Carbon Tail Risk

Emirhan Ilhan\textsuperscript{1}  Zacharias Sautner\textsuperscript{1}  Grigory Vilkov\textsuperscript{1}

\textsuperscript{1}Frankfurt School of Finance & Management

New Challenges in Insurance Conference
September 5, 2019
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


- 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.
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 occurring 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 $\beta$ coefficient in $IV = \alpha + \beta \times \Delta$. 
Measures and Data: *SlopeD* Illustration

Panel A

- **IV(0)**
- **IV(1)**

<table>
<thead>
<tr>
<th>Delta</th>
<th>Implied Volatility</th>
</tr>
</thead>
<tbody>
<tr>
<td>-0.1</td>
<td></td>
</tr>
<tr>
<td>-0.2</td>
<td></td>
</tr>
<tr>
<td>-0.3</td>
<td></td>
</tr>
<tr>
<td>-0.4</td>
<td></td>
</tr>
<tr>
<td>-0.5</td>
<td></td>
</tr>
<tr>
<td>0.0</td>
<td></td>
</tr>
<tr>
<td>0.1</td>
<td></td>
</tr>
<tr>
<td>0.2</td>
<td></td>
</tr>
<tr>
<td>0.3</td>
<td></td>
</tr>
<tr>
<td>0.4</td>
<td></td>
</tr>
<tr>
<td>0.5</td>
<td></td>
</tr>
</tbody>
</table>

Ilhan, Sautner, Vilkov

Carbon Tail Risk
Measures and Data: *SlopeD* Illustration

Panel B

- **IV(0)**
- **IV(2)**

Ilhan, Sautner, Vilkov

Carbon Tail Risk

September 5, 2019
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:

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

- Monthly averages for tail risk variables, focus on \textit{SlopeD} computed from 30-day options.

- Emissions become public by the end of October in year \( t - 1 \).

- \( X \) includes \( \log(\text{Assets}), \text{Dividends/Net Income}, \text{Debt/Assets}, \text{EBIT/Assets}, \text{CapEx/Assets}, \text{Book-to-Market}, \text{Returns} \).
## Results - Carbon Intensities and Option-Market Variables

<table>
<thead>
<tr>
<th>Dependent Variable:</th>
<th>SlopeD 30</th>
<th>SlopeD 30</th>
<th>SlopeD 30</th>
<th>SlopeD 30</th>
<th>MFIS 30</th>
<th>VRP 30</th>
</tr>
</thead>
<tbody>
<tr>
<td>High carbon-intensity industry</td>
<td>(1)</td>
<td>(2)</td>
<td>(3)</td>
<td>(4)</td>
<td>(5)</td>
<td>(6)</td>
</tr>
<tr>
<td><strong>$\log(\text{Scope 1/MV Industry})$</strong></td>
<td>0.008***</td>
<td>0.007***</td>
<td>0.024***</td>
<td>-0.006**</td>
<td>0.002***</td>
<td></td>
</tr>
<tr>
<td></td>
<td>(4.18)</td>
<td>(3.52)</td>
<td>(3.64)</td>
<td>(-2.00)</td>
<td>(3.80)</td>
<td></td>
</tr>
<tr>
<td><strong>$\log(\text{Scope 1/MV Firm})$</strong></td>
<td></td>
<td></td>
<td></td>
<td>0.008***</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>(3.88)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Model</td>
<td>Heckman</td>
<td>Heckman</td>
<td>Heckman</td>
<td>Heckman</td>
<td>Heckman</td>
<td>Heckman</td>
</tr>
<tr>
<td>Year-Quarter Fixed Effects</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>Year Fixed Effects</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>Quarter Fixed Effects</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>Level</td>
<td>Firm</td>
<td>Firm</td>
<td>Firm</td>
<td>Firm</td>
<td>Firm</td>
<td>Firm</td>
</tr>
<tr>
<td>Frequency</td>
<td>Monthly</td>
<td>Annual</td>
<td>Monthly</td>
<td>Monthly</td>
<td>Monthly</td>
<td>Monthly</td>
</tr>
<tr>
<td>Obs.</td>
<td>18,664</td>
<td>1,771</td>
<td>4,969</td>
<td>18,664</td>
<td>18,664</td>
<td>18,664</td>
</tr>
</tbody>
</table>
Results - Carbon Intensities and Option-Market Variables

<table>
<thead>
<tr>
<th>Dependent Variable:</th>
<th>SlopeD 30</th>
<th>SlopeD 30</th>
<th>SlopeD 30</th>
<th>SlopeD 30</th>
<th>MFIS 30</th>
<th>VRP 30</th>
</tr>
</thead>
<tbody>
<tr>
<td>High carbon-intensity industry</td>
<td>(1)</td>
<td>(2)</td>
<td>(3)</td>
<td>(4)</td>
<td>(5)</td>
<td>(6)</td>
</tr>
<tr>
<td>( \log(\text{Scope 1/MV Industry}) )</td>
<td>0.008***</td>
<td>0.007***</td>
<td>0.024***</td>
<td>-0.006**</td>
<td>0.002***</td>
<td></td>
</tr>
<tr>
<td>( \log(\text{Scope 1/MV Firm}) )</td>
<td>0.008***</td>
<td>(3.88)</td>
<td>0.008***</td>
<td>(3.80)</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Model</th>
<th>Heckman</th>
<th>Heckman</th>
<th>Heckman</th>
<th>Heckman</th>
<th>Heckman</th>
<th>Heckman</th>
</tr>
</thead>
<tbody>
<tr>
<td>Year-Quarter Fixed Effects</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>Year Fixed Effects</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>Quarter Fixed Effects</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>Level</td>
<td>Firm</td>
<td>Firm</td>
<td>Firm</td>
<td>Firm</td>
<td>Firm</td>
<td>Firm</td>
</tr>
<tr>
<td>Frequency</td>
<td>Monthly</td>
<td>Annual</td>
<td>Monthly</td>
<td>Monthly</td>
<td>Monthly</td>
<td>Monthly</td>
</tr>
<tr>
<td>Obs.</td>
<td>18,664</td>
<td>1,771</td>
<td>4,969</td>
<td>18,664</td>
<td>18,664</td>
<td>18,664</td>
</tr>
</tbody>
</table>
## Results - Carbon Intensities and Option-Market Variables

<table>
<thead>
<tr>
<th>Dependent Variable:</th>
<th>SlopeD 30</th>
<th>SlopeD 30</th>
<th>SlopeD 30</th>
<th>SlopeD 30</th>
<th>MFIS 30</th>
<th>VRP 30</th>
</tr>
</thead>
<tbody>
<tr>
<td>High carbon-intensity industry</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th></th>
<th>(1)</th>
<th>(2)</th>
<th>(3)</th>
<th>(4)</th>
<th>(5)</th>
<th>(6)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Log(Scope 1/MV Industry)</strong></td>
<td></td>
<td>1 std. ↑ in <strong>Log(Scope 1/MV Industry)</strong> = 0.14 std. ↑ in <strong>SlopeD 30</strong></td>
<td></td>
<td>-0.006** (-2.00)</td>
<td>0.002*** (3.80)</td>
<td></td>
</tr>
<tr>
<td><strong>Log(Scope 1/MV Firm)</strong></td>
<td></td>
<td>0.008*** (3.88)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Model</th>
<th>Heckman</th>
<th>Heckman</th>
<th>Heckman</th>
<th>Heckman</th>
<th>Heckman</th>
<th>Heckman</th>
</tr>
</thead>
<tbody>
<tr>
<td>Year-Quarter Fixed Effects</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>Year Fixed Effects</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>Quarter Fixed Effects</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Level</th>
<th>Firm</th>
<th>Firm</th>
<th>Firm</th>
<th>Firm</th>
<th>Firm</th>
<th>Firm</th>
</tr>
</thead>
<tbody>
<tr>
<td>Frequency</td>
<td>Monthly</td>
<td>Annual</td>
<td>Monthly</td>
<td>Monthly</td>
<td>Monthly</td>
<td>Monthly</td>
</tr>
<tr>
<td>Obs.</td>
<td>18,664</td>
<td>1,771</td>
<td>4,969</td>
<td>18,664</td>
<td>18,664</td>
<td>18,664</td>
</tr>
</tbody>
</table>
### Results - Carbon Intensities and Option-Market Variables

<table>
<thead>
<tr>
<th>Dependent Variable:</th>
<th>SlopeD 30</th>
<th>SlopeD 30</th>
<th>SlopeD 30</th>
<th>SlopeD 30</th>
<th>MFIS 30</th>
<th>VRP 30</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>High carbon-intensity industry</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>(1)</td>
<td>(2)</td>
<td>(3)</td>
<td>(4)</td>
<td>(5)</td>
<td>(6)</td>
</tr>
<tr>
<td>Log(Scope 1/MV Industry)</td>
<td></td>
<td>1 std. ↑ in Log(Scope 1/MV Industry) = 0.14 std. ↑ in SlopeD 30</td>
<td>0.008***</td>
<td>-0.006**</td>
<td>0.002***</td>
<td>(-2.00)</td>
</tr>
<tr>
<td>Log(Scope 1/MV Firm)</td>
<td>0.008***</td>
<td>-0.008***</td>
<td>(3.88)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Model</td>
<td>Year-Quarter Fixed Effects</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td></td>
<td>Year Fixed Effects</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td></td>
<td>Quarter Fixed Effects</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>Level</td>
<td>Firm</td>
<td>Firm</td>
<td>Firm</td>
<td>Firm</td>
<td>Firm</td>
<td>Firm</td>
</tr>
<tr>
<td>Frequency</td>
<td>Monthly</td>
<td>Annual</td>
<td>Monthly</td>
<td>Monthly</td>
<td>Monthly</td>
<td>Monthly</td>
</tr>
<tr>
<td>Obs.</td>
<td>18,664</td>
<td>1,771</td>
<td>4,969</td>
<td>18,664</td>
<td>18,664</td>
<td>18,664</td>
</tr>
</tbody>
</table>
## Results - Carbon Intensities and Option-Market Variables

<table>
<thead>
<tr>
<th>Dependent Variable:</th>
<th>SlopeD 30</th>
<th>SlopeD 30</th>
<th>SlopeD 30</th>
<th>SlopeD 30</th>
<th>MFIS 30</th>
<th>VRP 30</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>High carbon-intensity industry</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>(1)</td>
<td>(2)</td>
<td>(3)</td>
<td>(4)</td>
<td>(5)</td>
<td>(6)</td>
<td></td>
</tr>
<tr>
<td>Log(Scope 1/MV Industry)</td>
<td>0.008***</td>
<td>0.007***</td>
<td>0.024***</td>
<td>-0.006**</td>
<td>0.002***</td>
<td></td>
</tr>
<tr>
<td></td>
<td>(4.18)</td>
<td>(3.52)</td>
<td>(3.64)</td>
<td>(-2.00)</td>
<td>(3.80)</td>
<td></td>
</tr>
<tr>
<td>Log(Scope 1/MV Firm)</td>
<td>0.008***</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>(3.88)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Model</th>
<th>Heckman</th>
<th>Heckman</th>
<th>Heckman</th>
<th>Heckman</th>
<th>Heckman</th>
<th>Heckman</th>
</tr>
</thead>
<tbody>
<tr>
<td>Year-Quarter Fixed Effects</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>Year Fixed Effects</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>Quarter Fixed Effects</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>Level</td>
<td>Firm</td>
<td>Firm</td>
<td>Firm</td>
<td>Firm</td>
<td>Firm</td>
<td>Firm</td>
</tr>
<tr>
<td>Frequency</td>
<td>Monthly</td>
<td>Annual</td>
<td>Monthly</td>
<td>Monthly</td>
<td>Monthly</td>
<td>Monthly</td>
</tr>
<tr>
<td>Obs.</td>
<td>18,664</td>
<td>1,771</td>
<td>4,969</td>
<td>18,664</td>
<td>18,664</td>
<td>18,664</td>
</tr>
</tbody>
</table>
## Results - Carbon Intensities and Option-Market Variables

<table>
<thead>
<tr>
<th>Dependent Variable:</th>
<th>SlopeD 30</th>
<th>SlopeD 30</th>
<th>SlopeD 30</th>
<th>SlopeD 30</th>
<th>MFIS 30</th>
<th>VRP 30</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>High carbon-intensity industry</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>(1)</td>
<td>(2)</td>
<td>(3)</td>
<td>(4)</td>
<td>(5)</td>
<td>(6)</td>
<td></td>
</tr>
<tr>
<td>Log(Scope 1/MV Industry)</td>
<td>0.008*** (4.18)</td>
<td>0.007*** (3.52)</td>
<td>0.024*** (3.64)</td>
<td>-0.006** (-2.00)</td>
<td>0.002*** (3.80)</td>
<td></td>
</tr>
<tr>
<td>Log(Scope 1/MV Firm)</td>
<td>0.008*** (3.88)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Model</th>
<th>Heckman</th>
<th>Heckman</th>
<th>Heckman</th>
<th>Heckman</th>
<th>Heckman</th>
<th>Heckman</th>
</tr>
</thead>
<tbody>
<tr>
<td>Year-Quarter Fixed Effects</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>Year Fixed Effects</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>Quarter Fixed Effects</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Level</th>
<th>Firm</th>
<th>Firm</th>
<th>Firm</th>
<th>Firm</th>
<th>Firm</th>
<th>Firm</th>
</tr>
</thead>
<tbody>
<tr>
<td>Frequency</td>
<td>Monthly</td>
<td>Annual</td>
<td>Monthly</td>
<td>Monthly</td>
<td>Monthly</td>
<td>Monthly</td>
</tr>
<tr>
<td>Obs.</td>
<td>18,664</td>
<td>1,771</td>
<td>4,969</td>
<td>18,664</td>
<td>18,664</td>
<td>18,664</td>
</tr>
</tbody>
</table>
## Results - Carbon Intensities and Sector Options

<table>
<thead>
<tr>
<th>Dependent Variable:</th>
<th>$SlopeD_{30}$</th>
<th>$SlopeD_{30}$</th>
<th>$SlopeD_{30}$</th>
<th>$SlopeD_{30}$</th>
<th>$MFIS_{30}$</th>
<th>$VRP_{30}$</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>(1)</td>
<td>(2)</td>
<td>(3)</td>
<td>(4)</td>
<td>(5)</td>
<td>(6)</td>
</tr>
<tr>
<td>$\log(Scope1/MV\ Sector)$</td>
<td>0.037***</td>
<td>0.062**</td>
<td>0.039***</td>
<td>0.024*</td>
<td>-0.067*</td>
<td>0.005***</td>
</tr>
<tr>
<td></td>
<td>(2.80)</td>
<td>(2.19)</td>
<td>(2.83)</td>
<td>(1.85)</td>
<td>(-1.92)</td>
<td>(4.09)</td>
</tr>
<tr>
<td>Model</td>
<td>OLS</td>
<td>OLS</td>
<td>OLS</td>
<td>OLS</td>
<td>OLS</td>
<td>OLS</td>
</tr>
<tr>
<td>Sector Fixed Effects</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>Sector-Quarter Fixed Effects</td>
<td>No</td>
<td>No</td>
<td>Yes</td>
<td>No</td>
<td>No</td>
<td>No</td>
</tr>
<tr>
<td>Year-Quarter Fixed Effects</td>
<td>No</td>
<td>No</td>
<td>No</td>
<td>Yes</td>
<td>No</td>
<td>No</td>
</tr>
<tr>
<td>Quarter Fixed Effects</td>
<td>No</td>
<td>No</td>
<td>Yes</td>
<td>Yes</td>
<td>No</td>
<td>No</td>
</tr>
<tr>
<td>Year Fixed Effects</td>
<td>No</td>
<td>No</td>
<td>No</td>
<td>Yes</td>
<td>No</td>
<td>No</td>
</tr>
<tr>
<td>Level</td>
<td>Sector</td>
<td>Sector</td>
<td>Sector</td>
<td>Sector</td>
<td>Sector</td>
<td>Sector</td>
</tr>
<tr>
<td>Frequency</td>
<td>Monthly</td>
<td>Annual</td>
<td>Monthly</td>
<td>Monthly</td>
<td>Monthly</td>
<td>Monthly</td>
</tr>
<tr>
<td>Obs.</td>
<td>774</td>
<td>72</td>
<td>774</td>
<td>774</td>
<td>774</td>
<td>774</td>
</tr>
<tr>
<td>adj. R-sq.</td>
<td>0.138</td>
<td>0.027</td>
<td>0.132</td>
<td>0.393</td>
<td>0.366</td>
<td>0.043</td>
</tr>
</tbody>
</table>
## Results - Alternative Specifications

<table>
<thead>
<tr>
<th>Dependent Variable:</th>
<th>SlopeD 30</th>
<th>SlopeD 30</th>
<th>SlopeD 30</th>
<th>SlopeD 30</th>
<th>SlopeD 30</th>
<th>SlopeD 30</th>
<th>SlopeD 30</th>
<th>SlopeD 30</th>
</tr>
</thead>
<tbody>
<tr>
<td>Firm FE</td>
<td>Emissions Without Log</td>
<td>Emissions at SIC 2 Level</td>
<td>Yearly average of SlopeD</td>
<td>Add Oil Beta</td>
<td>Exclude Oil, Gas, Coal (SIC 29; 13)</td>
<td>Scope 2</td>
<td>Scope 1+2</td>
<td></td>
</tr>
<tr>
<td>(1)</td>
<td>(2)</td>
<td>(3)</td>
<td>(4)</td>
<td>(5)</td>
<td>(6)</td>
<td>(7)</td>
<td>(8)</td>
<td></td>
</tr>
<tr>
<td>Log(Scope 1/MV Industry)</td>
<td>0.016** (2.34)</td>
<td>0.007*** (3.84)</td>
<td>0.007*** (4.07)</td>
<td>0.007*** (4.12)</td>
<td>0.007*** (3.99)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Scope 1/MV Industry (x1,000)</td>
<td>0.024*** (3.80)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Log(Scope 2/MV Industry)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>0.002 (0.85)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Log(Scope 12/MV Industry)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>0.009*** (3.67)</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Model</th>
<th>Heckman</th>
<th>Heckman</th>
<th>Heckman</th>
<th>Heckman</th>
<th>Heckman</th>
<th>Heckman</th>
<th>Heckman</th>
<th>Heckman</th>
</tr>
</thead>
<tbody>
<tr>
<td>Year-Quarter Fixed Effects</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>No</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>Year Fixed Effects</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>Quarter Fixed Effects</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>No</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>Firm Fixed Effects</td>
<td>Yes</td>
<td>No</td>
<td>No</td>
<td>No</td>
<td>No</td>
<td>No</td>
<td>No</td>
<td>No</td>
</tr>
<tr>
<td>Level</td>
<td>Firm</td>
<td>Firm</td>
<td>Firm</td>
<td>Firm</td>
<td>Firm</td>
<td>Firm</td>
<td>Firm</td>
<td>Firm</td>
</tr>
<tr>
<td>Obs.</td>
<td>18,664</td>
<td>18,664</td>
<td>18,664</td>
<td>1,771</td>
<td>18,664</td>
<td>17,744</td>
<td>18,190</td>
<td>18,190</td>
</tr>
</tbody>
</table>
## Results - Term Structure

<table>
<thead>
<tr>
<th>Dependent Variable:</th>
<th>$\text{SlopeD 91}$</th>
<th>$\text{SlopeD 182}$</th>
<th>$\text{SlopeD 365}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\log(\text{Scope 1/MV Industry})$</td>
<td>0.003*** (3.40)</td>
<td>0.001** (2.19)</td>
<td>0.001** (2.34)</td>
</tr>
<tr>
<td>Model</td>
<td>Heckman</td>
<td>Heckman</td>
<td>Heckman</td>
</tr>
<tr>
<td>Year-Quarter Fixed Effects</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>Year Fixed Effects</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>Quarter Fixed Effects</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>Level</td>
<td>Firm</td>
<td>Firm</td>
<td>Firm</td>
</tr>
<tr>
<td>Frequency</td>
<td>Monthly</td>
<td>Monthly</td>
<td>Monthly</td>
</tr>
<tr>
<td>Obs.</td>
<td>18,663</td>
<td>18,663</td>
<td>18,663</td>
</tr>
</tbody>
</table>
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

<table>
<thead>
<tr>
<th>Dependent Variable:</th>
<th>SlopeD 30</th>
<th>SlopeD 30</th>
<th>SlopeD 30</th>
<th>SlopeD 30</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>High-emission industries</td>
<td>Low-emission industries</td>
<td>High-emission industries</td>
<td>Low-emission industries</td>
</tr>
<tr>
<td></td>
<td>(1)</td>
<td>(2)</td>
<td>(3)</td>
<td>(4)</td>
</tr>
</tbody>
</table>

### Log(Scope 1/MV Industry) x SVI Climate Change High

<table>
<thead>
<tr>
<th></th>
<th>(1)</th>
<th>(2)</th>
<th>(3)</th>
<th>(4)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Log(Scope 1/MV Industry) x SVI Climate Change High</td>
<td>0.014**</td>
<td>-0.001</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>(2.11)</td>
<td>(-0.22)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Log(Scope 1/MV Industry) x SVI Climate Change</td>
<td></td>
<td></td>
<td>0.040*</td>
<td>-0.000</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>(1.85)</td>
<td>(-0.01)</td>
</tr>
<tr>
<td>Log(Scope 1/MV Industry)</td>
<td>0.020***</td>
<td>-0.004*</td>
<td>0.009</td>
<td>-0.004</td>
</tr>
<tr>
<td></td>
<td>(3.18)</td>
<td>(-1.65)</td>
<td>(0.89)</td>
<td>(-0.98)</td>
</tr>
<tr>
<td>SVI Climate Change High</td>
<td>-0.090**</td>
<td>-0.001</td>
<td>-0.245*</td>
<td>0.023</td>
</tr>
<tr>
<td></td>
<td>(-2.11)</td>
<td>(-0.14)</td>
<td>(-1.84)</td>
<td>(1.27)</td>
</tr>
</tbody>
</table>

### Model

<table>
<thead>
<tr>
<th>Model</th>
<th>Heckman</th>
<th>Heckman</th>
<th>Heckman</th>
<th>Heckman</th>
</tr>
</thead>
<tbody>
<tr>
<td>Year-Quarter Fixed Effects</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>Year Fixed Effects</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>Quarter Fixed Effects</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>Level</td>
<td>Firm</td>
<td>Firm</td>
<td>Firm</td>
<td>Firms</td>
</tr>
<tr>
<td>Frequency</td>
<td>Monthly</td>
<td>Monthly</td>
<td>Monthly</td>
<td>Monthly</td>
</tr>
<tr>
<td>Obs.</td>
<td>4,969</td>
<td>13,695</td>
<td>4,969</td>
<td>13,695</td>
</tr>
</tbody>
</table>
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

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

<table>
<thead>
<tr>
<th>Dependent Variable:</th>
<th>EnvPolU</th>
<th>With non-disclosers</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>(1)</td>
<td>(2)</td>
</tr>
<tr>
<td>$\log(Scope\ 1/MV\ Industry)$</td>
<td>4.171***</td>
<td>5.182***</td>
</tr>
<tr>
<td></td>
<td>(4.28)</td>
<td>(3.59)</td>
</tr>
<tr>
<td>$\log(Scope\ 1/MV\ Industry\ All)$</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Model</th>
<th>Heckman</th>
<th>OLS</th>
<th>OLS</th>
</tr>
</thead>
<tbody>
<tr>
<td>Year Fixed Effects</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>Level</td>
<td>Firm</td>
<td>Firm</td>
<td>Firm</td>
</tr>
<tr>
<td>Frequency</td>
<td>Annual</td>
<td>Annual</td>
<td>Annual</td>
</tr>
<tr>
<td>Obs.</td>
<td>1,208</td>
<td>1,208</td>
<td>1,780</td>
</tr>
<tr>
<td>adj. R-sq.</td>
<td>0.073</td>
<td>0.074</td>
<td></td>
</tr>
</tbody>
</table>
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 CO₂ output.