Carbon Tail Risk

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Importance of Climate Change Risks

- Climate change imposes large risks on companies (Litterman 2016).
- Increased regulation needed to meet the Paris Agreement (e.g. carbon taxes, emission trading schemes).
- Climate policy uncertainty has heterogeneous effects across firms in the economy. Climate policies can lead to
  - stranded assets,
  - an increase in the cost of doing business,
  - create financing constraints.
- Financial impact of future climate regulation is difficult to quantify, investors face tail risk and variance risk.

Policy Uncertainty and Asset Prices

- Political uncertainty about regulation affects asset prices (Pastor and Veronesi 2012; Kelly, Pastor, and Veronesi 2016; Koijen, Philipson, and Uhlig 2016).
- In PV (2013) model,
  - Policy changes are driven by political costs of new policies.
  - Investors are uncertain about which policies will be chosen.
  - Investors learn about political costs by observing political signals (i.e. outcomes of various political events).
- Policy uncertainty leads investors to demand compensation after political debates and elections.
- Investors' expectations about future policy changes, rather than policy changes themselves, affect asset prices.

This Paper

- KPV (2016) find that options whose lives span political events tend to be more expensive.
- Such options provide valuable protection against the price, variance, and tail risks associated with political events.
- We test whether climate policy uncertainty is priced in the option market.
- Specifically, we explore whether the cost of option protection against tail and variance risks is larger for firms with more carbon-intense business models.

Main Results

1. Options provide valuable protection/insurance against tail risks and variance risks associated with climate regulation.
2. Results driven by firms in carbon-intense industries.
3. For these firms, the cost of option protection goes up with attention to climate change.
4. The cost of downward protection at highly carbon-intense sectors decreased after the Trump Election.
5. Environmental policy uncertainty is higher for carbon-intense firms as measured from quarterly conference calls (Hassan et al. 2019).

Measures and Data: Carbon Emissions

- Carbon emissions data from annual CDP survey.
- CDP is supported by institutional signatories with $87 trillion in assets under management in 2018.
- Participation in CDP surveys among S&P 500 firms has steadily increased over time.
- 3 types of emissions:
  - Scope 1: direct emissions from combustion of fossil fuels.
  - Scope 2: indirect emissions from the generation of purchased energy.
  - Scope 3: all other indirect emissions occuring in the value chain.

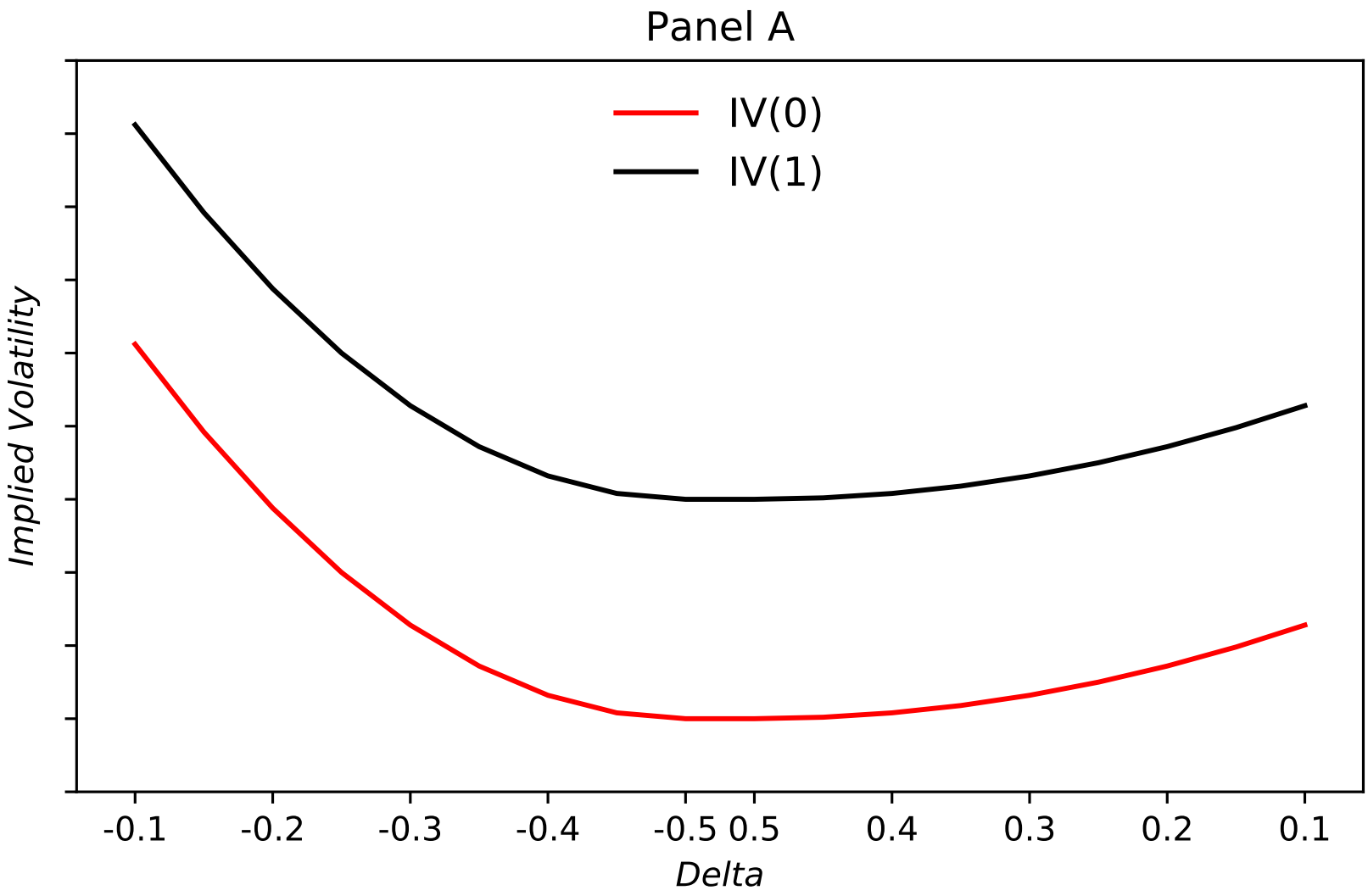
Measures and Data: Carbon Emissions

- We use Scope 1 Intensity $= \log\left(1 + \frac{\text{Scope 1 Emissions Industry}}{\text{Equity Market Values}}\right)$.
  - Industry characteristics explain a firm's carbon intensity, R^2 0.17 to 0.69. (Also see, Bolton and Kacperczyk 2019).
- Reporting to CDP is voluntary, so need to account for potential selection bias.
- CDP data is widely used by institutional investors (Krueger, Sautner, Starks 2019) and ESG data providers (MSCI ESG Research, Bloomberg, Sustainalytics).

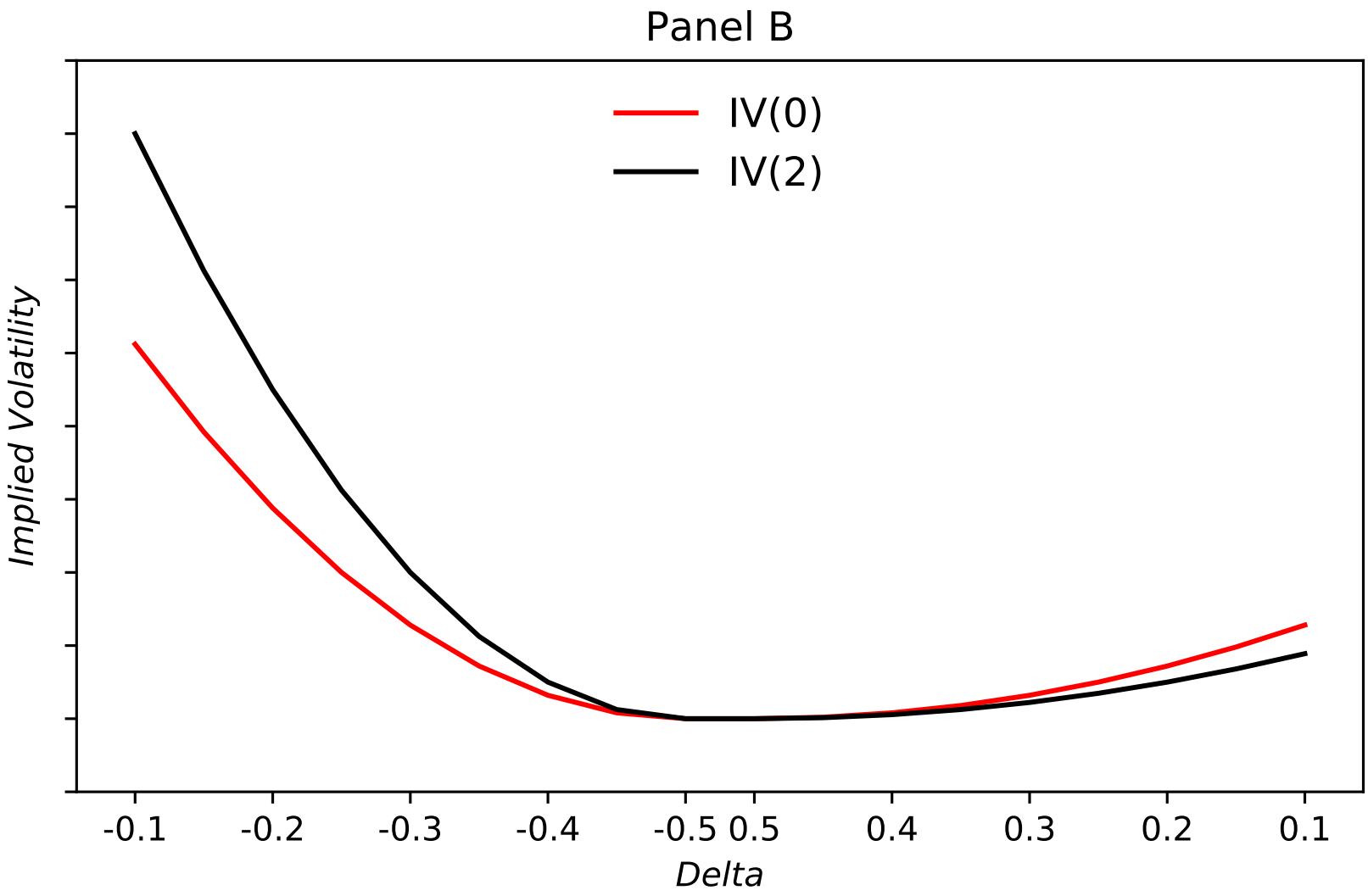
Measures and Data: Option Implied Measures

- Daily options data for stocks and sectors of the S&P 500 from the Surface File of Ivy DB OptionMetrics.
- Select all OTM options for 30-, 91-, 182-, 365-day maturities.
- Options-based measures reflect expectations about all possible future events.
- Main dependent variable: implied volatility slope (*SlopeD*) from KPV (2016).
  - For OTM puts, *SlopeD* equals the β coefficient in IV $= \alpha + \beta$ * Delta.

Measures and Data: *SlopeD* Illustration



Measures and Data: *SlopeD* Illustration



Measures and Data: Option Implied Measures

- Also use model-free implied skewness (*MFIS*) constructed following Bakshi, Kapadia, and Madan (2003).
  - Quantifies the asymmetry of the risk-neutral distribution.
- And variance risk premium (*VRP*) also used by KPV 2016, computed as the difference between the risk-neutral expected variance and the realized variance.
  - Captures insurance against uncertainty in both value directions.
  - But compensation for downside tail risks accounts for a large fraction of the variance risk premium (Bollerslev and Todorov 2011).

Empirical Analysis

- Heckman (1979) two-step model:

$$CDP\ Disclosure_{it} = \gamma_0 + \gamma_1 Industry\ CDP\ Disclosure_{it-1} + \gamma X_{it-1} + \eta_{it}$$
$$OMM_{imt} = \beta_0 + \beta_1 Log(Scope\ 1/MV\ Industry)_{it-1} + \beta X_{it-1} + \epsilon_{it}$$

- Monthly averages for tail risk variables, focus on *SlopeD* computed from 30-day options.
- Emissions become public by the end of October in year $t-1$.
- X includes *Log(Assets)*, *Dividends/Net Income*, *Debt/Assets*, *EBIT/Assets*, *CapEx/Assets*, *Book-to-Market*, *Returns*.

Results - Carbon Intensities and Option-Market Variables

Dependent Variable:	*SlopeD 30*	*SlopeD 30*	*SlopeD 30*	*SlopeD 30*	*MFIS 30*	*VRP 30*
			High carbon-intensity industry			
	(1)	(2)	(3)	(4)	(5)	(6)
Log(Scope 1/MV Industry)	0.008***	0.007***	0.024***		-0.006**	0.002***
	(4.18)	(3.52)	(3.64)		(-2.00)	(3.80)
Log(Scope 1/MV Firm)				0.008***		
				(3.88)		
Model	Heckman	Heckman	Heckman	Heckman	Heckman	Heckman
Year-Quarter Fixed Effects	Yes	Yes	Yes	Yes	Yes	Yes
Year Fixed Effects	Yes	Yes	Yes	Yes	Yes	Yes
Quarter Fixed Effects	Yes	Yes	Yes	Yes	Yes	Yes
Level	Firm	Firm	Firm	Firm	Firm	Firm
Frequency	Monthly	Annual	Monthly	Monthly	Monthly	Monthly
Obs.	18,664	1,771	4,969	18,664	18,664	18,664

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1 std. $\uparrow$ in *Log(Scope 1/MV Industry)* = 0.14 std. $\uparrow$ in *SlopeD 30*

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Frequency	Monthly	Annual	Monthly	Monthly	Monthly	Monthly
Obs.	18,664	1,771	4,969	18,664	18,664	18,664

1 std. $\uparrow$ in *Log(Scope 1/MV Industry)* = 0.14 std. $\uparrow$ in *SlopeD 30*

1 std. $\downarrow$ in *EBIT/Assets* = 0.08 std. $\uparrow$ in *SlopeD 30*

Results - Carbon Intensities and Option-Market Variables

Dependent Variable:	*SlopeD 30*	*SlopeD 30*	*SlopeD 30*	*SlopeD 30*	*MFIS 30*	*VRP 30*
			High carbon-intensity industry			
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Year Fixed Effects	Yes	Yes	Yes	Yes	Yes	Yes
Quarter Fixed Effects	Yes	Yes	Yes	Yes	Yes	Yes
Level	Firm	Firm	Firm	Firm	Firm	Firm
Frequency	Monthly	Annual	Monthly	Monthly	Monthly	Monthly
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Year Fixed Effects	Yes	Yes	Yes	Yes	Yes	Yes
Quarter Fixed Effects	Yes	Yes	Yes	Yes	Yes	Yes
Level	Firm	Firm	Firm	Firm	Firm	Firm
Frequency	Monthly	Annual	Monthly	Monthly	Monthly	Monthly
Obs.	18,664	1,771	4,969	18,664	18,664	18,664

Results - Carbon Intensities and Sector Options

Dependent Variable:	*SlopeD 30*	*SlopeD 30*	*SlopeD 30*	*SlopeD 30*	*MFIS 30*	*VRP 30*
	(1)	(2)	(3)	(4)	(5)	(6)
Log(Scope 1/MV Sector)	0.037***	0.062**	0.039***	0.024*	-0.067*	0.005***
	(2.80)	(2.19)	(2.83)	(1.85)	(-1.92)	(4.09)
Model	OLS	OLS	OLS	OLS	OLS	OLS
Sector Fixed Effects	Yes	Yes	Yes	Yes	Yes	Yes
Sector-Quarter Fixed Effects	No	No	Yes	No	No	No
Year-Quarter Fixed Effects	No	No	No	Yes	No	No
Quarter Fixed Effects	No	No	Yes	Yes	No	No
Year Fixed Effects	No	No	No	Yes	No	No
Level	Sector	Sector	Sector	Sector	Sector	Sector
Frequency	Monthly	Annual	Monthly	Monthly	Monthly	Monthly
Obs.	774	72	774	774	774	774
adj. R-sq.	0.138	0.027	0.132	0.393	0.366	0.043

Results - Alternative Specifications

Dependent Variable:	*SlopeD 30*	*SlopeD 30*	*SlopeD 30*	*SlopeD 30*	*SlopeD 30*	*SlopeD 30*	*SlopeD 30*	*SlopeD 30*
	Firm FE	Emissions Without Log	Emissions at SIC 2 Level	Yearly average of SlopeD	Add Oil Beta	Exclude Oil, Gas, Coal (SIC 29; 13)	Scope 2	Scope 1+2
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Log(Scope 1/MV Industry)	0.016**		0.007***	0.007***	0.007***	0.007***		
	(2.34)		(3.84)	(4.07)	(4.12)	(3.99)		
Scope 1/MV Industry (x1,000)		0.024***						
		(3.80)						
Log(Scope 2/MV Industry)							0.002	
							(0.85)	
Log(Scope 12/MV Industry)								0.009***
								(3.67)
Model	Heckman	Heckman	Heckman	Heckman	Heckman	Heckman	Heckman	Heckman
Year-Quarter Fixed Effects	Yes	Yes	Yes	No	Yes	Yes	Yes	Yes
Year Fixed Effects	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Quarter Fixed Effects	Yes	Yes	Yes	No	Yes	Yes	Yes	Yes
Firm Fixed Effects	Yes	No	No	No	No	No	No	No
Level	Firm	Firm	Firm	Firm	Firm	Firm	Firm	Firm
Frequency	Monthly	Monthly	Monthly	Annual	Monthly	Monthly	Monthly	Monthly
Obs.	18,664	18,664	18,664	1,771	18,664	17,744	18,190	18,190

Results - Term Structure

Dependent Variable:	*SlopeD 91*	*SlopeD 182*	*SlopeD 365*
	(1)	(2)	(3)
Log(Scope 1/MV Industry)	0.003***	0.001**	0.001**
	(3.40)	(2.19)	(2.34)
Model	Heckman	Heckman	Heckman
Year-Quarter Fixed Effects	Yes	Yes	Yes
Year Fixed Effects	Yes	Yes	Yes
Quarter Fixed Effects	Yes	Yes	Yes
Level	Firm	Firm	Firm
Frequency	Monthly	Monthly	Monthly
Obs.	18,663	18,663	18,663

Investor Attention to Climate Change

- The cost of protection against the risks associated with climate policy should be magnified when public attention to climate change spikes.
- Investor attention can be triggered by public events such as the Paris Climate Summit or natural disasters.
- Google Search Volume Index as in Da, Engelberg, and Gao (2011).
- Use the search term "Climate Change" in the U.S.

Results - Investor Attention to Climate Change

Dependent Variable:	*SlopeD 30*	*SlopeD 30*	*SlopeD 30*	*SlopeD 30*
	High-emission industries	Low-emission industries	High-emission industries	Low-emission industries
	(1)	(2)	(3)	(4)
Log(Scope 1/MV Industry) x SVI Climate Change High	0.014**	-0.001		
	(2.11)	(-0.22)		
Log(Scope 1/MV Industry) x SVI Climate Change			0.040*	-0.000
			(1.85)	(-0.01)
Log(Scope 1/MV Industry)	0.020***	-0.004*	0.009	-0.004
	(3.18)	(-1.65)	(0.89)	(-0.98)
SVI Climate Change High	-0.090**	-0.001		
	(-2.11)	(-0.14)		
SVI Climate Change			-0.245*	0.023
			(-1.84)	(1.27)
Model	Heckman	Heckman	Heckman	Heckman
Year-Quarter Fixed Effects	Yes	Yes	Yes	Yes
Year Fixed Effects	Yes	Yes	Yes	Yes
Quarter Fixed Effects	Yes	Yes	Yes	Yes
Level	Firm	Firm	Firm	Firms
Frequency	Monthly	Monthly	Monthly	Monthly
Obs.	4,969	13,695	4,969	13,695

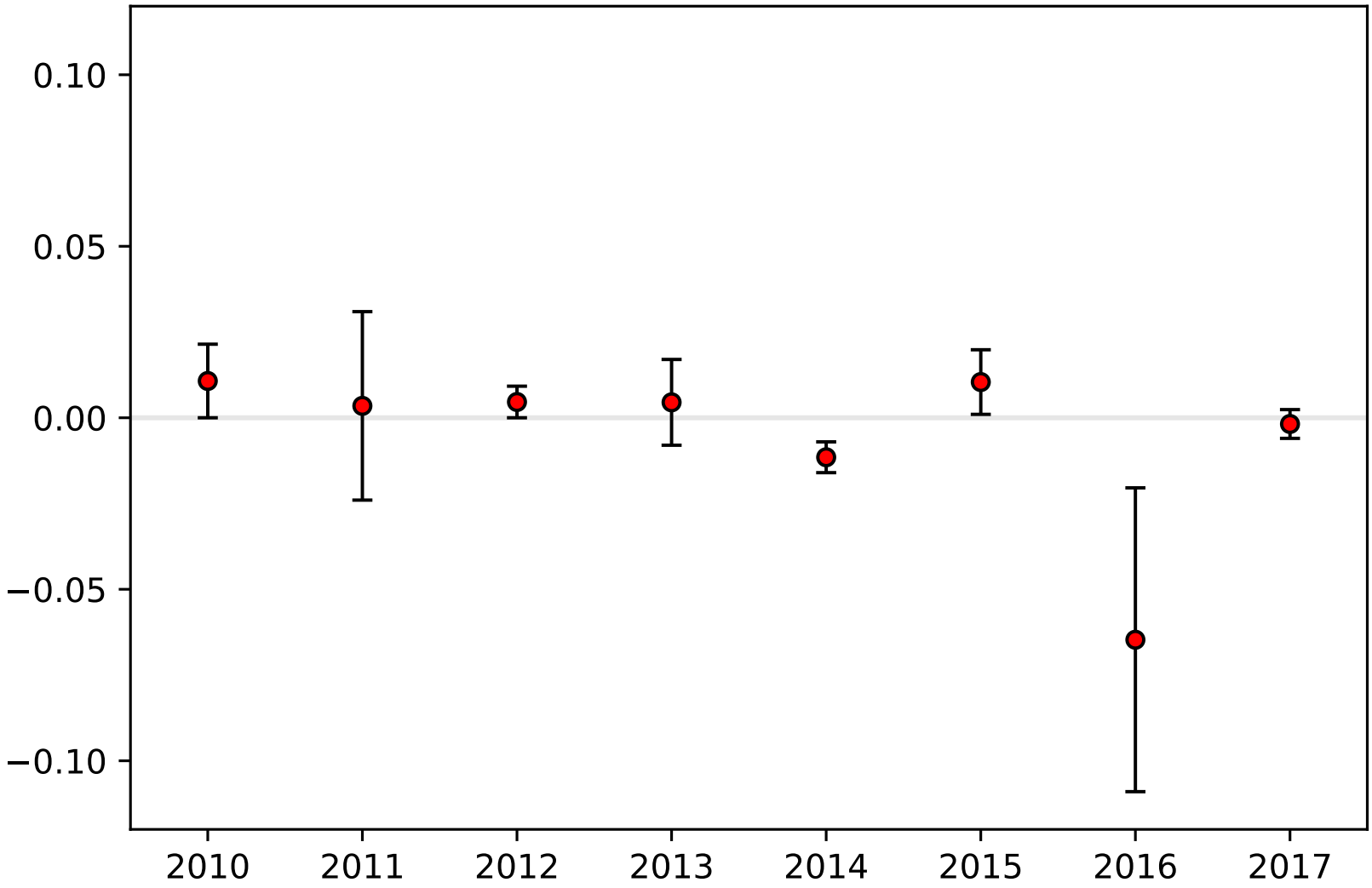
Climate Policy Uncertainty and the Trump Election

- During his 2016 campaign, Trump dubbed climate change "a hoax" and tweeted that
  - "the concept of global warming was created by and for the Chinese in order to make U.S. manufacturing non-competitive."
- Use Trump's election as a shock that reduced climate policy uncertainty in the short term.
- The Trump Election was largely unexpected ex-ante. Betting site Betfair has put the probability of a Trump victory at 17% on Election Day morning.
- Diff-in-diff around the Trump Election using sector options, as they are highly liquid even on a daily basis.

Results - The Trump Election

Dependent Variable:	*SlopeD 30*	*SlopeD 30*	*SlopeD 30*	*SlopeD 30*
Event Window:	[-100; +100]	[-100; -50] U [+50; +100]	[-50; +50]	[-10; +10]
	(1)	(2)	(3)	(4)
Post Trump Election x High Scope 1/MV Sector	-0.025**	-0.033**	-0.016*	-0.041
	(-3.26)	(-2.46)	(-2.11)	(-1.73)
High Scope 1/MV Sector	-0.070*	-0.057*	-0.083*	-0.049***
	(-2.10)	(-2.16)	(-2.05)	(-6.07)
Post Trump Election	0.002	0.003	0.002	0.041
	(0.30)	(0.29)	(0.34)	(1.66)
Model	DiD	DiD	DiD	DiD
Level	Sector	Sector	Sector	Sector
Frequency	Daily	Daily	Daily	Daily
Obs.	1,790	882	890	171
adj. R-sq.	0.053	0.062	0.048	0.100

The Trump Election Placebo Tests



Carbon Intensities and Analyst Conference Calls

- Another way to measure what concerns investors is through conference calls.
- More questions over environmental issues should be raised at calls of carbon-intense firms.
- Environmental policy uncertainty (Hassan et al. 2019) as reflected in conferences calls and general uncertainty about firm earnings.
  - Define a political library $\mathbb{P}$ (associated with the environment) and a non-political library $\mathbb{N}$ containing bigrams.
  - Decompose each conference call transcript into bigrams.
  - Count number of bigrams b such that $b \in \mathbb{P} \setminus \mathbb{N}$ around the synonyms of words *risk* and *uncertainty*.

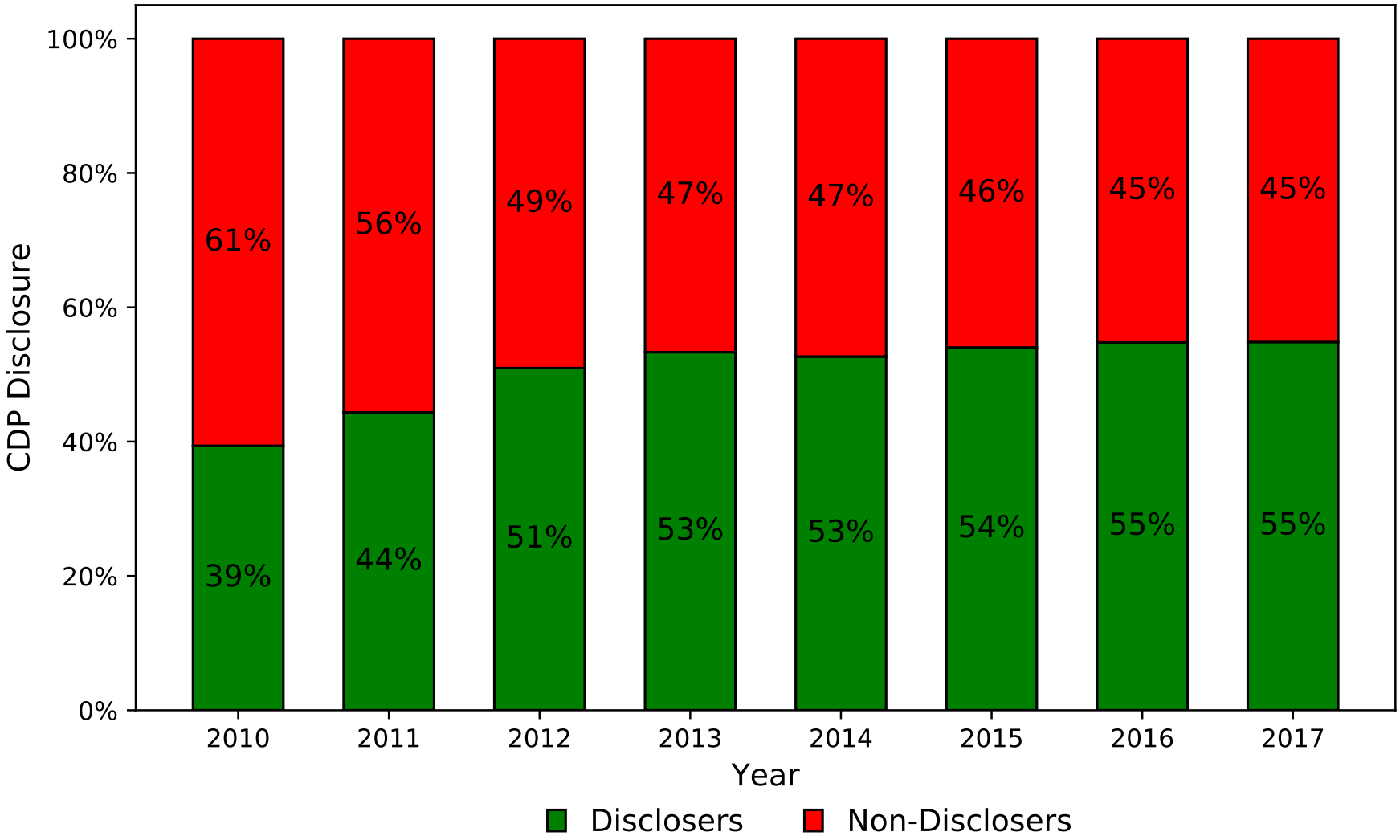
Carbon Intensities and Analyst Conference Calls

Dependent Variable:	*EnvPolU*		
			With non-disclosers
	(1)	(2)	(3)
Log(Scope 1/MV Industry)	4.171***	5.182***	
	(4.28)	(3.59)	
Log(Scope 1/MV Industry All)			4.348***
			(3.70)
Model	Heckman	OLS	OLS
Year Fixed Effects	Yes	Yes	Yes
Level	Firm	Firm	Firm
Frequency	Annual	Annual	Annual
Obs.	1,208	1,208	1,780
adj. R-sq.		0.073	0.074

Conclusion

- The cost of option protection against tail and variance risks is larger for firms in carbon-intense industries.
- This cost is amplified at times when investor attention to climate change spikes and decreased after the Trump Election.
- Carbon-intensive firms also face more questions about risks and uncertainties associated with environmental policies.
- Carbon emissions financially matter and investors expect something potentially disastrous to happen to firms with high CO_2 output.

CDP Disclosure



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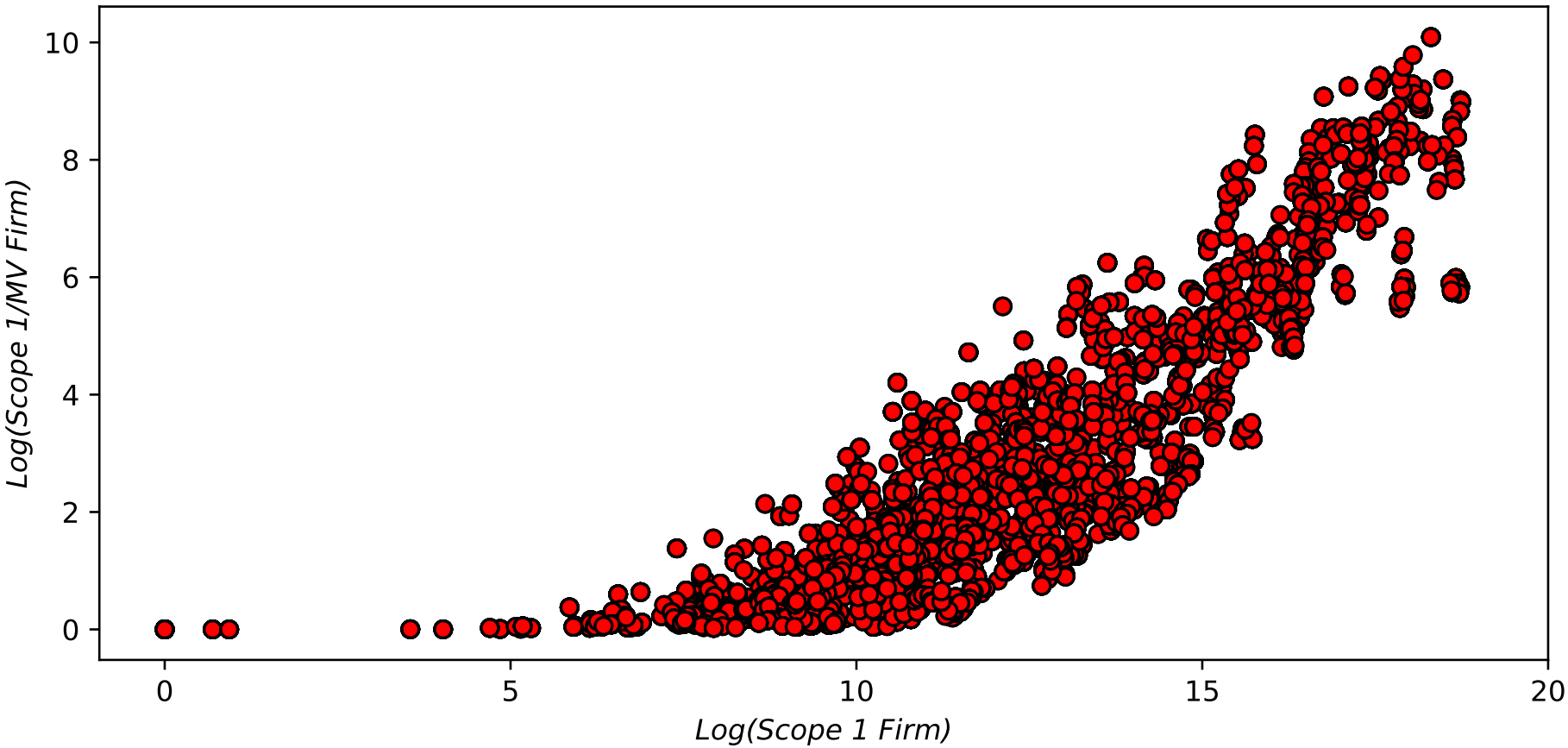
Carbon Emissions and Carbon Intensities



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