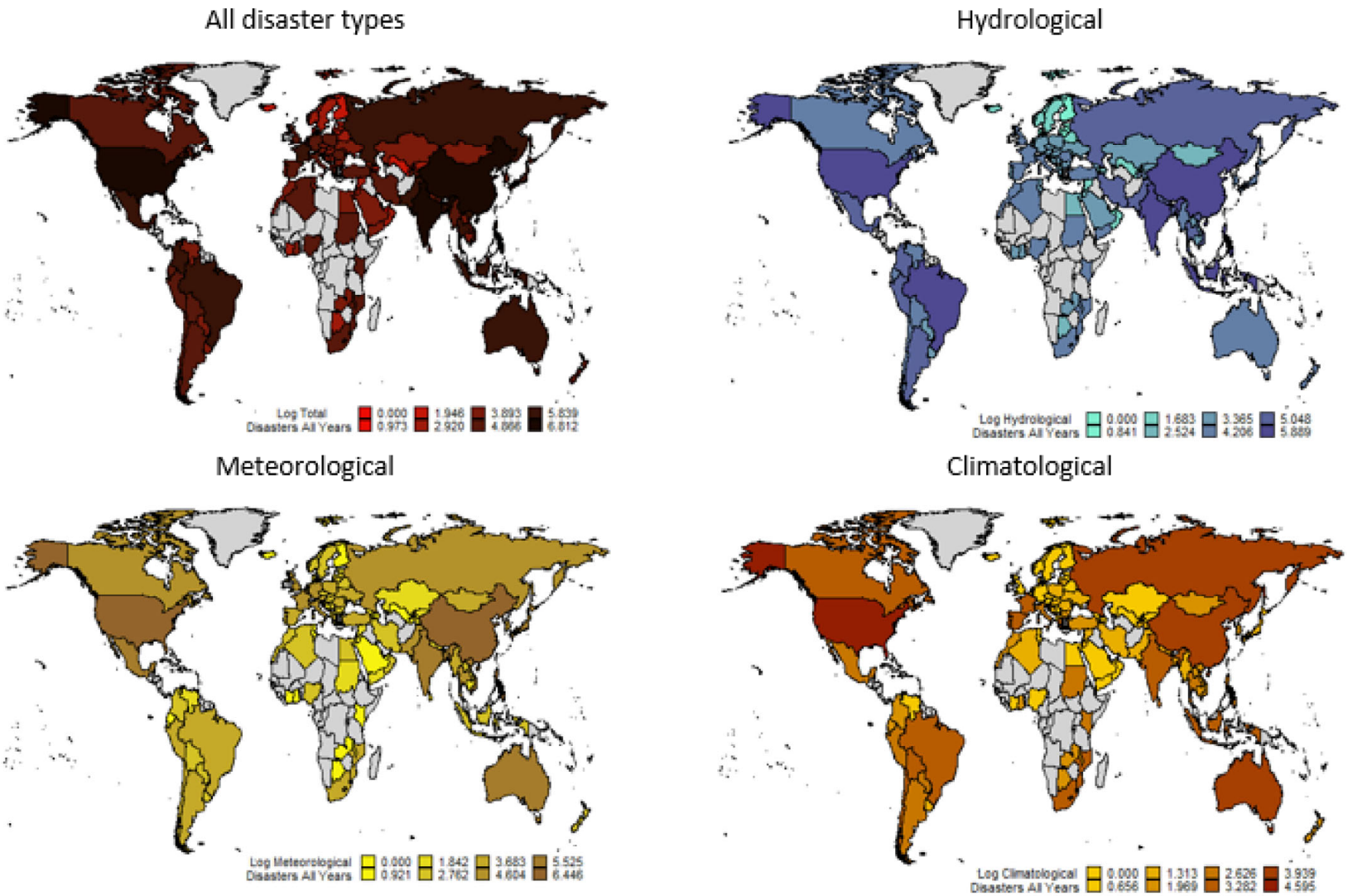
Climate Disaster Data

Figure: Climate-related disaster events by country group



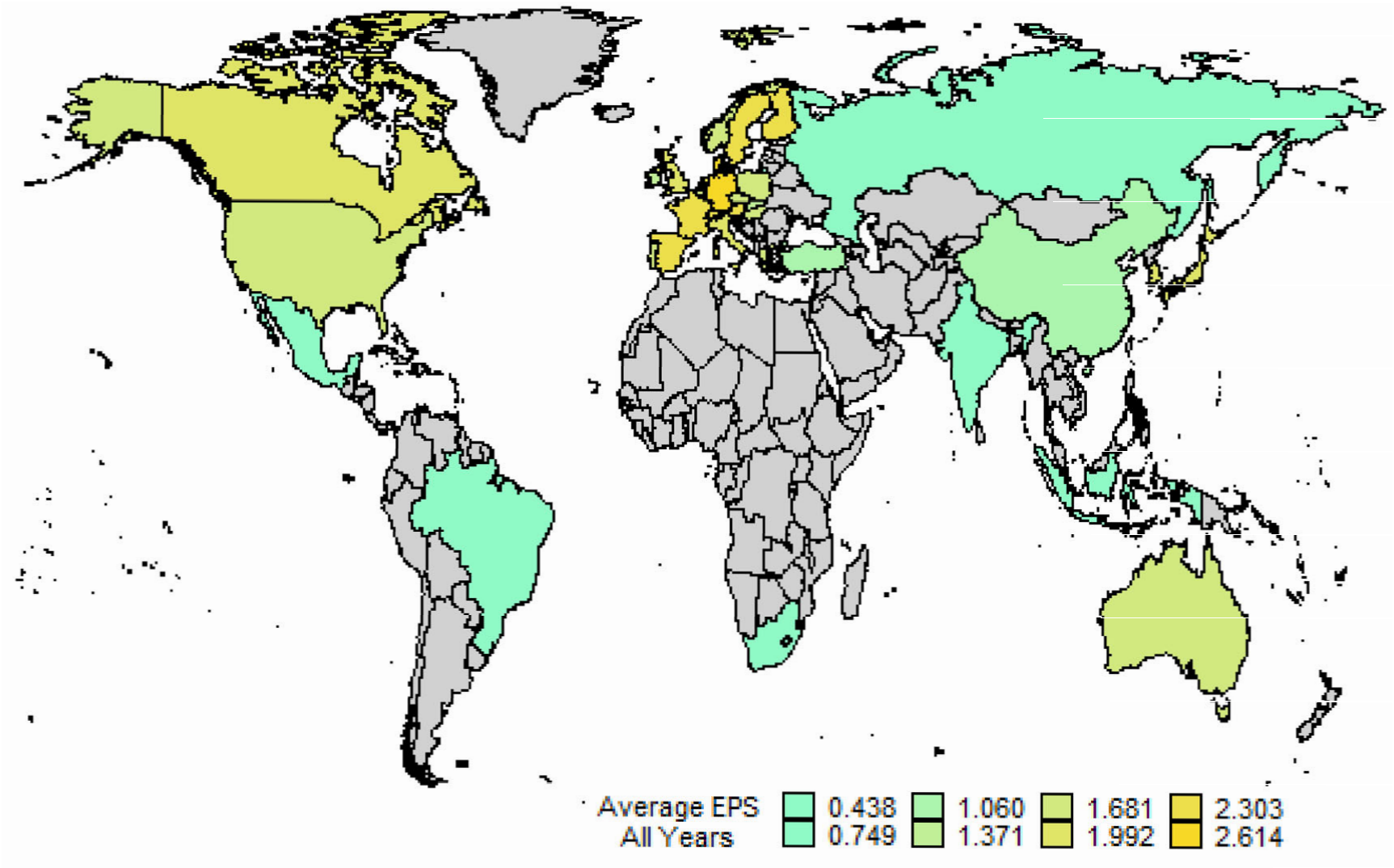
Climate Disaster Data

Figure: Climate-related disaster event map



Climate Policy Data

Figure: Environmental policy stringency map

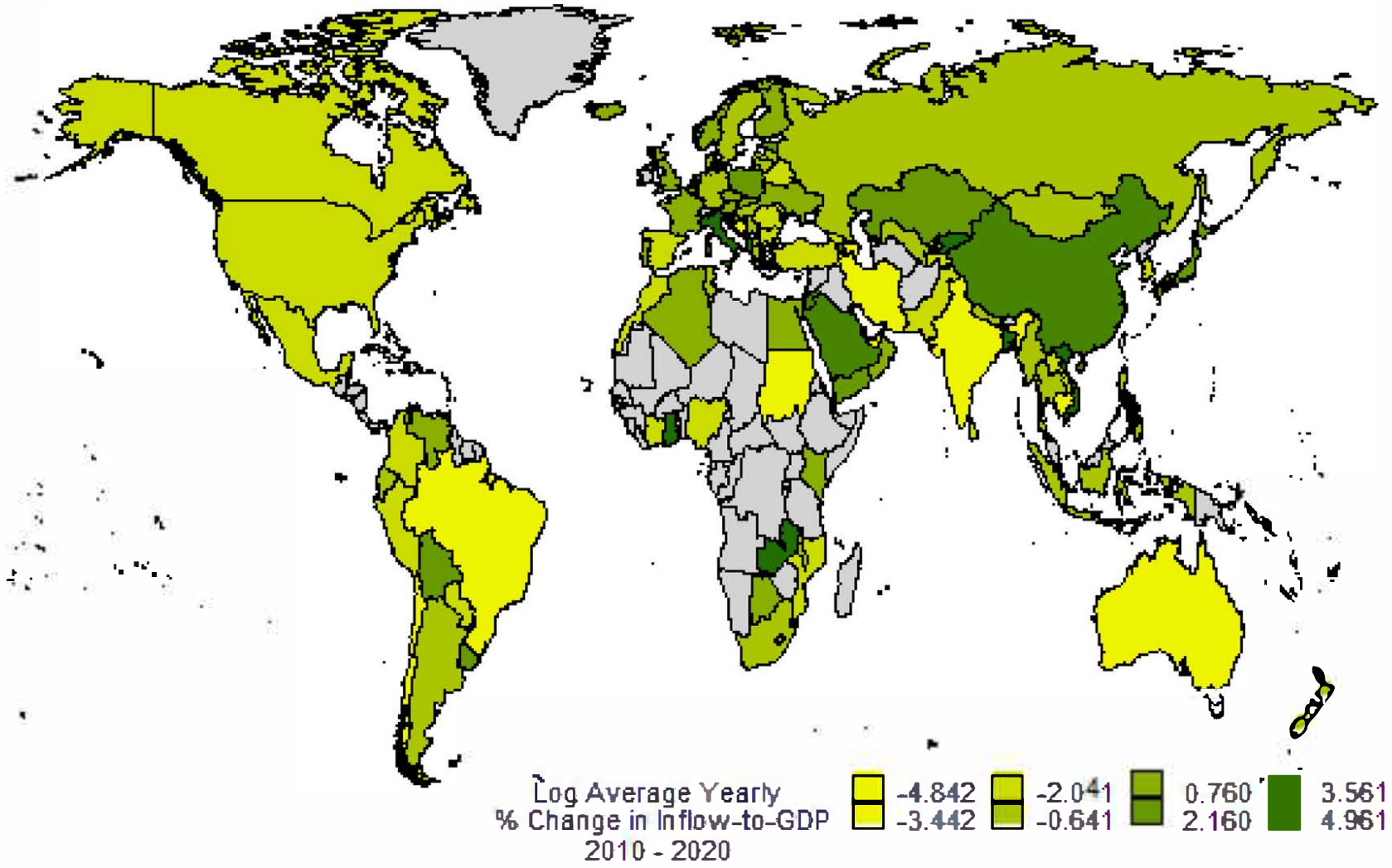


FDI Data: Country level and Bilateral

- WDI (1970-2019, 94 countries)
- Net inflows of investment to acquire a lasting management interest (10 percent or more of voting stock) in an enterprise operating in an economy other than that of the investor
- Includes equity capital, reinvestment of earnings, other long-term capital, and short-term capital as shown in the balance of payments
- Divided by GDP
- Bilateral: IMF CDIS (2009-2019, 125 countries), target-country's received FDI share in source-country' total outflow position
- Macro: Trade/GDP, PPI inflation, Real GDP Growth

FDI Data: Country level

Figure: Average annual change in net FDI inflows



FDI Data: Country-industry level

- OECD International Direct Investment Statistics Yearbook 2005-2019, 49 industries

- Classified by ISIC4 codes (2-digit level). Manually merged with WIOD industries to combine with emissions and value added data

FDI Data: Firm level

- ORBIS (2007-2019)
- Restrict to firms with total assets in excess of 1 billion USD for a given year: An unbalanced firm-year panel with 5915 firms from 66 countries with affiliates across 206 countries with the total of over a million of firm-target country-year observations
- For each firm, aggregate information on affiliates by target country and year
- Firm headquarter country and its industry
- Exclude OFCs as target countries, but do keep firms with headquarters in OFCs
- Sample includes up to 138,824 observations, with 2140 firms located in 31 countries (2 OFCs) and affiliates in 32 countries (10 EMEs, 22 AEs).

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FDI Data: Firm level

- An intensive margin: the number of affiliates in a given country in a given year as a share of total number of affiliates that the firm has in that year

- An extensive margin: an indicator of whether a firm has an affiliate in a given country in a given year

Main Effects: Extensive Results

Effect on FDI (extensive: inflow)										
Sample years		Bilateral-Linear 2010-2016			2006-2015		2009-15	2008-2016		
LHS		I(D.FDI / Total FDI from SC>0)			I(TC Inflow/VA>0)			I(new affiliates in TC)		
Source:										
Climatological		**-0.01**	**-0.01**	0.00				-0.005	-0.004	-0.006
Meteorological		0.00	0.00	0.00				0.002	0.002	0.002
Hydrological		**0.00**	**0.01**	0.00				-0.003	-0.003	-0.002
EPS		**-0.02**	**-0.03**	-0.01				**-0.028**	**-0.028**	**-0.027**
CO2 Tax		0.03	0.03	0.02				**0.011**	0.005	**0.028**
Emissions		-0.14	-0.23	0.02				0.315	0.284	**0.400**
Climate risk								0.000	0.001	-0.001
Target:										
Climatological		0.00	0.01	-0.01	0.029	0.055	-0.020	-0.002	-0.005	0.006
Meteorological		0.00	0.00	0.00	-0.022	-0.034	0.032	**-0.001**	0.000	**-0.002**
Hydrological		0.00	0.00	0.00	0.009	0.006	-0.034	-0.001	0.000	-0.001
EPS		0.00	0.00	0.00	0.012	-0.030	0.433	0.003	**0.006**	**0.011**
CO2 Tax		-0.01	0.00	0.01				**0.011**	0.005	**0.028**
Emissions		0.01	-0.11	-0.12	**-6.12**	**-5.83**	-28.22	0.148	0.163	**-0.037**
Effect on FDI (extensive: outflow)										
LHS		I(D.FDI / Total FDI from SC<0)			I(TC Inflow/VA<0)			I(no more affiliates in TC)		
Source:										
Climatological		**0.01**	0.01	0.01				0.004	0.004	0.002
Meteorological		**0.00**	**-0.01**	0.00				0.000	0.000	0.000
Hydrological		0.00	0.00	0.00				**0.004**	**0.004**	**0.005**
EPS		0.00	0.00	0.00				-0.006	-0.006	-0.008
CO2 Tax		0.03	0.04	0.01				0.002	**0.010**	0.000
Emissions		0.15	0.20	0.06				-0.008	-0.007	-0.007
Climate risk								0.006	**0.009**	-0.001
Target:								0.000	0.000	0.000
Climatological		0.00	0.01	0.00	-0.026	-0.039	0.012	**0.002**	0.001	**0.007**
Meteorological		0.00	0.00	0.00	0.006	0.010	-0.023	**0.000**	-0.001	**-0.001**
Hydrological		0.00	0.01	0.00	-0.001	0.002	0.021	0.000	0.000	**0.001**
EPS		0.00	0.01	-0.02	0.038	0.072	-0.270	0.001	0.001	**0.005**
CO2 Tax		**0.03**	0.01	-0.01				0.002	**0.010**	0.000
Emissions		-0.24	-0.34	**0.43**	3.117	2.49	30.95	**-0.031**	0.015	-0.076

Emission-Productivity Interactions: Extensive Margins

Effect on FDI (extensive: inflow)										
Sample years		Bilateral-Linear Probability 2010-2016			2006-2015		2009-15	2008-2016		
FEs		TC*SC, SC*Year			TC*TI, TI*Year, TC*Year			Firm*Year, TC, TI		
LHS		I(D.FDI / Total FDI from SC>0)			I(TC Inflow/VA>0)			I(new affiliates in TC)		
Source:										
Climatological		-0.02	0.01	-0.03				-0.009	0.002	0.019
Meteorological		0.00	0.00	-0.02				0.002	0.000	-0.001
Hydrological		0.05	0.05	0.04				-0.009	-0.008	-0.007
EPS		0.10	0.14	**0.23**				-0.006	-0.002	0.008
CO2 Tax		-0.01	-0.08	-0.13				-0.055	-0.019	0.030
Emissions		-1.31	-0.93	-0.66				0.066	0.029	**0.310**
Climate risk								-0.008	-0.017	0.026
Target:										
Climatological		0.16	0.02	-0.02	**2.64**	**3.20**	-17.45	**-0.102**	0.013	-0.034
Meteorological		-0.06	-0.08	0.04	0.10	0.08	8.62	**0.030**	0.028	**0.064**
Hydrological		0.00	-0.06	-0.01	-0.49	-0.64	-2.00	0.003	0.049	0.008
EPS		0.08	0.02	0.21	**-3.81**	-2.38	-83.48	-0.058	-0.046	-0.323
CO2 Tax		0.06	0.32	-2.97				0.020	0.346	1.040
Emissions		-0.29	-0.18	-0.73	-1.00	-4.85	126.20	0.181	0.095	0.237
Effect on FDI (extensive: outflow)										
LHS		I(D.FDI / Total FDI from SC<0)			I(TC Inflow/VA<0)			I(no more affiliates in TC)		
Source:										
Climatological		-0.05	-0.13	0.15				-0.005	-0.003	-0.014
Meteorological		-0.03	-0.01	-0.04				**0.003**	**0.003**	0.003
Hydrological		0.04	0.01	0.07				0.000	0.000	-0.002
EPS		**0.32**	**0.42**	0.27				0.002	0.004	-0.029
CO2 Tax		-0.09	-0.27	-0.09				-0.026	0.017	**-0.075**
Emissions		-0.59	-0.63	-1.88				**0.101**	**0.114**	0.088
Climate risk								**0.033**	**0.037**	**-0.042**
Target:										
Climatological		0.09	0.14	0.18	-0.51	-1.08	17.82	**-0.021**	0.003	-0.008
Meteorological		-0.01	0.01	-0.10	**-0.42**	**-0.40**	-8.72	-0.005	-0.007	**-0.027**
Hydrological		0.04	0.01	0.05	0.54	0.81	2.31	**-0.008**	0.002	-0.004
EPS		0.12	0.16	0.39	0.00	**-1.32**	81.13	-0.011	-0.011	-0.093
CO2 Tax		-0.12	1.01	3.01				0.049	0.086	**1.960**
Emissions		**-1.39**	-1.88	-0.56	**6.42**	**9.61**	-119.7	-0.009	-0.018	0.131

Result Summary

- Do MNEs incorporate climate risks into their FDI decisions? "Not yet."
- Main takeaways:
  - Most statistically robust effects are consistent with model predictions, but few significant results and small in magnitude
  - The effects of physical risks are smaller than those of transition risks or emission productivity
  - Higher emission productivity dampens or amplify the effects of climate risks in the data, as the model predicts
  - But attention of MNEs to climate risks are rising and more exposed firms react more to transition risk $\rightarrow$ Future large and abrupt FDI changes are coming as climate risks intensify