The Effect of Carbon Pricing on Firm Performance: Worldwide Evidence

Tinghua Duan (IESEG School of Management)
Frank Weikai Li (Singapore Management University)
Hong Zhang (Singapore Management University)

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Background

- Climate change, mainly caused by concentration of green house gas (GHG) in earth's atmosphere, is one of the most pressing societal challenges
- Economists (Stiglitz, 2019) view that putting a price on carbon emissions is the **most flexible and cost-effective method** of tackling climate change – '*carbon pricing*'
- Pedersen (2023): green finance is not needed if the carbon price equals its social cost
- Two major types of compliance carbon pricing instruments
    - **Emissions trading systems and carbon taxes (Compliance carbon markets)**
    - Voluntary carbon credit market also exists, but less credible and much smaller


ENVIRONMENT

A carbon tax is 'single most powerful' way to combat climate change, IMF says

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Emma Newburger
@EMMA_NEWBURGER

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Background

- Carbon taxes set a price on carbon by defining a tax rate on GHG emissions
  - provide certainty over carbon price, but not the quantity of emissions reduced

- ETS places a limit on the amount of GHG emissions from covered entities
  - provides certainty over the quantity of emissions reduced and let market determine the carbon price

Global Coverage of Carbon Pricing Initiatives

KEY STATISTICS FOR 2023 ON INITIATIVE(S) IMPLEMENTED

73 Carbon pricing initiatives selected

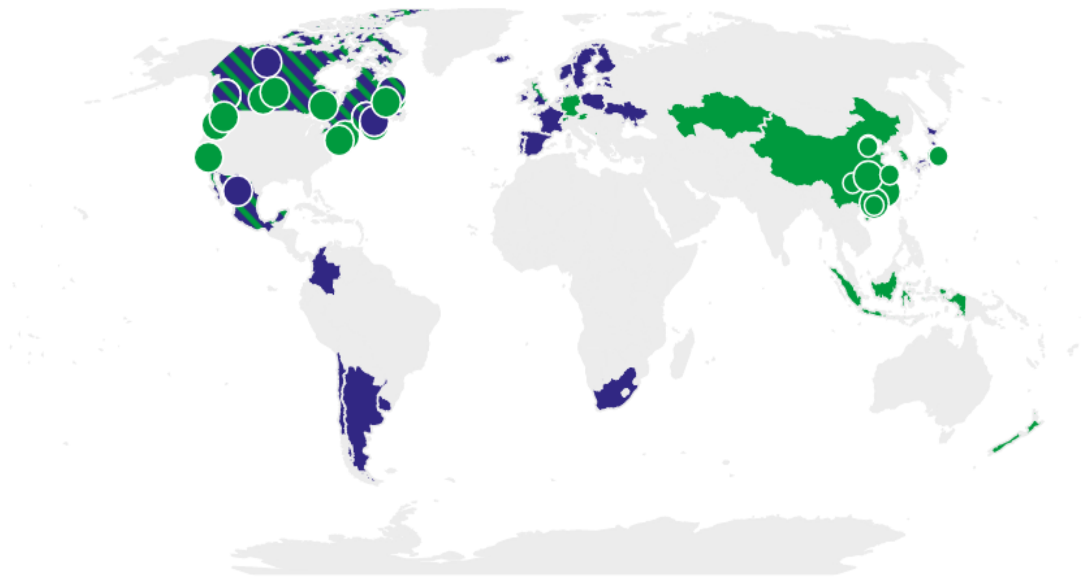
39 National jurisdictions are covered by the initiatives selected

33 Subnational jurisdictions are covered by the initiatives selected

In 2023, these initiatives would cover **11.66 $GtCO_2e$**, representing **23%** of global GHG emissions

Data last updated March, 31 2023

Summary map of regional, national and subnational carbon pricing initiatives



STATUS
- [x] Implemented
- [ ] Scheduled
- [ ] Under consideration

TYPE OF INSTRUMENT
- [ ] Carbon tax
- [ ] ETS
- [ ] Undecided

TYPE OF JURISDICTION
- [ ] Regional
- [ ] Subnational

- ETS implemented or scheduled for implementation
- ETS or carbon tax under consideration
- ETS implemented or scheduled, ETS or carbon tax under ...
- Carbon tax implemented or scheduled for implementati...
- ETS and carbon tax implemented or scheduled
- Carbon tax implemented or scheduled, ETS under consid...

Note: Carbon pricing initiatives are considered "scheduled for implementation" once they have been formally adopted through legislation and have an official, planned start date.
Carbon pricing initiatives are considered "under consideration" if the government has announced its intention to work towards the implementation of a carbon pricing initiative and this has been formally confirmed by official government sources.

Motivation

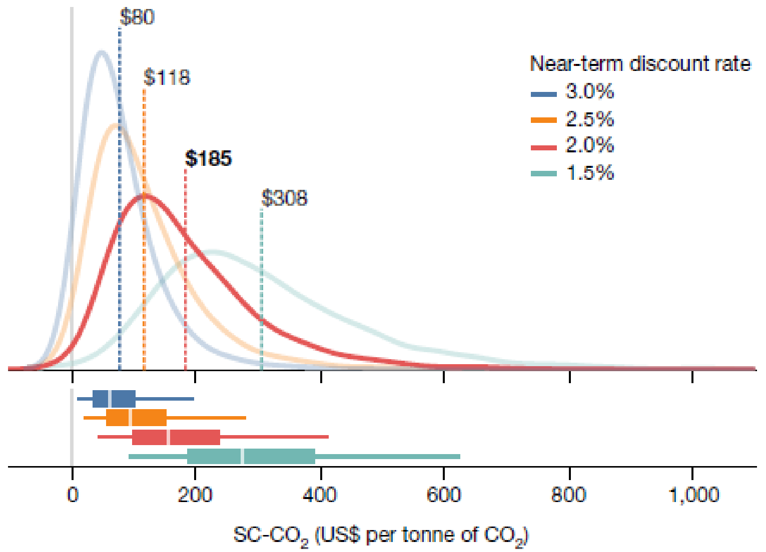
- Prior studies show that carbon pricing is **effective** in reducing carbon emissions
  - Andersson (AEJ 2019); Martinsson et al. (RFS 2024); Bai and Ru (MS 2024)
  - We confirm the effectiveness of carbon pricing in reducing firm-level emissions
- A major block to pricing carbon pollution is concern about the economic costs
  - Trump administration's decision to retreat from any climate policy is motivated by the (perceived) heavy costs to the US economy
- This concern is further amplified by the large discrepancies in carbon prices across different jurisdictions around the world
  - In a global economy, a high local carbon price in one region would simply move the most carbon-intensive activities elsewhere – known as "carbon leakage"
  - To prevent carbon leakage, EU introduced Carbon Border Adjustment Mechanism (CBAM) (started transitional phase on 1 October, 2023)

Motivation

- Most empirical studies, however, find no discernable negative impacts of carbon pricing on aggregate economic growth, employment, or inflation
  - Metcalf and Stock (AER P&P, 2020): carbon tax has **insignificantly positive** effects on GDP growth and employment
  - Moessner (2022): higher carbon prices have NOT led to large increases in headline inflation
  - de Silva and Tenreyro (JEEA, 2021): The impact of climate policies on GDP growth or inflation was largely insignificant
  - In contrast, theoretical studies based on computable general equilibrium models tend to find contractionary output effects (McKibbin et al., 2017; Goulder and Hafstead, 2018)
- These macro-level evidence raise an important question:
- **If carbon pricing is effective in reducing emissions and have no negative impacts on the macroeconomy, why do not we see more countries adopting carbon pricing and in a more aggressive way**?

Motivation

- The current global carbon price is far below the social cost of carbon calculated by scientists (Rennert et al., Nature 2022)



- Several possibilities:
  - Carbon price is still too low to have any discernable impacts
  - Carbon pricing has largely distributional impacts (and not equally shared)
  - Endogeneity issue: macroeconomic factors can influence policymakers' climate policy stance

Research Question

- Our paper examines the **distributional** impacts of carbon pricing policies across firms within an economy
    - The effect could be negative mainly for carbon-intensive firms, which need to either purchase carbon allowances to offset emissions or downsize production
- No aggregate impacts because green firms benefit from carbon pricing policies
    - Green firms (such as Tesla) could sell their unused allowances to other firms
    - Governments typically recycle revenues raised through carbon pricing back to the economy to promote the development of low-emission technologies or business practices
- Yet another possibility is even high-emission firms may not be materially affected by carbon pricing initiatives if they can
    - relocate carbon-intensive productions to jurisdictions with more lenient climate policies
    - or pass higher operating costs to customers
    - or switch to green technologies rapidly

What We Do

- We conduct a comprehensive analysis of the impact of carbon pricing (including both carbon taxes and ETS) on individual firms around the world
  - 104,100 firm-year observations covering 16,222 unique firms from 52 countries
  - Sample period from 2002 to 2019
- We use a triple-difference approach to estimate the causal effect of carbon pricing policies on firms' **operating performance**, **market value**, and **investment**
  - Staggered enactment of carbon pricing initiatives across different jurisdictions
  - Exploit the heterogeneity across firms within the same jurisdiction conditional on carbon intensity
  - Fixed effects to absorb time-invariant firm heterogeneity or time-varying local economic conditions and industry-specific trends

Preview of Main Findings

- We compare change in various outcomes of high-emission firms relative to low-emission firms after a jurisdiction adopted carbon pricing:
  - Profitability (ROA/ROE) ↓
  - Components of profits (sales ↓ and costs of goods sold) ↑
  - Firm value (measured by Tobin's *q*) ↓
  - Expected future cash flows (measured by analyst earnings forecast) ↓
  - Exposure to climate regulatory risk and cost of capital ↑
  - Real investment (CapEx, R&Ds, and employees) ↓
- Cross-country heterogeneity tests show stronger effect for firms headquartered in
  - Countries with large fossil fuel sectors and with higher energy consumption per capita
  - North America

Contribution

1. Economic impacts of carbon pricing on macroeconomy and firms/households

- Metcalf and Stock (AER P&P, 2020), de Silva and Tenreyro (JEEA, 2021), Martin et al. (2014), Känzig (2022)
- Existing studies focus on either ETS or carbon taxes within a single jurisdiction
- **We examine the impacts of both ETS and carbon taxes around the world**
- A global problem requires a global study

2. The Pricing of climate transition risk in financial markets

- Bolton and Kacperczyk (JFE 2021; JF 2023): carbon risk is priced in the US and global equity markets
- Recent studies challenge the existence of carbon premium (Aswani et al., RF 2023; Zhang, JF forth)
- Findings are mixed because the traditional asset pricing methodologies (portfolio sorting and FM regressions) cannot fully address the omitted variable concern
- **We exploit the staggered adoption of carbon pricing across jurisdictions and use a triple difference approach to mitigate omitted variables concern**

Data

- Data on carbon pricing initiatives from the **World Bank Carbon Pricing Dashboard**
- By 2019, 32 countries in our sample have adopted carbon pricing initiatives at either national (regional) and subnational level
  - The earliest carbon pricing initiatives is carbon tax in Finland and Portland in 1990
  - The European Union established ETS in 2005 (world's largest carbon market)
  - 8 regional pilot ETS in China: Beijing, Shanghai, Tianjin, Chongqing, Shenzhen, Guangdong , Hubei, and Fujian, which preceded the national ETS in 2021
  - Regional Greenhouse Gas Initiative (RGGI) and California Cap-and-Trade Program in US
- Firm-level carbon emissions data from the **S&P Global Trucost**
- Firm-level financial data from the Worldscope and analyst forecast data from I/B/E/S
- Country-level macroeconomic data from IMF
- Final sample includes 104,100 firm-year observations covering 16,222 unique firms from 52 countries over the period 2002-2019

Carbon Pricing Initiatives – National/Regional Level

Panel A: Country-level carbon pricing initiatives

Country	Carbon tax		ETS	
	Year	Name of initiative	Year	Name of initiative
	(1)	(2)	(3)	(4)
Argentina	2018	Argentina carbon tax	-	-
Austria	-	-	2005	EU ETS
Belgium	-	-	2005	EU ETS
Chile	2017	Chile carbon tax	-	-
Colombia	2017	Colombia carbon tax	-	-
Canada	2019	Canada federal fuel charge	2019	Canada federal OBPS
Denmark	1992	Denmark carbon tax	2005	EU ETS
Finland	1990	Finland carbon tax	2005	EU ETS
France	2014	France carbon tax	2005	EU ETS
Germany	2019	-	2005	EU ETS
Greece	-	-	2005	EU ETS
Ireland	2010	Ireland carbon tax	2005	EU ETS
Italy	-	-	2005	EU ETS
Japan	2012	Japan carbon tax	-	-
South Korea	-	-	2015	Korea ETS
Luxembourg			2005	EU ETS
Mexico	2014	Mexico carbon tax	-	-
Netherlands	-	-	2005	EU ETS
New Zealand	-	-	2008	New Zealand ETS
Norway	1991	Norway carbon tax	2008	EU ETS
Poland	1990	Poland carbon tax	2005	EU ETS
Portugal	2015	Portugal carbon tax	2005	EU ETS
Singapore	2019	Singapore carbon tax	-	-
South Africa	2019	South Africa carbon tax	-	-
Spain	2014	Spain carbon tax	2005	EU ETS
Sweden	1991	Sweden carbon tax	2005	EU ETS
Switzerland	2008	Switzerland carbon tax	2008	Switzerland ETS
United Kingdom	2013	UK carbon price support	2005	EU ETS

Carbon Pricing Initiatives – Subnational Level

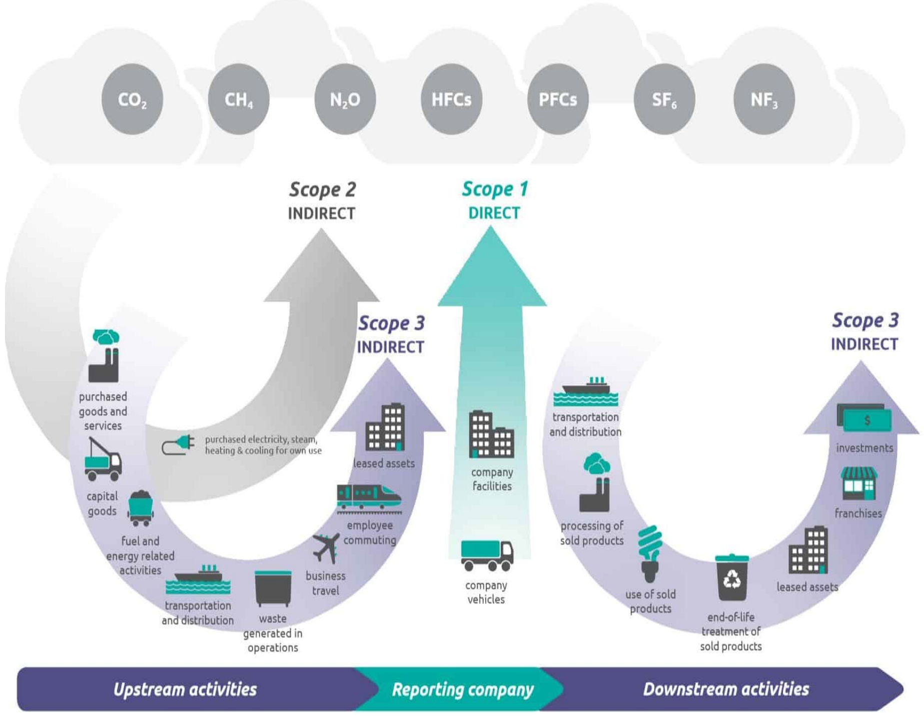
Panel B: Subnational carbon pricing initiatives

Sub-country	Carbon tax		ETS	
	Year (1)	Name of initiative (2)	Year (3)	Name of initiative (4)
Canada, Alberta	-	-	2007	Alberta TIER
Canada, British Columbia	2008	BC carbon tax	2016	BC GGIRCA
Canada, Newfoundland and Labrador	2019	Newfoundland and Labrador carbon tax	2019	Newfoundland and Labrador PSS
Canada, Northwest Territories	2019	Northwest Territories carbon tax	-	-
Canada, Nova Scotia	-	-	2019	Nova Scotia CaT
Canada, Prince Edward Island	2019	Prince Edward Island carbon tax	-	-
China, Beijing	-	-	2013	Beijing pilot ETS
China, Chongqing	-	-	2014	Chongqing pilot ETS
China, Fujian	-	-	2016	Fujian pilot ETS
China, Guangdong (except Shenzhen)	-	-	2013	Guangdong pilot ETS
China, Hubei	-	-	2014	Hubei pilot ETS
China, Shenzhen	-	-	2013	Shenzhen pilot ETS
China, Shanghai	-	-	2013	Shanghai pilot ETS
China, Tianjin	-	-	2013	Tianjin pilot ETS
Japan, Tokyo	-	-	2010	Tokyo CaT
Japan, Saitama	-	-	2011	Saitama ETS
United States, California	-	-	2013	California CaT
United States, Connecticut	-	-	2009	RGGI
United States, Delaware	-	-	2009	RGGI
United States, Maine	-	-	2009	RGGI
United States, Maryland	-	-	2009	RGGI
United States, Massachusetts	-	-	2018	RGGI
United States, New Hampshire	-	-	2009	RGGI
United States, New Jersey	-	-	2009	RGGI
United States, New York	-	-	2009	RGGI
United States, Rhode Island	-	-	2009	RGGI
United States, Vermont	-	-	2009	RGGI

We measure carbon pricing initiatives at jurisdiction level, which can be a region (EU), a country, or a sub-nation

Measuring Firm-level Carbon Emissions

- Carbon emissions are measured in tons of carbon dioxide equivalent (tCO2e)
  - Classified into three scopes following the Greenhouse Gas Protocol
- Carbon emissions level cannot be compared across firms with different size
  - **Carbon intensity**, measured as tCO2e/revenue ($ million)
  - A standard metric of measuring carbon footprint used by both practitioners (e.g., MSCI low carbon index) and academia
  - Take log(Intensity) due to highly skewed distribution of CEI



Econometric Specification – Triple Difference

- $Y_{i,c,t} = \beta_0 + \beta_1 Log(Intensity1 + 1)_{i,c,t} + \beta_2 Post_{c,t} + \beta_3 Post_{c,t} \times Log(Intensity1 + 1)_{i,c,t} + \gamma' \boldsymbol{X}_{\boldsymbol{i,c,t}} + k' \boldsymbol{Z}_{\boldsymbol{c,t}} + \varepsilon_{i,c,t}$
- $Y_{i,c,t}$: outcome variable of firm *i* headquartered in jurisdiction *c* of year *t*, including ROA/ROE, Tobin's q, Investment, EPS forecast etc
- $Post_{c,t}$: dummy variable equals to one if the jurisdiction *c* has implemented some form of carbon pricing initiatives (either the carbon tax initiative or the ETS initiative) in year *t*
- $Log(Intensity1 + 1)_{i,c,t}$: the natural log of one plus (scope 1) carbon intensity of firm *i* in year *t* (continuous treatment variable)
- The parameter of interest is β_3 and we predict β_3<0 when ROA/ROE is the outcome variable
- $\boldsymbol{X}_{\boldsymbol{i,c,t}}$ is a set of firm-level control variables, including *Log(Assets)*, *Leverage*, *Cash*, *Sales growth*, *CapEx_assets*, *R&D_sales*
- $\boldsymbol{Z}_{\boldsymbol{c,t}}$: country-level variables including *Log(GDP per capita)* and *Law and order*
- Baseline specification also includes firm and year fixed effects
- Standard errors clustered at firm level

Are Carbon Pricing Initiatives Effective in Reducing Emissions?

Variables	Log(Intensity1)	Log(Intensity1)	Log(Intensity2)	Log(Intensity2)	Log(Intensity3)	Log(Intensity3)
	(1)	(2)	(3)	(4)	(5)	(6)
Post	-0.0848***	-0.0841***	-0.0501***	-0.0506***	-0.0083	-0.0083
	(-5.079)	(-5.035)	(-3.053)	(-3.080)	(-1.567)	(-1.572)
Controls	NO	YES	NO	YES	NO	YES
Firm FEs	YES	YES	YES	YES	YES	YES
Year FEs	YES	YES	YES	YES	YES	YES
Adjusted R^2	0.9337	0.9338	0.8440	0.8445	0.9759	0.9759
Observations	103,991	103,991	104,025	104,025	104,100	104,100

- DiD estimates: the implementation of carbon pricing initiatives leads to lower firm-level carbon emissions
- The effect is significant for scope 1 and scope 2 emissions, but not for scope 3 emissions
- Consistent with the fact that carbon pricing initiatives do not cover scope 3 emissions

Carbon Pricing and Firm Profitability – Baseline Results

Variables	ROA (1)	ROA (2)	ROE (3)	ROE (4)
Post*Log(Intensity1+1)	-0.0021***	-0.0024***	-0.0059***	-0.0061***
	(-4.635)	(-5.463)	(-4.358)	(-4.632)
Post	0.0139***	0.0145***	0.0360***	0.0360***
	(7.576)	(8.322)	(6.687)	(6.746)
Log(Intensity1+1)	-0.0025***	-0.0016***	-0.0066***	-0.0047***
	(-4.127)	(-2.712)	(-3.875)	(-2.813)
Log(Assets)		0.0046***		0.0153***
		(3.568)		(4.301)
Leverage		-0.1642***		-0.2892***
		(-35.129)		(-17.556)
Cash		0.0837***		0.1673***
		(16.115)		(13.044)
Sales_growth		0.0289***		0.0768***
		(24.909)		(25.085)
CapEx_assets		0.1516***		0.3890***
		(15.619)		(14.586)
R&D_sales		-0.3504***		-0.6103***
		(-10.282)		(-8.402)
Log(GDP per capita)		-0.0092***		-0.0082
		(-3.656)		(-1.129)
Law and order		0.0019		-0.0008
		(1.167)		(-0.147)
Constant	0.0477***	0.0557*	0.1092***	-0.1095
	(23.015)	(1.809)	(18.759)	(-1.236)
Firm FEs	YES	YES	YES	YES
Year FEs	YES	YES	YES	YES
Adjusted R^2	0.5668	0.6213	0.4595	0.4928
Observations	104,100	104,100	104,100	104,100

Carbon Pricing and Firm Profitability – Dummy Treatment Variable

Panel A: Using dummy variable to indicate firms with above-median (scope 1) carbon intensity

Variables	ROA (1)	ROA (2)	ROE (3)	ROE (4)
Post*D(Intensity1>Median)	-0.0044***	-0.0055***	-0.0111**	-0.0123***
	(-2.814)	(-3.724)	(-2.436)	(-2.755)
Post	0.0096***	0.0099***	0.0235***	0.0232***
	(6.981)	(7.710)	(5.824)	(5.834)
D(Intensity1>Median)	-0.0005	-0.0000	-0.0016	-0.0010
	(-0.309)	(-0.034)	(-0.376)	(-0.238)
Constant	0.0397***	0.0510*	0.0887***	-0.1239
	(43.701)	(1.657)	(32.758)	(-1.398)
Controls	NO	YES	NO	YES
Firm FEs	YES	YES	YES	YES
Year FEs	YES	YES	YES	YES
Adjusted R^2	0.5663	0.6209	0.4590	0.4924
Observations	104,100	104,100	104,100	104,100

- **Economic effect**: Firms with above-median carbon intensity experienced 55 bps reduction in ROA after carbon pricing
- 13% (6.7%) of the mean (STDev) of ROA, respectively

Dynamic Effect Analysis – Testing Parallel Trend Assumption

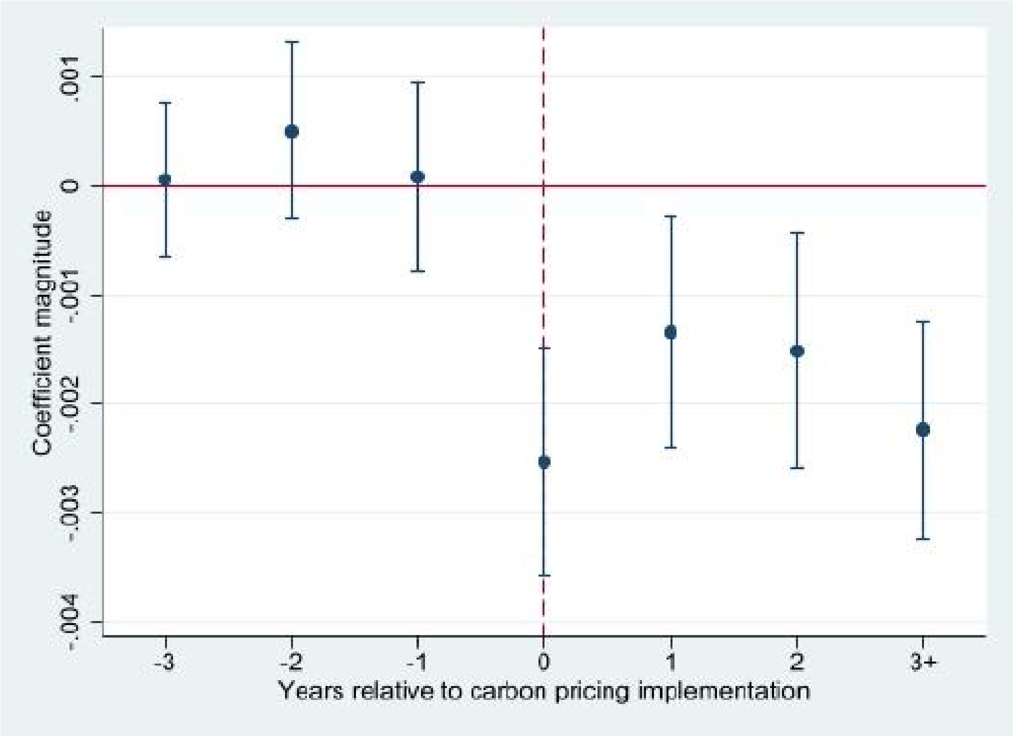


Figure 1a

Insignificant pre-trend supports the Parallel Trend Assumption

Confounding Effect from Local Economic Conditions or Industry Trends

Panel B: Alternative fixed effects specifications

Variables	ROA (1)	ROA (2)	ROE (3)	ROE (4)
Post*Log(Intensity1+1)	-0.0015***	-0.0014***	-0.0036***	-0.0048***
	(-3.270)	(-3.005)	(-2.757)	(-3.331)
Post		0.0103***		0.0276***
		(5.671)		(5.010)
Log(Intensity1+1)	-0.0017***	-0.0013**	-0.0050***	-0.0027
	(-2.907)	(-2.211)	(-3.063)	(-1.634)
Constant	-0.0223	0.0786**	-0.1800**	-0.0689
	(-0.781)	(2.568)	(-2.299)	(-0.783)
Controls	YES	YES	YES	YES
Firm FEs	YES	YES	YES	YES
Jurisdiction*Year FEs	YES	NO	YES	NO
Industry*Year FEs	NO	YES	NO	YES
Adjusted R^2	0.6274	0.6276	0.5017	0.4991
Observations	104,100	104,100	104,100	104,100

- Government decisions to enact carbon pricing could be affected by local economic condition
- Jurisdiction*Year fixed effects absorb the effects of local macroeconomic variables
- Industry*Year fixed effects absorb the effects of industry-specific trends in profitability

Robustness Checks

- The effect on firm profitability is robust when we
  - Examine the effects of carbon tax and ETS initiatives separately
  - Stacked DiD regression approach
  - Exclude US firms
  - Exclude firms with foreign assets
  - Alternative ways of clustering standard errors
- Results using scope 2 and 3 emission intensity

Carbon Prices and Firm Profitability

Panel B: Subsample of firms in jurisdictions with carbon pricing policies

Variables	ROA	ROE
	(1)	(2)
Log(Carbon tax price+1)*Log(Intensity1+1)	-0.0009***	-0.0019**
	(-3.073)	(-2.157)
Log(ETS price+1)*Log(Intensity1+1)	-0.0001	-0.0006
	(-0.694)	(-1.093)
Log(Carbon tax price+1)	0.0034***	0.0030
	(3.046)	(0.964)
Log(ETS price+1)	0.0009	0.0054***
	(1.337)	(2.614)
Log(Intensity1+1)	-0.0012	-0.0049*
	(-1.227)	(-1.748)
Constant	-0.1150	-0.6263***
	(-1.535)	(-2.842)
Controls	YES	YES
Firm FEs	YES	YES
Year FEs	YES	YES
Adjusted R2	0.6447	0.5427
Observations	46,257	46,257

- Examine the impact of (annual) carbon prices on firm profitability
- **Use only the subsample of firm-years in jurisdictions with carbon pricing (Post=1)**

- Higher prices of carbon taxes (but not ETSs) incrementally reduce the profitability of high-emission firms
- Why the effect of ETS price is insignificant?
  - ETS price is determined by demand and supply. Higher demand for carbon permits usually occurs when carbon-intensive firms are doing well
  - Känzig (2023) identifies carbon policy surprises and show it negatively affects the economy

Carbon Pricing and Components of Firm Profits

- Carbon-intensive firms can use several approaches to comply with carbon pricing policies
  - Keep the same level of production/emissions, pay carbon taxes or buy carbon allowances
  - Reduce emission intensity by adopting green technologies/using renewable energy
  - Reduce the level of emissions by downsizing production/sales

Variables	CGS_sales (1)	Sales growth (2)	SGA_sales (3)
Post*Log(Intensity1+1)	0.0025*	-0.0039**	-0.0013
	(1.797)	(-1.962)	(-1.140)
Post	-0.0048	0.0314***	-0.0035
	(-0.876)	(4.000)	(-0.730)
Log(Intensity1+1)	0.0024*	-0.0042	0.0006
	(1.682)	(-1.554)	(0.342)
Constant	0.7460***	1.0202***	0.5042***
	(9.583)	(7.647)	(6.740)
Controls	YES	YES	YES
Firm FEs	YES	YES	YES
Year FEs	YES	YES	YES
Adjusted R^2	0.8952	0.1968	0.9067
Observations	93,329	104,100	87,615

Carbon Pricing and Earnings Expectations

- In addition to realized earnings, investors lower earnings expectation for high-emission firms, as measured by analyst forecast of EPS over various horizons
- But not long-term earnings growth (LTG) forecast (adaption in the long-run)
- Evidence that analyst consensus forecasts are unbiased/rational

Variables	EPS forecast/price			LTG
	1-year ahead	2-year ahead	3-year ahead	
	(1)	(2)	(3)	(4)
Post*Log(Intensity1+1)	-0.0697***	-0.0728***	-0.0816***	0.0010
	(-4.170)	(-4.024)	(-3.757)	(0.663)
Post	0.2643***	0.2519***	0.2377***	-0.0019
	(4.748)	(4.225)	(3.335)	(-0.345)
Log(Intensity1+1)	-0.0209	-0.0231	-0.0322	0.0029
	(-1.077)	(-1.044)	(-1.145)	(1.572)
Constant	5.1827***	5.4338***	6.9336***	0.8166***
	(3.888)	(3.720)	(3.623)	(8.474)
Controls	YES	YES	YES	YES
Firm FEs	YES	YES	YES	YES
Year FEs	YES	YES	YES	YES
Adjusted R^2	0.8671	0.8768	0.8792	0.2754
Observations	76,951	74,576	57,315	49,736

Carbon Pricing and Firm-level Climate Risk Exposure

- Carbon-intensive firms' exposure to climate regulatory risk increases after carbon pricing
- But no effect on firms' exposure to physical risk (placebo test)
  - Earnings call-based measure of firm-level climate change exposure from Sautner et al. (JF 2023)

Panel B: The effects of carbon pricing on firm-level climate risk exposure

Variables	Regulatory risk	Physical risk
	(1)	(2)
Post*Log(Intensity1+1)	0.0010***	0.0001
	(3.352)	(1.536)
Post	-0.0024***	0.0001
	(-3.595)	(0.536)
Log(Intensity1+1)	0.0001	-0.0001
	(0.476)	(-0.970)
Constant	0.0152	0.0018
	(1.496)	(0.511)
Controls	YES	YES
Firm FEs	YES	YES
Year FEs	YES	YES
Adjusted R^2	0.4596	0.2815
Observations	41,140	41,140

Carbon Pricing and Cost of Capital

- **The "carbon premium" hypothesis**: investors demand higher expected returns on high-emission assets to compensate for greater transition risk (Bolton and Kacperczyk, 2021)
- We find carbon pricing policies lead to higher cost of debt, implied cost of equity, and perceived cost of capital (Gormsen and Huber, 2023) for high-emission firms

Panel A: The effects of carbon pricing on cost of capital

Variables	Cost of debt	Implied cost of equity	Perceived cost of capital
	Interests/Debt	r_mpeg	r_cost_captial
	(1)	(2)	(3)
Post*Ln(Intensity+1)	0.0009**	0.0022*	0.0004***
	(2.138)	(1.918)	(4.541)
Post	-0.0019	-0.0046	-0.0020***
	(-1.101)	(-1.199)	(-5.305)
Ln(Intensity+1)	0.0002	0.0045***	-0.0002*
	(0.293)	(3.519)	(-1.648)
Controls	YES	YES	YES
Firm FEs	YES	YES	YES
Year FEs	YES	YES	YES
Adjusted R^2	0.5324	0.8444	0.8530
Observations	96,184	78,718	21,432

Carbon Pricing and Firm Value

- Higher cost of capital and lower expected cash flows imply a negative effect of carbon pricing policies on firm value (measured by Tobin's *q*) and contemporaneous stock returns

Variables	Tobin's *q*	Ret_annual
	(1)	(2)
Post*Log(Intensity1+1)	-0.0179***	-0.0149***
	(-2.672)	(-6.597)
Post	0.0087	0.0904***
	(0.282)	(10.386)
Log(Intensity1+1)	-0.0133	0.0063**
	(-1.406)	(2.149)
Constant	7.6406***	2.7639***
	(13.717)	(18.222)
Controls	YES	YES
Firm FEs	YES	YES
Year FEs	YES	YES
Adjusted R^2	0.7959	0.1476
Observations	78,711	104,074

Carbon Pricing and Real Investments

- q theory of investment predicts the optimal level of investment should also decrease
- High-emission firms cut capital expenditures, R&D expenses, and number of employees (scaled by total assets or sales) after enactment of carbon pricing
- Insignificant relative effect on climate-related patents of high-emission firms

Panel A: Effects on firm-level investments

Variables	CapEx_assets	R&D_sales	Employees_sales
	(1)	(2)	(3)
Post*Log(Intensity1+1)	-0.0008***	-0.0004**	-0.0767***
	(-2.820)	(-2.273)	(-3.837)
Post	0.0016	0.0038***	0.3982***
	(1.596)	(3.969)	(5.173)
Log(Intensity1+1)	-0.0003	0.0001	0.1264***
	(-0.855)	(0.254)	(3.424)
Constant	0.1990***	-0.0482***	48.8951***
	(10.165)	(-2.932)	(20.026)
Controls	YES	YES	YES
Firm FEs	YES	YES	YES
Year FEs	YES	YES	YES
Adjusted R^2	0.6620	0.9285	0.8859
Observations	104,100	104,100	89,537

Cross-Country Heterogeneity: Energy Intensity and Energy Use

Panel A: Heterogeneity based on a country's energy intensity

Variables	ROA (1)	ROA (2)	ROE (4)	ROE (5)
Post*Log(Intensity1+1)*Energy intensity	-0.0006**		-0.0020**	
	(-2.168)		(-2.505)	
Post*Energy intensity	0.0017		0.0051*	
	(1.560)		(1.712)	
Post*Log(Intensity1+1)	0.0008	0.0009	0.0039	0.0053
	(0.617)	(0.652)	(0.990)	(1.207)
Log(Intensity1+1)*Energy intensity	0.0008***		0.0017**	
	(2.720)		(2.279)	
Post	0.0051	-0.0066	0.0100	-0.0302*
	(0.974)	(-1.251)	(0.668)	(-1.782)
Log(Intensity1+1)	-0.0051***	-0.0007	-0.0128***	0.0014
	(-3.406)	(-0.508)	(-3.287)	(0.338)
Energy intensity	-0.0066***		-0.0173***	
	(-4.147)		(-3.794)	
Post*Log(Intensity1+1)*Energy use		-0.0007**		-0.0025***
		(-2.091)		(-2.592)
Post*Energy use		0.0045***		0.0154***
		(3.662)		(4.001)
Log(Intensity1+1)*Energy use		-0.0001		-0.0011
		(-0.368)		(-1.207)
Energy use		-0.0037**		-0.0152***
		(-1.977)		(-2.609)
Constant	0.0875**	0.0660	0.0080	-0.0635
	(2.457)	(1.515)	(0.078)	(-0.492)
Controls	YES	YES	YES	YES
Firm FEs	YES	YES	YES	YES
Year FEs	YES	YES	YES	YES
Adjusted R^2	0.6175	0.5707	0.4915	0.4322
Observations	99,177	48,679	99,177	48,679

- The effect is stronger for countries with larger fossil fuel energy sectors and where consumption of energy per capita is high
- *Energy intensity* is an indication of how much energy is used to produce one unit of economic output
- *Energy use* is a country's energy consumption (in kg of oil equivalent per capita) in a given year

Conclusion and Policy Implications

- Carbon pricing policies have large distributional impacts on the operating performance and value of publicly listed firms around the world
- Relative to green firms, carbon-intensive firms experience
  - Lower profits and market value, and higher cost of capital
  - Such firms also cut investments and lay off employees more
  - Possible under-estimation as private brown firms with less financial slack may respond more strongly to stringent carbon pricing policies
- Why should we care about distributional impacts?
  - A successful transition to a low-carbon economy requires public support
- Targeted fiscal policies could be an effective way to reduce the economic costs of carbon pricing and gain public support
  - E.g., recycling some of the revenues generated from carbon pricing to most affected firms/workers

Appendix 1: Separate Effects of Carbon Tax and ETS

Panel A: Separate Effects of Carbon tax and ETS initiatives

Variables	ROA (1)	ROA (2)	ROE (3)	ROE (4)
Post_tax*Log(Intensity1+1)	-0.0024***	-0.0015***	-0.0050***	-0.0032**
	(-3.929)	(-2.763)	(-2.985)	(-1.988)
Post_ETS*Log(Intensity1+1)	-0.0012**	-0.0018***	-0.0043***	-0.0052***
	(-2.286)	(-3.606)	(-2.801)	(-3.437)
Post_tax	0.0170***	0.0063***	0.0264***	0.0058
	(7.434)	(2.898)	(4.194)	(0.932)
Post_ETS	0.0090***	0.0136***	0.0288***	0.0363***
	(4.413)	(6.871)	(4.834)	(6.044)
Log(Intensity1+1)	-0.0024***	-0.0015***	-0.0062***	-0.0045***
	(-3.869)	(-2.616)	(-3.660)	(-2.733)
Constant	0.0462***	0.0557*	0.1074***	-0.0514
	(22.328)	(1.727)	(18.379)	(-0.555)
Controls	NO	YES	NO	YES
Firm FEs	YES	YES	YES	YES
Year FEs	YES	YES	YES	YES
Adjusted R^2	0.5673	0.6214	0.4596	0.4929
Observations	104,100	104,100	104,100	104,100

- Separate the *Post* into two dummies: *Post_tax* and *Post_ETS*
- Both ETS and carbon tax initiatives significantly reduce the profitability of carbon-intensive firms

Appendix 2: Stacked DiD Regression

- Recent studies argue staggered DiD estimates are biased (Baker, Larcker, and Wang, JFE 2022)
  - The potential biases associated with staggered DiD is less severe if the fraction of never-treated observations is high (40.8% in our sample)
- We further correct the bias using the stacked DiD regression approach

Variable	ROA (1)	ROA (2)	ROE (3)	ROE (4)
Post*Log(Intensity1+1)	-0.0013***	-0.0017***	-0.0042***	-0.0046***
	(-2.739)	(-3.801)	(-2.982)	(-3.473)
Post	0.0130***	0.0127***	0.0330***	0.0309***
	(7.006)	(7.280)	(6.135)	(5.880)
Log(Intensity1+1)	-0.0018***	-0.0012***	-0.0043***	-0.0032***
	(-6.382)	(-4.389)	(-5.621)	(-4.265)
Constant	0.0555***	0.0745***	0.1253***	0.1336***
	(57.156)	(4.391)	(46.561)	(2.663)
Controls	NO	YES	NO	YES
Cohort*Firm FEs	YES	YES	YES	YES
Cohort*Year FEs	YES	YES	YES	YES
Adjusted R^2	0.5834	0.6354	0.4736	0.5049
Observations	410,382	410,382	410,382	410,382

Appendix 3: Excluding US Firms

Panel C: Excluding US firms

Variables	ROA (1)	ROE (2)
Post*Log(Intensity1+1)	-0.0018***	-0.0042***
	(-4.075)	(-3.155)
Post	0.0134***	0.0334***
	(7.525)	(6.374)
Log(Intensity1+1)	-0.0016**	-0.0042**
	(-2.553)	(-2.491)
Constant	0.0915***	-0.0424
	(2.791)	(-0.455)
Controls	YES	YES
Firm FEs	YES	YES
Year FEs	YES	YES
Adjusted R^2	0.6021	0.4645
Observations	82,337	82,337

- Results are similar if we exclude US firms, which account for 20% of the sample

Appendix 4: Excluding Firms with Foreign Assets

Panel D: Excluding firms with foreign assets

Variables	ROA (1)	ROE (2)
Post*Log(Intensity1+1)	-0.0023***	-0.0053**
	(-3.244)	(-2.488)
Post	0.0120***	0.0255***
	(3.875)	(2.687)
Log(Intensity1+1)	-0.0015*	-0.0065***
	(-1.881)	(-2.905)
Constant	-0.0480	-0.1743
	(-0.832)	(-1.065)
Controls	YES	YES
Firm FEs	YES	YES
Year FEs	YES	YES
Adjusted R^2	0.6511	0.5319
Observations	41,388	41,388

Results are similar if we exclude firms with foreign facilities, which is proxied by firms with foreign assets

Appendix 5: Alternative ways of clustering standard errors

Variable	ROA			ROE		
	(1)	(2)	(3)	(4)	(5)	(6)
Post*Log(Intensity1+1)	-0.0024***	-0.0024***	-0.0024***	-0.0061**	-0.0061**	-0.0061***
	(-3.246)	(-3.161)	(-4.536)	(-2.618)	(-2.399)	(-3.281)
Post	0.0145***	0.0145***	0.0145***	0.0360***	0.0360**	0.0360***
	(3.789)	(3.695)	(6.049)	(2.778)	(2.663)	(4.447)
Log(Intensity1+1)	-0.0016**	-0.0016**	-0.0016**	-0.0047**	-0.0047**	-0.0047**
	(-2.441)	(-2.379)	(-2.581)	(-2.577)	(-2.473)	(-2.649)
Constant	0.0557	0.0557	0.0557	-0.1095	-0.1095	-0.1095
	(1.176)	(1.028)	(1.203)	(-0.681)	(-0.540)	(-0.655)
Controls	YES	YES	YES	YES	YES	YES
Firm FEs	YES	YES	YES	YES	YES	YES
Year FE	YES	YES	YES	YES	YES	YES
Clustered standard errors	Jurisdiction	Jurisdiction and Year	Firm and Year	Jurisdiction	Jurisdiction and Year	Firm and Year
Adjusted R^2	0.6213	0.6213	0.6213	0.4928	0.4928	0.4928
Observations	104,100	104,100	104,100	104,100	104,100	104,100

Appendix 6: Results for Scope 2 and 3 Emission Intensity

Panel D: Using scope 2 and 3 carbon intensity

Variables	ROA	ROA	ROE	ROE
	(1)	(2)	(3)	(4)
Post*Log(Intensity2+1)	-0.0019***		-0.0019	
	(-3.045)		(-1.025)	
Post	0.0133***	0.0203***	0.0234***	0.0363***
	(5.910)	(5.245)	(3.455)	(3.095)
Log(Intensity2+1)	0.0001		-0.0009	
	(0.243)		(-0.525)	
Post*Log(Intensity3+1)		-0.0027***		-0.0039*
		(-3.521)		(-1.678)
Log(Intensity3+1)		-0.0016		-0.0087
		(-0.826)		(-1.593)
Constant	0.0503	0.0574*	-0.1239	-0.0867
	(1.633)	(1.792)	(-1.396)	(-0.937)
Controls	YES	YES	YES	YES
Firm FEs	YES	YES	YES	YES
Year FEs	YES	YES	YES	YES
Adjusted R^2	0.6209	0.6209	0.4923	0.4924
Observations	104,100	104,100	104,100	104,100

Appendix 7: Carbon pricing and analyst forecast error

- Are analyst forecasts are rational or systematically biased given available information?
- Test using signed EPS forecast error suggests analysts correctly anticipate the impacts of carbon pricing on firm profits

	Signed Forecast Error		
Variables	1-year ahead EPS	2-year ahead EPS	3-year ahead EPS
	(1)	(2)	(3)
Post*Log(Intensity1+1)	-0.0184	-0.0185	0.0223
	(-1.349)	(-0.667)	(0.449)
Post	0.1765***	0.3265***	0.3941**
	(3.852)	(3.463)	(2.221)
Log(Intensity1+1)	-0.0160	0.0066	-0.0108
	(-1.051)	(0.223)	(-0.194)
Constant	2.0675***	9.1610***	15.9874***
	(2.850)	(6.217)	(5.807)
Controls	YES	YES	YES
Firm FEs	YES	YES	YES
Year FEs	YES	YES	YES
Adjusted R2	0.1459	0.1489	0.1744
Observations	84056	79814	61238

Appendix 8: Carbon pricing and climate patents

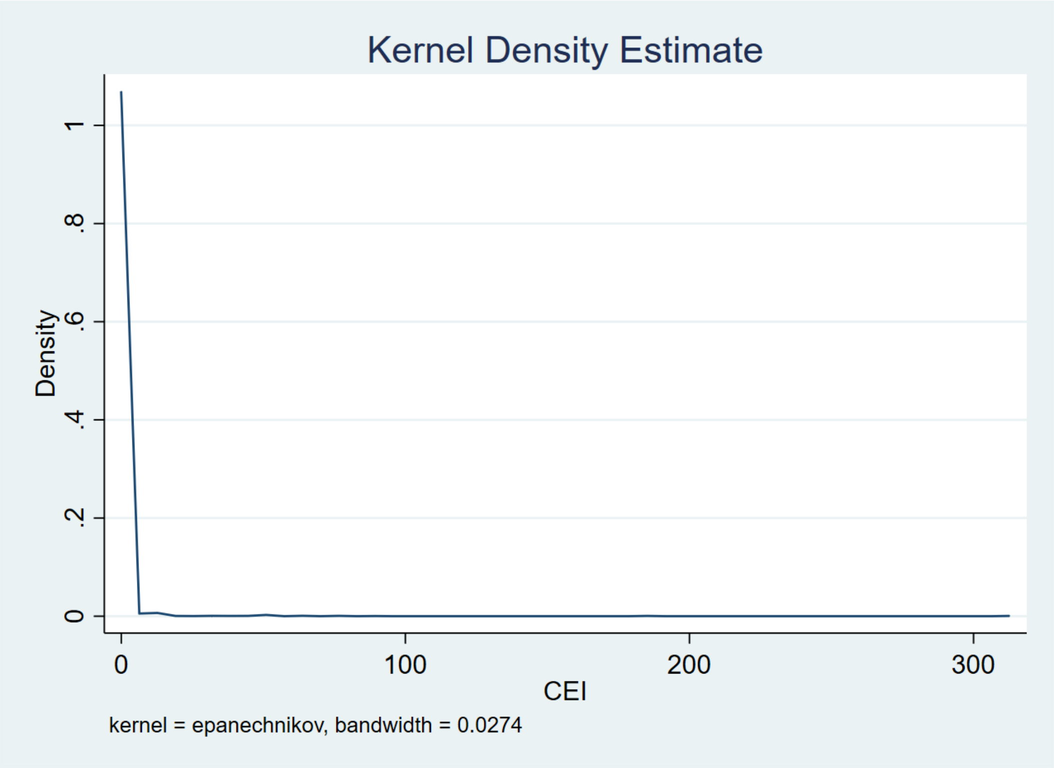
- Use Cooperative Patent Classification codes from PatentsView to identify climate-related patents
- No significant impact of carbon pricing on the number and ratio of climate-related innovation for high-emission firm

Variables	# of Climate patents (Y02 and Y04s)	# of Climate patents (Y02)	Climate Patents Ratio (Y02 and Y04s)	Climate Patents Ratio (Y02)
	(1)	(2)	(3)	(4)
Post*Log(Intensity1+1)	-0.0042	-0.0008	-0.0087	-0.0054
	(-0.211)	(-0.039)	(-0.575)	(-0.342)
Post	-0.1317	-0.1520	-0.1177	-0.1424*
	(-1.290)	(-1.467)	(-1.572)	(-1.774)
Log(Intensity1+1)	0.0057	0.0045	-0.0032	0.0103
	(0.186)	(0.142)	(-0.121)	(0.379)
Controls	YES	YES	YES	YES
Firm FEs	YES	YES	YES	YES
Year FEs	YES	YES	YES	YES
Pseudo R2	0.9426	0.9435	0.2068	0.2125
Observations	90,285	90,285	90,285	90,285

Why taking the natural log of carbon intensity?

- The distribution of carbon intensity measure is highly skewed

Panel A: Kernel Density Estimates of Carbon Intensity



Panel B: Kernel Density Estimates of ln(CEI)