Pricing Climate Event Risks and Opportunities in the Options Market

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CLIMATE POLICY EVENTS AFFECT MARKETS

Fortune[1]**:**

FORTUNE

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Paris Climate Deal Sinks Coal Stocks, Lifts Renewable Energy

BY **REUTERS**

December 14, 2015 at 12:35 PM EST

BBC news[2]**:**

Page last updated at 17:15 GMT, Monday, 21 December 2009

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Copenhagen deal causes EU carbon price fall

Carbon prices in Europe dropped to a six-month low after agreements made at the Copenhagen climate summit to cut emissions disappointed traders.

COPENHAGEN SUMMIT 2009

KEY STORIES

- Copenhagen depresses carbon price

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[1] https://fortune.com/2015/12/14/paris-climate-deal-sinks-coal-stocks-lifts-renewable-energy/

[2] http://news.bbc.co.uk/2/hi/business/8425293.stm

INTRODUCTION

The idea of the paper in a nutshell:

- Climate policy events such as UN climate summits or national elections affect markets.
- *Ex post* there are (stock) market reactions pricing in the new information.
  - Example: Following the 2015 Paris Agreement, green stocks rose while brown stocks declined (Adler et al., 2025).
- Are such climate policy / transition risks priced *ex ante* in the option market?
- Does the price of a stock option spanning a climate policy event depend on the ”greenness” of the firm?

Results

- In the days leading up to the Paris Agreement, OTM options were more expensive for S&P 500 firms with higher absolute climate change exposure.
- There is a non-monotonic relationship between firms' climate change exposure and option expensiveness preceding the event.
- Similar results are obtained using a larger panel of UN climate change conferences.
- The results hold for a different sample of European firms (STOXX Europe 600).
- Firms' option-implied risk premia preceding the Paris Agreement vary significantly with climate change exposure.

CONTRIBUTION

New perspective:

- Existing research suggests that options are more expensive for ”brown” firms (Ilhan et al. (2021) or Cao et al. (2021))
  - I show theoretically and empirically that the uncertain outcomes of events affect both ”green” and ”brown” firms.

New methodology:

- Existing papers use traditional approaches (portfolio sorting) to measure the relation between firm’s greenness and option prices
  - I apply an event based approach and compare price of affected options with neighboring unaffected options, bringing a methodology similar to Kelly et al. (2016) to the cross-section.

New ”greenness” measure:

- Instead of ESG scores I use textual-analysis ”greenness” scores.

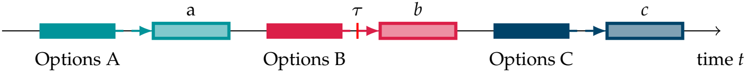
Empirical methodology

Option data

- OptionsMetrics provides implied volatilities (= rescaled option prices) via option price file or volatility surface file.
- I first focus on OTM Call and Put options of S&P 500 firms using deltas between 0.1 and 0.5 (OTM options have higher sensitivity to volatility changes than ITM options).

Empirical approach

- At time τ, a climate policy event occurs.
- Options B are *traded before* the event, but *expire after* τ at time b.
- "Control" options A or C both trade and expire either before or after τ, so are not directly affected by the event (options C maybe indirectly). I use 30 days to maturity vsf options.
- *Hypothesis*: The expensiveness of options B on a firm i, measured relative to options A and C on the same firm, will depend on the firm's climate policy exposure.



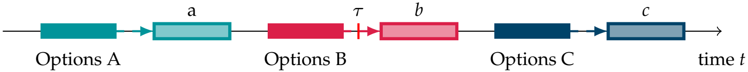
Implied volatility difference

- I compute the average implied volatilites IV_a^i, IV_b^i, and IV_c^i for firm i over 15 trading days using options A, B, and C.
- The firm's implied volatility difference IVD^i is:

$$IVD^i = IV_b^i - \frac{1}{2}(IV_a^i + IV_c^i) \tag{1}$$

- Alternative measure IVD_{ba}^i - excludes options C (relies only on information available prior to τ):

$$IVD_{ba}^i = IV_b^i - IV_a^i \tag{2}$$



REGRESSIONS

- I obtain CO_2 Scope 1 and Scope 2 CO_2 emissions from CDP[3] and textual-analysis based climate change exposure measures from the paper by Sautner et al. (2023)
- I use them to obtain "brownness" scores B^i, and run regressions to see if a higher level of brownness is associated with higher implied volatility difference.

$$IVD^i = \alpha + \beta B^i + \gamma CV^i + \varepsilon_i \tag{3}$$

- CV^i stands for optional control variables (e.g. β_{Market}, B/M, $Size$)

[3] https://www.cdp.net/en

Theoretical framework

Theoretical framework - Quick overview

- I assume the log return of stock i follows a factor model with a *greenness* factor $F_{g,t}$ ("brown" − "green") :

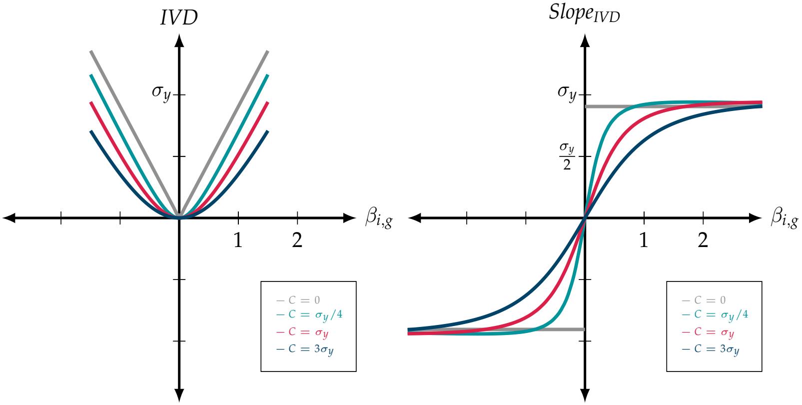
$$R_{i,t} = \beta_{i,g} F_{g,t} + \boldsymbol{\beta_i'} \boldsymbol{F_t} + \varepsilon_i \tag{4}$$

- "browner" firms: $\beta_{i,g} > 0$, but "greener" firms: $\beta_{i,g} < 0$. Both are thus exposed to jump risks of the *greenness* factor.
- There is an expected shock to $F_{g,t}$ with variance σ_y^2 to $F_{g,t}$ at the time of the policy event τ that affects $Var(R_{i,t=\tau}) \propto \beta_{i,g}^2 \sigma_y^2$.
- Similarly, the return volatility over an (option) period spanning the climate event depends non-monotonically on $\beta_{i,g}$, and so does the implied volatility difference.

Go to Theory

Theoretical plots

- Volatility difference and slope for different exposures to the *greenness* (or climate risk) factor ($\beta_{i,g}$) and different levels of noise and variance of other factors (C).



INSIGHTS

- Blindly regressing IVD on a measure of climate policy risk exposure $\beta_{i,g}$ could lead to misleading results due to the non-monotonic relationship between IVD and $\beta_{i,g}$.
- When performing regressions, we need to carefully consider what measure is used to proxy for $\beta_{i,g}$ and which part of the graph is covered (left half, right half, entire graph?).
- This problem could be addressed by taking the absolute value of $\beta_{i,g}$ which effectively means we are reflecting the left part of the graph of IVD on the right part of the graph, thereby eradicating non-monotonicity problems.
- All else equal, the coefficient of $\beta_{i,g}$ will be closer to zero with more noise and variance in other factors.

Empirical results

DATA, VARIABLES, HYPOTHESES

- CO_2 emissions data from CDP
  - Higher emissions signal higher transition risk, but lower emissions don't signal higher opportunities, covers $\beta^+_{i,g}$. I thus expect a positive relation to *IVD*.
- Firm level climate change exposures from Sautner et al. (2023) and theoretical coverage of $\beta_{i,g}$
  1. *cc_expo* and *cc_risk* measure exposure to climate change, cover $|\beta_{i,g}|$
  2. *rg_cc_expo* measures exposure to regulatory risk, covers $\beta^+_{i,g}$
  3. *op_cc_expo* measures exposure to climate change opportunities, covers $|\beta^-_{i,g}|$

     $\rightarrow$ All above variables are positive. I expect a positive relation.
  4. *cc_senti* measures sentiment of firms towards climate change, positive and negative, covers entire range of $\beta_{i,g}$ $(-\beta_{i,g})$.

     $\rightarrow$ I expect a negative relation to *IVD* for "low" sentiment firms and a positive relation for "high" sentiment firms.

Paris Agreement 2015

- The Paris agreement was reached on Saturday, December 12, 2015 during the COP21 climate conference in Paris.
- On the following Monday there were large return differences between stocks of ”green” and ”brown” firms (see introduction).
- As a start, I choose December 10, 2015 as the eventdate τ. I use monthly vsf options with 30 days to maturity. For each firm i I compute the average IV^i of OTM options with open interest in the previous 15 trading days. I proceed in a similar way using neighboring options to compute IVD^i and IVD^i_{ba}

Paris results *IVD*

Dep. Var.:	*IVD*					
Model:	(1)	(2)	(3)	(4)	(5)	(6)
Scope1Em	0.066***					
	(4.12)					
Scope2Em		0.115				
		(1.11)				
CCExposure			2.88***			
			(3.63)			
CCRisk				54.0***		
				(4.50)		
$CCExposure^{Reg}$					24.7***	
					(2.60)	
$CCExposure^{Opp}$						6.73***
						(5.55)
Observations	345	335	679	679	679	679
R^2	0.013	0.0001	0.028	0.033	0.006	0.040

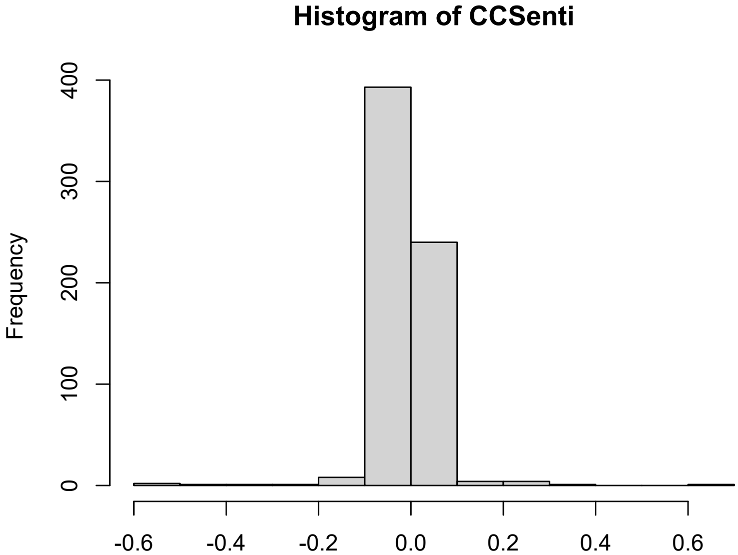
*Signif. Codes: ***: 0.01, **: 0.05, *: 0.1*

PARIS RESULTS IVD_{ba}

Dep. Var.:			IVD_{ba}			
Model:	(1)	(2)	(3)	(4)	(5)	(6)
$Scope1Em$	0.087***					
	(3.00)					
$Scope2Em$		0.282				
		(1.64)				
$CCExposure$			2.13**			
			(2.35)			
$CCRisk$				53.3***		
				(2.78)		
$CCExposure^{Reg}$					22.2*	
					(1.79)	
$CCExposure^{Opp}$						4.87***
						(2.87)
Observations	339	329	656	656	656	656
R^2	0.048	0.007	0.010	0.011	0.008	0.009

*Signif. Codes: ***: 0.01, **: 0.05, *: 0.1*

HISTOGRAM OF *CCSenti*



Results with *CCSenti*

Non-monotonic relationship between *IVD* and CC sentiment.

Dep. Variable:	*IVD*				
cc_senti sample:	full	full	high $[q_{0.66}, q_1]$	mid $[q_{0.33}, q_{0.66}]$	low $[q_0, q_{0.33}]$
Variables					
$\lvert CCSenti \rvert$	11.5***				
	(4.78)				
CCSenti		-1.56	10.1***	-563.2	-11.1***
		(-0.454)	(2.79)	(-1.26)	(-3.07)
Fit statistics					
Observations	665	665	225	228	212
R^2	0.017	0.0003	0.016	0.002	0.032

HC robust standard errors, t-stats in parenthesess
*Signif. Codes: ***: 0.01, **: 0.05, *: 0.1*

Results are similar when splitting into 5 subsamples.

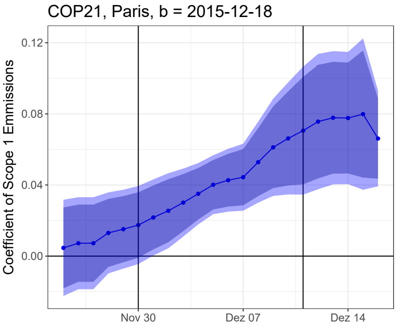
Robustness tests

VARYING EVENTDATE τ

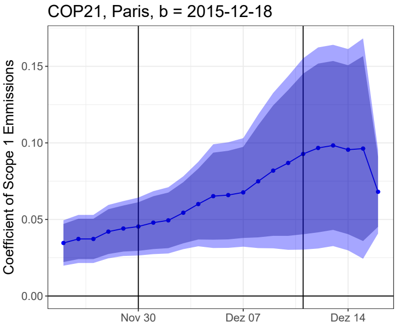
How does the significance depend on the choice of the event date τ?

Note: The plots display rolling regression coefficients based on 15-trading-day windows before each event date τ, as indicated on the x-axes, and 15-trading-day windows of adjacent options used to compute *IVD* and IVD_{ba}

(a) $IVD \sim Scope\ 1\ Emissions$



(b) $IVD_{ba} \sim Scope\ 1\ Emissions$



External validity - panel regression results

I use climate change conferences from 2009 to 2020

Dependent Variable:	IVD					
Model:	(1)	(2)	(3)	(4)	(5)	(6)
Scope1Em	0.042**					
	(2.51)					
CCExposure		-0.301				
		(-0.639)				
CCRisk			11.1**			
			(2.19)			
$CCExposure^{Reg}$				-2.86		
				(-1.14)		
$CCExposure^{Opp}$					-0.903	
					(-1.17)	
$\lvert CCSenti \rvert$						-0.753
						(-0.451)
β_{market}	-0.139	-0.090	-0.076	-0.085	-0.091	-0.088
	(-0.422)	(-0.327)	(-0.278)	(-0.310)	(-0.330)	(-0.320)
B/M	0.211	0.882***	0.885***	0.886***	0.879***	0.886***
	(0.607)	(2.70)	(2.71)	(2.71)	(2.69)	(2.71)
log(market cap)	-1.32×10^{-5}*	-8.53×10^{-7}	-8.54×10^{-7}	-8.64×10^{-7}	-8.49×10^{-7}	-8.57×10^{-7}
	(-1.86)	(-0.401)	(-0.405)	(-0.406)	(-0.400)	(-0.403)
Fixed-effects						
year	Yes	Yes	Yes	Yes	Yes	Yes
firm	Yes	Yes	Yes	Yes	Yes	Yes
Observations	2,811	6,097	6,097	6,097	6,097	6,097
R^2	0.379	0.382	0.382	0.382	0.383	0.382

*Signif. Codes: ***: 0.01, **: 0.05, *: 0.1*

Conclusion and Further Results

- Climate policy events can influence the pricing of both ”green” and ”brown” firms *ex ante* in the options market.
- Results are robust in a sample of European firms (STOXX Europe 600) and when controlling for standard factors (market, size, value).
- Following Liu et al. (2022), I compute option-implied risk premia which significantly correlate with firms’ climate change exposure in the days before the Paris Agreement.
- Limitations: the analysis currently focuses only on UN climate change conferences and on U.S. and European options.
- Further research could expand the scope of events, firms, and regions analyzed.

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THEORETICAL FRAMEWORK

- Let's assume the log return of a stock i follows a factor structure:

$$R_{i,t} = \beta_{i,g} F_{g,t} + \boldsymbol{\beta_i'} \boldsymbol{F_t} + \varepsilon_i \tag{5}$$

- $\beta_{i,g}$ is the exposure to a presumed climate transition risk or *greenness* factor $F_{g,t}$
- Assume that the greenness factor $F_{g,t}$ is created as a brown-minus-green portfolio return based on firms with high climate transition risk and low climate transition risk.
  $\rightarrow$ "browner" firms: $\beta_{i,g} > 0$ whereas "greener" firms: $\beta_{i,g} < 0$.
- vector $\boldsymbol{\beta_i'}$ comprises exposures to other potentially relevant factors $\boldsymbol{F_t}$ (e.g. market, size, book-to-market, etc.)
- ε_i is a residual following a normal distribution with mean zero, $\varepsilon_i \sim N(0, \sigma^2_{\varepsilon_i})$

Theoretical framework

- Further assume the other factors $\boldsymbol{F_t}$ are constructed in such a way that they are orthogonal to the climate factor and to any other factor, e.g. by using the Gram-Schmidt process.
  $\rightarrow CoV(F_{k,t}, F_{l,t}) = 0$ for $k \neq l$.
- A climate policy event happens at time τ
- the factors $F_{k,t}, k \in \{1 \ldots K\}$ comprised in $\boldsymbol{F_t}$ follow independent normal distributions $F_{k,t} \sim N(\mu_k, \sigma_k^2)\ \forall\, k, t$
- $F_{g,t}$ follows $F_{g,t} = X_t + \xi_t$ where:

$$X_t \sim N(\mu_g, \sigma_g^2), \quad \xi_t = \begin{cases} 0, & \text{if } t \neq \tau \\ Y \sim N(\mu_y, \sigma_y^2), & \text{if } t = \tau \end{cases} \tag{6}$$

THEORETICAL FRAMEWORK

- Assuming independence of the shocks we then get the following expression for the variance of stock i's return :

$$Var(R_{i,t}) = \beta_{i,g}^2(\sigma_g^2 + \mathbf{1}_{\{t=\tau\}}\sigma_y^2) + \sum_{k=1}^{K} \beta_{i,k}^2 \sigma_k^2 + \sigma_{\varepsilon_i}^2 \tag{7}$$

  $\rightarrow$ firms with higher squared exposure to the climate risk factor ($\beta_{i,g}^2$) exhibit higher variance at the time of the climate policy event.

- The log return of the stock over the remaining lifetime of an option until maturity T is given by $\sum_t^T R_{i,t}$ and due to independence of the $R_{i,t}$ its variance is given by $\sum_t^T Var(R_{i,t})$

THEORETICAL FRAMEWORK

- The difference of the stock's variance over the lifetime of an option b spanning the climate event at τ and its variance over the lifetime of an option a with the same time to maturity that doesn't span the event is consequently given by:

$$\sum_{t,\tau\in t}^{T_b} Var(R_{i,t}) - \sum_{t,\tau\notin t}^{T_a} Var(R_{i,t}) = \beta_{i,g}^2 \sigma_y^2 \tag{8}$$

- Assume an option expires in N days, the volatility difference of stock i over the lifetime of the option spanning the event is

$$IVD_i = \sqrt{\beta_{i,g}^2 (N\sigma_g^2 + \sigma_y^2) + N\left(\sum_{k=1}^{K} \beta_{i,k}^2 \sigma_k^2 + \sigma_{\varepsilon_i}^2\right)} - \sqrt{\beta_{i,g}^2 N\sigma_g^2 + N\left(\sum_{k=1}^{K} \beta_{i,k}^2 \sigma_k^2 + \sigma_{\varepsilon_i}^2\right)}$$