# Virtual Seminar on Climate Economics

**Organizing Committee:**
Glenn Rudebusch (Brookings Institution)
Michael Bauer (Federal Reserve Bank of San Francisco)
Stephie Fried (Federal Reserve Bank of San Francisco)
Òscar Jordà (UC Davis, Federal Reserve Bank of San Francisco)
Fernanda Nechio (Federal Reserve Bank of San Francisco)
Toàn Phan (Federal Reserve Bank of Richmond)

# An Empirical Test of the Green Paradox for Climate Legislation

Maya Norman[1] and Wolfram Schlenker[1,2]

[1] Columbia University
[2] National Bureau of Economic Research (NBER)

Virtual Seminar on Climate Economics

# Outline

# Outline

# Climate Legislation: Setting Cap in Future

- Climate legislation often establishes goals for the future
  - Give companies and consumers time to adapt and plan for a transition away from fossil fuels
  - Examples:
    - European Union enacted the goal to be climate neutral (net zero emissions) by 2050
    - China established the same goal for 2060

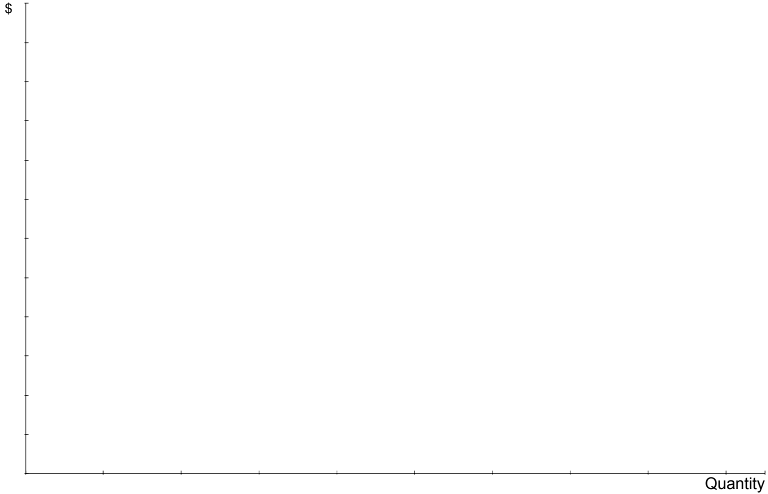
# Climate Legislation: Setting Cap in Future

- Climate legislation often establishes goals for the future
  - Give companies and consumers time to adapt and plan for a transition away from fossil fuels
  - Examples:
    - European Union enacted the goal to be climate neutral (net zero emissions) by 2050
    - China established the same goal for 2060
- Fossil fuels are exhaustible resources
  - Finite availability dictates their use and price path
  - Large scarcity rents for producers
    - Saudi Arabia: cost to extract oil at $8 per barrel, sell for $70per barrel
  - Why does price exceed marginal cost?
    - Higher price ensures that some of the resource is saved for future periods

# Climate Legislation: Setting Cap in Future

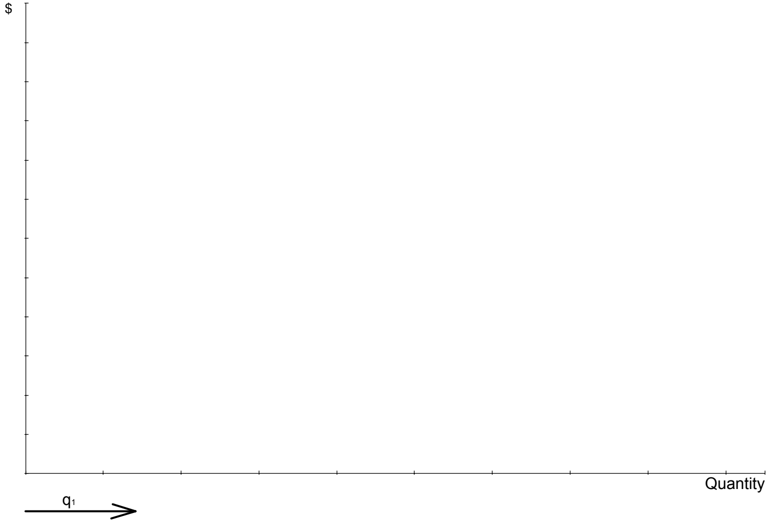
- Climate legislation often establishes goals for the future
  - Give companies and consumers time to adapt and plan for a transition away from fossil fuels
  - Examples:
    - European Union enacted the goal to be climate neutral (net zero emissions) by 2050
    - China established the same goal for 2060
- Fossil fuels are exhaustible resources
  - Finite availability dictates their use and price path
  - Large scarcity rents for producers
    - Saudi Arabia: cost to extract oil at $8 per barrel, sell for $70per barrel
  - Why does price exceed marginal cost?
    - Higher price ensures that some of the resource is saved for future periods
- Green Paradox: limiting fossil fuel use in the future through legislation
  - puts a cap on how much producers want to save for the future
  - shifts production towards the present → lower price

# Intuition: Green Paradox



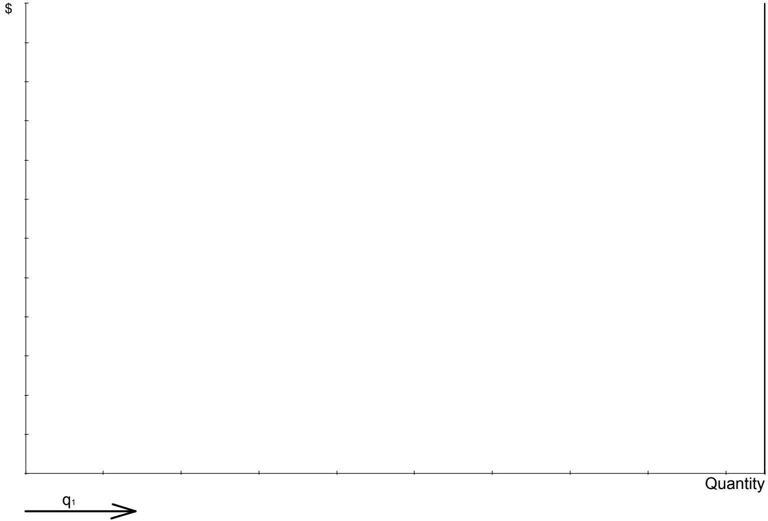

- Optimal allocation

# Intuition: Green Paradox



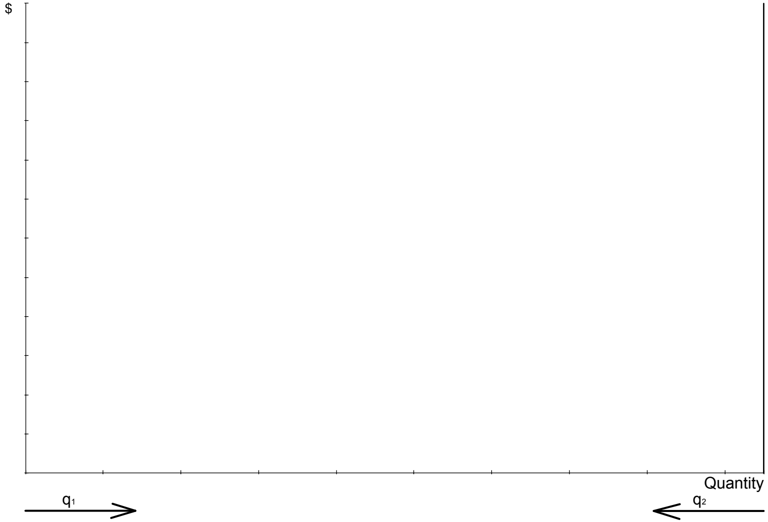

- Optimal allocation

# Intuition: Green Paradox



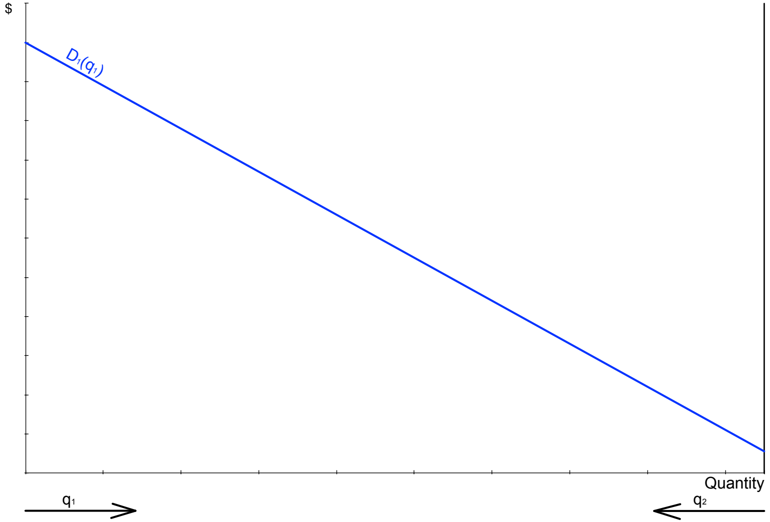

- Optimal allocation
  - Exhaustible resource
  - Zero extraction cost
  - Availability is fixed
    - $q_1 + q_2 = \bar{q}$

# Intuition: Green Paradox



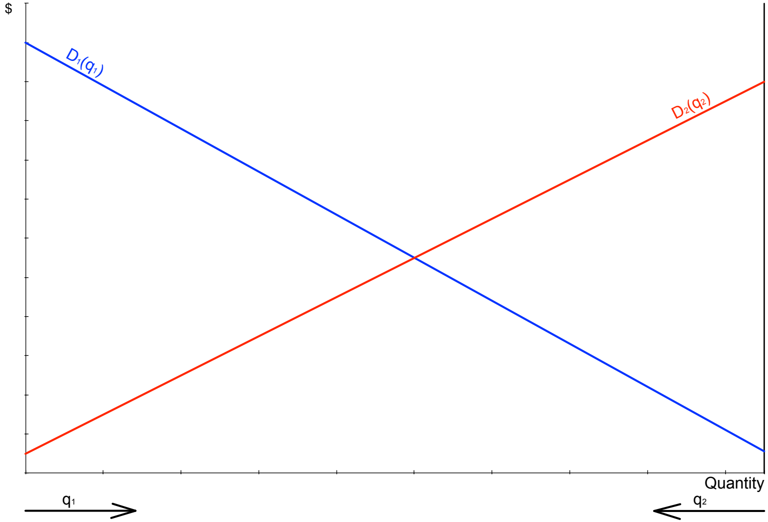

- Optimal allocation
  - Exhaustible resource
  - Zero extraction cost
  - Availability is fixed
    - ★ $q_1 + q_2 = \bar{q}$

# Intuition: Green Paradox



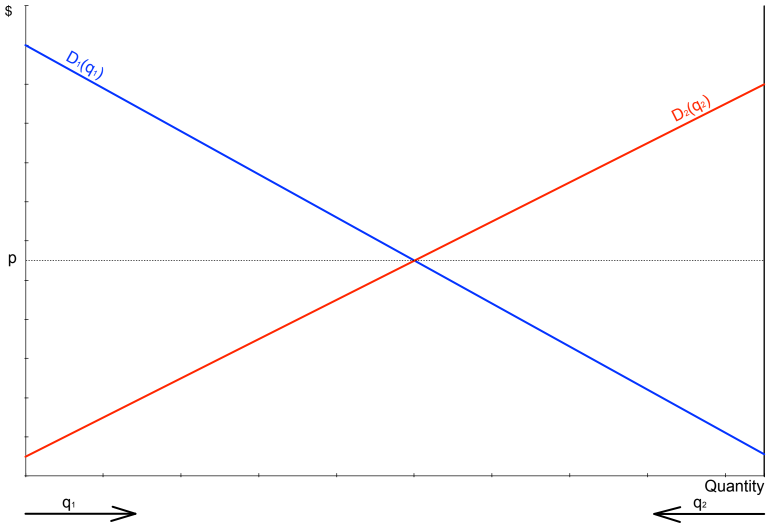

- Optimal allocation
  - Exhaustible resource
  - Zero extraction cost
  - Availability is fixed
    - $q_1 + q_2 = \bar{q}$
- Demand $D_1(q_1)$

# Intuition: Green Paradox



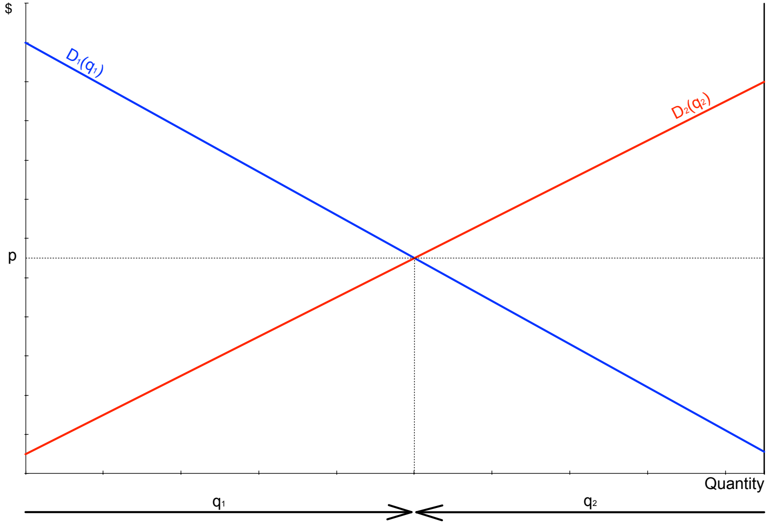

- Optimal allocation
  - Exhaustible resource
  - Zero extraction cost
  - Availability is fixed
    - $q_1 + q_2 = \bar{q}$
- Demand $D_1(q_1)$
  - Period 2: discounted
  - $D_2(q_2) = \frac{D_1(q_1)}{1+r}$

# Intuition: Green Paradox



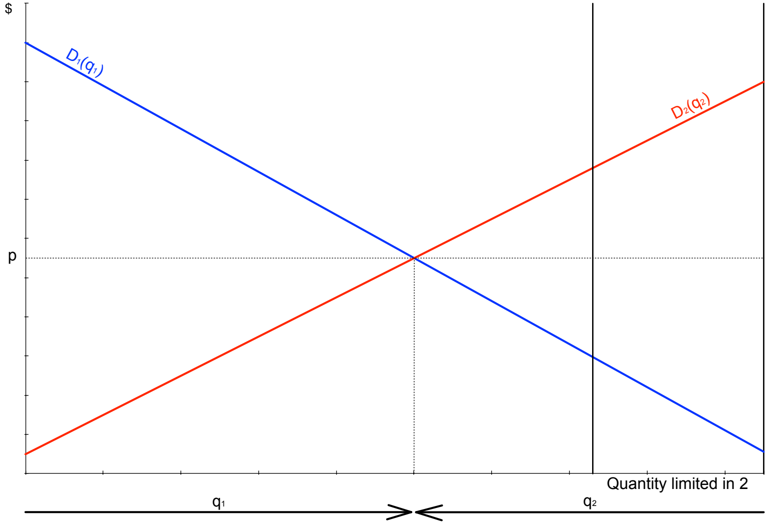

- Optimal allocation
  - Exhaustible resource
  - Zero extraction cost
  - Availability is fixed
    - $q_1 + q_2 = \bar{q}$
- Demand $D_1(q_1)$
  - Period 2: discounted
  - $D_2(q_2) = \frac{D_1(q_1)}{1+r}$
- Equate price

# Intuition: Green Paradox



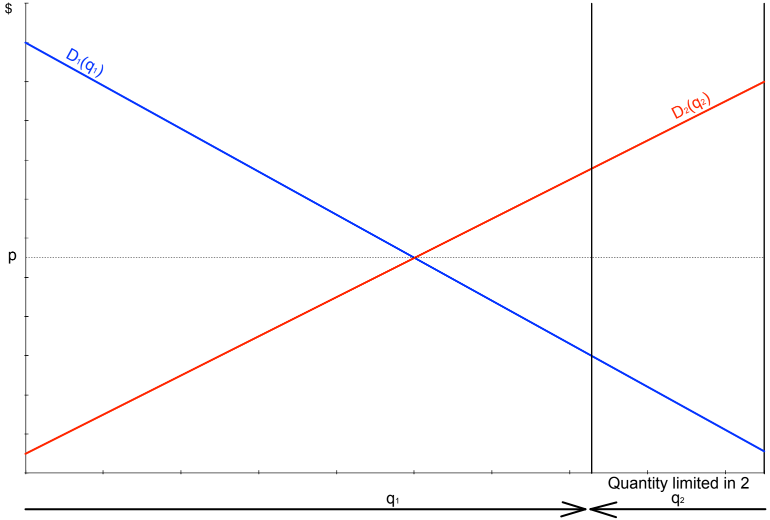

- Optimal allocation
  - Exhaustible resource
  - Zero extraction cost
  - Availability is fixed
    - $q_1 + q_2 = \bar{q}$
- Demand $D_1(q_1)$
  - Period 2: discounted
  - $D_2(q_2) = \frac{D_1(q_1)}{1+r}$
- Equate price
  - Optimal split

# Intuition: Green Paradox

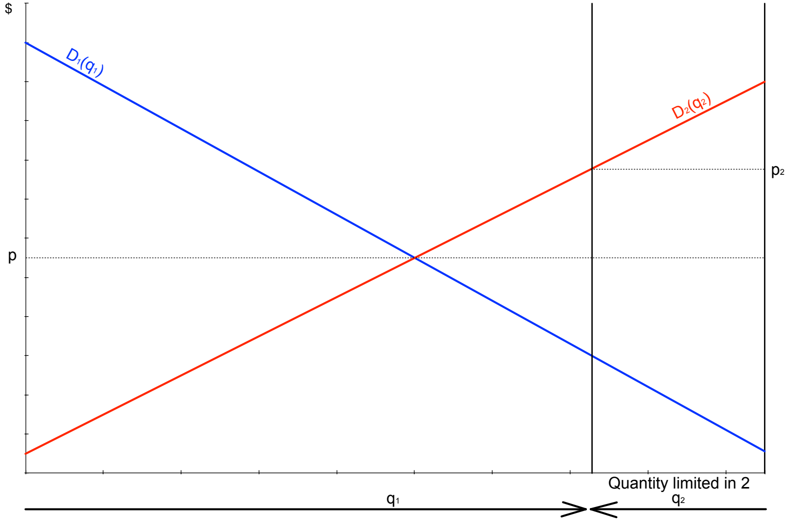



- Optimal allocation
  - Exhaustible resource
  - Zero extraction cost
  - Availability is fixed
    - $q_1 + q_2 = \bar{q}$
- Demand $D_1(q_1)$
  - Period 2: discounted
  - $D_2(q_2) = \frac{D_1(q_1)}{1+r}$
- Equate price
  - Optimal split
- Limit in period 2

# Intuition: Green Paradox

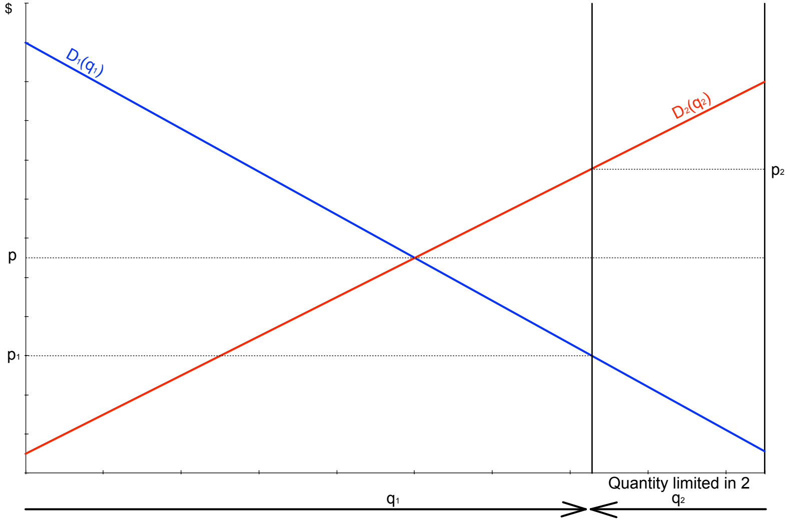



- Optimal allocation
  - Exhaustible resource
  - Zero extraction cost
  - Availability is fixed
    - $q_1 + q_2 = \bar{q}$
- Demand $D_1(q_1)$
  - Period 2: discounted
  - $D_2(q_2) = \frac{D_1(q_1)}{1+r}$
- Equate price
  - Optimal split
- Limit in period 2
  - $q_2 \downarrow$, $q_1 \uparrow$




- Optimal allocation
  - Exhaustible resource
  - Zero extraction cost
  - Availability is fixed
    - ★ $q_1 + q_2 = \bar{q}$
- Demand $D_1(q_1)$
  - Period 2: discounted
  - $D_2(q_2) = \frac{D_1(q_1)}{1+r}$
- Equate price
  - Optimal split
- Limit in period 2
  - $q_2 \downarrow$, $q_1 \uparrow$
  - $p_2 \uparrow$

# Intuition: Green Paradox




- Optimal allocation
  - Exhaustible resource
  - Zero extraction cost
  - Availability is fixed
    - $q_1 + q_2 = \bar{q}$
- Demand $D_1(q_1)$
  - Period 2: discounted
  - $D_2(q_2) = \frac{D_1(q_1)}{1+r}$
- Equate price
  - Optimal split
- Limit in period 2
  - $q_2 \downarrow$, $q_1 \uparrow$
  - $p_2 \uparrow$ ,$p_1 \downarrow$

# Previous Literature

- Green Paradox: large theoretical literature
  - E.g., Sinn (2008), Hoel (2010), Van der Ploeg and Withagen (2012, 2015)
  - Supply response to announcements that future use might be limited
  - Anticipation effect: rational actors will adjust even before laws are passed

# Previous Literature

- Green Paradox: large theoretical literature
  - E.g., Sinn (2008), Hoel (2010), Van der Ploeg and Withagen (2012, 2015)
  - Supply response to announcements that future use might be limited
  - Anticipation effect: rational actors will adjust even before laws are passed
- Some empirical evidence
  - Di Maria, Lange & van der Werf (2014), Merrill (2018), Grafton, Kompas, Long & To (2014)
    - Pre-post comparison after passage of environmental regulation
    - Less clear when markets updated their beliefs / what beliefs were
  - Lemoine (2017)
    - Closest to our study
    - Abnormal coal price returns on day when Senator Graham abandoned bill
    - Challenge: same week as Deep Horizon Disaster

# Contributions of Our Study

1. Various data sources and time scales
   - High-frequency (daily) data
   - Monthly data on environmental policy spanning decades
   - Event study of surprise court ruling

# Contributions of Our Study

1. Various data sources and time scales
   - High-frequency (daily) data
   - Monthly data on environmental policy spanning decades
   - Event study of surprise court ruling
2. Using data that reveal market beliefs and awareness
   - Estimate of market belief from prediction market (InTrade)
   - Internet searches (google trends) to establish salience of topic

# Contributions of Our Study

1. Various data sources and time scales
   - High-frequency (daily) data
   - Monthly data on environmental policy spanning decades
   - Event study of surprise court ruling
2. Using data that reveal market beliefs and awareness
   - Estimate of market belief from prediction market (InTrade)
   - Internet searches (google trends) to establish salience of topic
3. Focus on temporal aspect across different maturities of futures contracts
   - Classical short-term shocks to spot price phase out over time
   - Green Paradox effects *all* maturities, i.e., consistent effect across maturities
     - ★ Might even phase-in if production decision in short-term are fixed

# Outline

# Oil Prices

- WTI crude oil prices from Cushing, Oklahoma

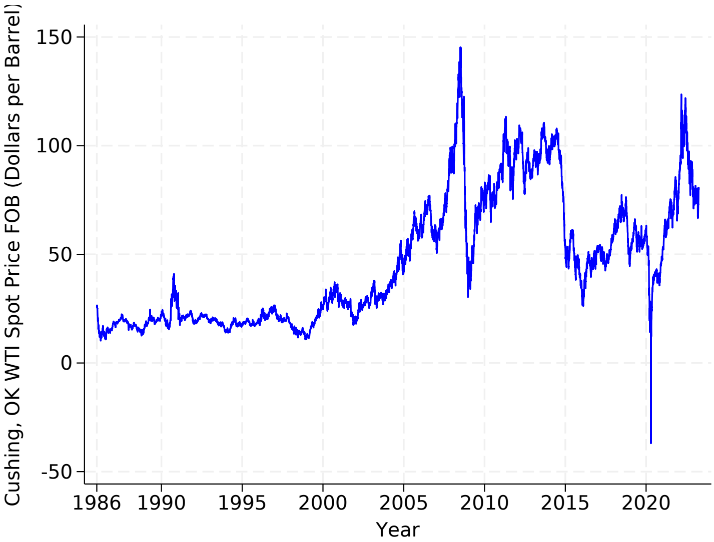
# Oil Prices

- WTI crude oil prices from Cushing, Oklahoma
- Oil Futures
  - Oil futures contracts are the market's assessment of future oil prices
  - NYMEX: futures on the West Texas Intermediate (WTI) crude price
    - 24 actively traded maturities $f = 1 \ldots 24$ months into the future

# Oil Prices

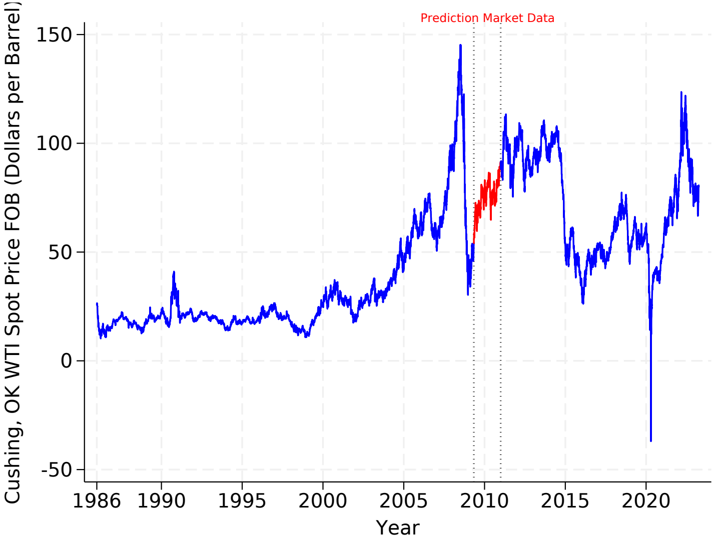
- WTI crude oil prices from Cushing, Oklahoma
- Oil Futures
  - Oil futures contracts are the market's assessment of future oil prices
  - NYMEX: futures on the West Texas Intermediate (WTI) crude price
    - ⋆ 24 actively traded maturities $f = 1 \ldots 24$ months into the future
- Coal Futures
  - NYMEX: futures on Central Appalachian Contract
    - ⋆ 24 actively traded maturities $f = 1 \ldots 24$ months into the future

# Oil Prices




- Spot price
  - Briefly negative during COVID

# Oil Prices




- Spot price
  - Briefly negative during COVID
- Prediction market active
  - May 1, 2009 through December 31, 2010
  - Time when US climate bill is discussed

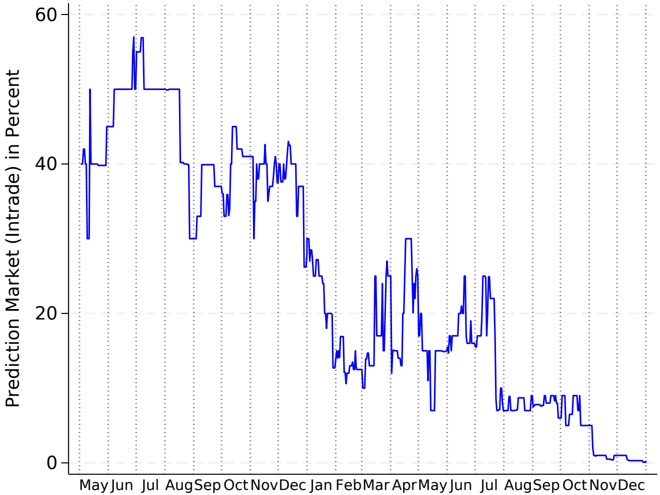
# Prediction Market (Intrade)

- Prediction market contract
  - Bet on the realization of a particular event by a given date
  - Our study: "A cap-and-trade system for emissions trading to be established before midnight ET on 31 Dec 2010"

# Prediction Market (Intrade)

- Prediction market contract
  - Bet on the realization of a particular event by a given date
  - Our study: "A cap-and-trade system for emissions trading to be established before midnight ET on 31 Dec 2010"
- Waxman-Markey bill
  - US climate bill (passed by House, taken up by Senate)
    - ⋆ Sizable reduction in $CO_2$ emissions: 83-percent emissions reduction from 2005 levels by 2050
  - Intrade prices from May 1, 2009 to December 31, 2010
    - ⋆ Prices exceeded 50% (probability of passing larger than 50%)

# Prediction Market Prices (May 2009 - December 2010)




- Prices (cents)
  - Probability of law passing
- Initial above 50%
  - House passed bill 219–212
  - June 26, 2009
- Probability approached zero
  - Bill was abandoned

# Other Controls

- Market movement (S&P500 index)
  - Obtained from Bloomberg terminals
  - Oil prices respond to overall market conditions
    - ★ We control for S&P500 index

# Other Controls

- Market movement (S&P500 index)
  - Obtained from Bloomberg terminals
  - Oil prices respond to overall market conditions
    - ★ We control for S&P500 index
- Google trends data on internet searches
  - Search volume for "Waxman-Markey"
  - Results are normalized
    - ★ Day with highest search volume is set to zero
    - ★ Day with value of 5 implies search volume is 5% of the day with the highest search volume

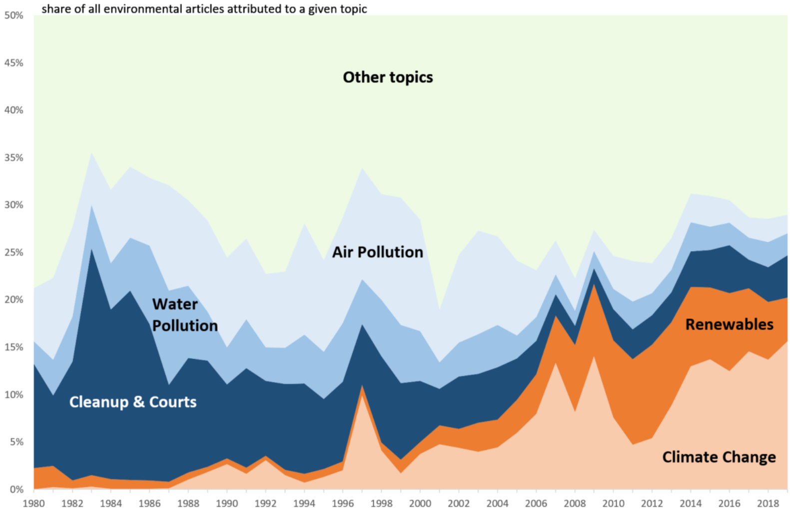
# Policy Salience

- Monthly index from Noailly et al. (2021) from text-mining 15 million articles
  - Published between 1981 and 2019 in 10 major newspapers
    - New York Times, Washington Post, Wall Street Journal, Houston Chronicle, Dallas Morning News, San Francisco Chronicle, Boston Herald, Tampa Bay Times, San Jose Mercury News, and San Diego Union Tribune
  - Vector machine algorithm trained on 2,464 labeled articles

# Policy Salience

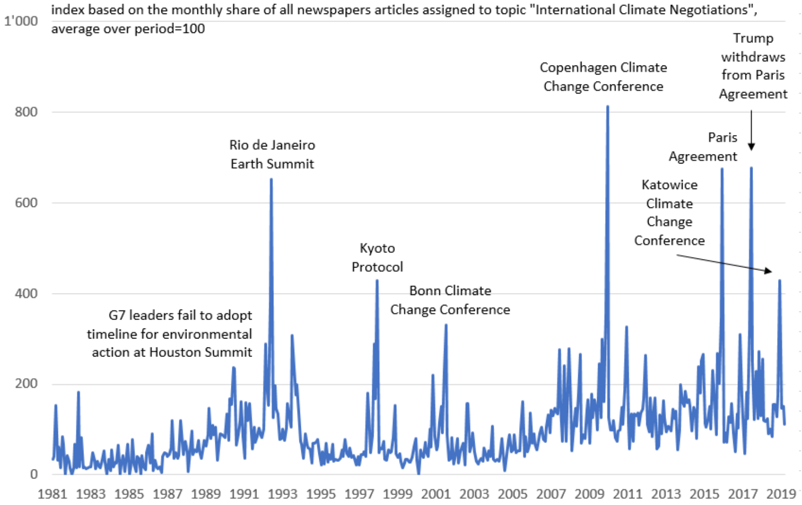
- Monthly index from Noailly et al. (2021) from text-mining 15 million articles
  - Published between 1981 and 2019 in 10 major newspapers
    - New York Times, Washington Post, Wall Street Journal, Houston Chronicle, Dallas Morning News, San Francisco Chronicle, Boston Herald, Tampa Bay Times, San Jose Mercury News, and San Diego Union Tribune
  - Vector machine algorithm trained on 2,464 labeled articles
- Also classify environmental policy articles into sub-topics (topic modeling, an unsupervised learning algorithm)
  - International climate negotiations
    - Words/ phrases such as agreement, united, international, government, country, state, world, trade, president, European, Mexico, China, etc.
    - Correlated with US climate policy
  - Renewable policy
    - Words/phrases such as renewable energy, wind, solar, energy, turbine, energy, power, electricity, renewable, wind power, farm, solar energy, turbine, etc.

# Policy Salience




- Share of topics
  - over time

# Policy Salience




- International climate negotiations
  - over time

# Outline

# Step 1: Oil Spot Price Shock Permanence - Evolution Over Time

$$\Delta y_{ft} = \alpha_{fm(t)} + \beta_f \ \Delta p_t + \gamma_f \ \Delta z_t + \epsilon_{ft}$$

- where

$\Delta y_{ft}$: Percent change in the price of oil future on day $t$ with maturity $f$
  - ★ 24 actively traded maturities $f = 1 \ldots 24$ months into the future
  - ★ Price change derived using closing prices on day $t$ relative to $t-1$

$\alpha_{fm(t)}$: Maturity-by-month fixed effects
  - ★ We focus on variation within a calendar month

$\Delta p_t$: Change in oil spot price on day $t$

$\Delta z_t$: Market movement on day $t$ (percent change of S&P500)

$\epsilon_{ft}$: Error term (clustered by day in baseline)
  - ★ Errors of 24 maturities allowed to be correlated

# Step 1: Oil Spot Price Shock Permanence - Evolution Over Time

$$\Delta y_{ft} = \alpha_{fm(t)} + \beta_f \ \Delta p_t + \gamma_f \ \Delta z_t + \epsilon_{ft}$$

- where

$\Delta y_{ft}$: Percent change in the price of oil future on day $t$ with maturity $f$
  - ★ 24 actively traded maturities $f = 1 \ldots 24$ months into the future
  - ★ Price change derived using closing prices on day $t$ relative to $t-1$

$\alpha_{fm(t)}$: Maturity-by-month fixed effects
  - ★ We focus on variation within a calendar month

$\Delta p_t$: Change in oil spot price on day $t$

$\Delta z_t$: Market movement on day $t$ (percent change of S&P500)

$\epsilon_{ft}$: Error term (clustered by day in baseline)
  - ★ Errors of 24 maturities allowed to be correlated

# Step 1: Oil Spot Price Shock Permanence - Evolution Over Time

$$\Delta y_{ft} = \alpha_{fm(t)} + \beta_f \; \Delta p_t + \gamma_f \; \Delta z_t + \epsilon_{ft}$$

- where

$\Delta y_{ft}$: Percent change in the price of oil future on day $t$ with maturity $f$
  - ★ 24 actively traded maturities $f = 1 \dots 24$ months into the future
  - ★ Price change derived using closing prices on day $t$ relative to $t-1$

$\alpha_{fm(t)}$: Maturity-by-month fixed effects
  - ★ We focus on variation within a calendar month

$\Delta p_t$: Change in oil spot price on day $t$

$\Delta z_t$: Market movement on day $t$ (percent change of S&P500)

$\epsilon_{ft}$: Error term (clustered by day)
  - ★ Errors of 24 maturities allowed to be correlated

# Step 1: Oil Spot Price Shock Permanence - Evolution Over Time

$$\Delta y_{ft} = \alpha_{fm(t)} + \beta_f \, \Delta p_t + \gamma_f \, \Delta z_t + \epsilon_{ft}$$

- where

$\Delta y_{ft}$: Percent change in the price of oil future on day $t$ with maturity $f$
  - ★ 24 actively traded maturities $f = 1 \ldots 24$ months into the future
  - ★ Price change derived using closing prices on day $t$ relative to $t-1$

$\alpha_{fm(t)}$: Maturity-by-month fixed effects
  - ★ We focus on variation within a calendar month

$\Delta p_t$: Change in oil spot price on day $t$

$\Delta z_t$: Market movement on day $t$ (percent change of S&P500)

$\epsilon_{ft}$: Error term (clustered by day)
  - ★ Errors of 24 maturities allowed to be correlated

# Step 1: Oil Spot Price Shock Permanence - Evolution Over Time

$$\Delta y_{ft} = \alpha_{fm(t)} + \beta_f \ \Delta p_t + \gamma_f \ \Delta z_t + \epsilon_{ft}$$

- where

$\Delta y_{ft}$: Percent change in the price of oil future on day $t$ with maturity $f$
  - ★ 24 actively traded maturities $f = 1 \dots 24$ months into the future
  - ★ Price change derived using closing prices on day $t$ relative to $t-1$

$\alpha_{fm(t)}$: Maturity-by-month fixed effects
  - ★ We focus on variation within a calendar month

$\Delta p_t$: Change in oil spot price on day $t$

$\Delta z_t$: Market movement on day $t$ (percent change of S&P500)

$\epsilon_{ft}$: Error term (clustered by day)
  - ★ Errors of 24 maturities allowed to be correlated

# Step 1: Oil Spot Price Shock Permanence - Evolution Over Time

$$\Delta y_{ft} = \alpha_{fm(t)} + \beta_f \; \Delta p_t + \gamma_f \; \Delta z_t + \epsilon_{ft}$$

- where

$\Delta y_{ft}$: Percent change in the price of oil future on day $t$ with maturity $f$

  - ★ 24 actively traded maturities $f = 1 \ldots 24$ months into the future
  - ★ Price change derived using closing prices on day $t$ relative to $t-1$

$\alpha_{fm(t)}$: Maturity-by-month fixed effects

  - ★ We focus on variation within a calendar month

$\Delta p_t$: Change in oil spot price on day $t$

$\Delta z_t$: Market movement on day $t$ (percent change of S&P500)

$\epsilon_{ft}$: Error term (clustered by day)

  - ★ Errors of 24 maturities allowed to be correlated

# Step 2: Cap & Trade Prediction Market

$$\Delta y_{ft} = \alpha_{fm(t)} + \beta\ \Delta x_t + \gamma_f\ \Delta z_t + \epsilon_{ft}$$

- where

$\Delta y_{ft}$: Percent change in the price of oil future on day $t$ with maturity $f$
  - ★ 24 actively traded maturities $f = 1 \ldots 24$ months into the future
  - ★ Price change derived using closing prices on day $t$ relative to $t-1$

$\alpha_{fm(t)}$: Maturity-by-month fixed effects
  - ★ We focus on variation within a calendar month

$\Delta x_t$: Change in prediction price on day $t$
  - ★ Price in cents (0-100) equivalent to probability of law passing
  - ★ Change in price is belief update (change in probability)
  - ★ In sensitivity check we estimate a separate $\beta_f$ by maturity
  - ★ In sensitivity check we estimate a flexible $g(\Delta x_t)$ using restricted cubic splines

$\Delta z_t$: Market movement on day $t$ (percent change of S&P500)

$\epsilon_{ft}$: Error term (clustered by day in baseline)
  - ★ Errors of 24 maturities allowed to be correlated

# Step 2: Cap & Trade Prediction Market

$$\Delta y_{ft} = \alpha_{fm(t)} + \beta \; \Delta x_t + \gamma_f \; \Delta z_t + \epsilon_{ft}$$

- where

$\Delta y_{ft}$: Percent change in the price of oil future on day $t$ with maturity $f$

  - ★ 24 actively traded maturities $f = 1 \ldots 24$ months into the future
  - ★ Price change derived using closing prices on day $t$ relative to $t-1$

$\alpha_{fm(t)}$: Maturity-by-month fixed effects

  - ★ We focus on variation within a calendar month

$\Delta x_t$: Change in prediction price on day $t$

  - ★ Price in cents (0-100) equivalent to probability of law passing
  - ★ Change in price is belief update (change in probability)
  - ★ In sensitivity check we estimate a separate $\beta_f$ by maturity
  - ★ In sensitivity check we estimate a flexible $g(\Delta x_t)$ using restricted cubic splines

$\Delta z_t$: Market movement on day $t$ (percent change of S&P500)

$\epsilon_{ft}$: Error term (clustered by day in baseline)

  - ★ Errors of 24 maturities allowed to be correlated

# Step 3: Urgenda v. Netherlands Ruling

- First successful climate liability suit brought under human rights and tort law
  - Ruling released on June 24, 2015
  - Judge stated that climate change's threat was severe
    - Under Dutch law a threat of damage suffices for injunctive relief

# Step 3: Urgenda v. Netherlands Ruling

- First successful climate liability suit brought under human rights and tort law
  - Ruling released on June 24, 2015
  - Judge stated that climate change's threat was severe
    - ★ Under Dutch law a threat of damage suffices for injunctive relief

- Ruling was unexpected, notable and historic
  - NYTimes (6/29/15) "Ruling Says Netherlands Must Reduce Greenhouse Gas Emissions"
    - ★ Marjan Minnesma (director of Urgenda) "everybody in the legal scene said, 'This will never happen — this is just a P.R. stunt.' This is not a P.R. stunt."
    - ★ Michael Gerrard (Sabin Center for Climate Change Law at Columbia): "I think this will encourage lawyers in several other countries to see if they have opportunities in their domestic courts to pursue similar litigation"
  - Dutch share of global fossil fuel consumption is minimal
    - ★ Precedent that other countries subject to the European Convention might follow

# Step 3: Urgenda v. Netherlands Verdict Announcement

$$\Delta y_{ft} = \alpha_{fm(t)} + \beta\, \mathbb{1}_v + \gamma_f \Delta z_t + \epsilon_{ft}$$

- where

$\Delta y_{ft}$: Percent change in the price of oil future on day $t$ with maturity $f$
  - ★ 24 actively traded maturities $f = 1 \ldots 24$ months into the future
  - ★ Price change derived using closing prices on day $t$ relative to $t-1$

$\alpha_{fm(t)}$: Maturity-by-month fixed effects
  - ★ We focus on variation within a calendar month

$\mathbb{1}_v$: Dummy for June 24, 2015, the day the Urgenda v. Netherlands verdict was rendered
  - ★ In sensitivity check we estimate a separate $\beta_f$ by maturity

$\Delta z_t$: Market movement on day $t$ (percent change of S&P500)

$\epsilon_{ft}$: Error term (clustered by day in baseline)
  - ★ Errors of 24 maturities allowed to be correlated

# Step 3: Urgenda v. Netherlands Verdict Announcement

$$\Delta y_{ft} = \alpha_{fm(t)} + \beta \, \mathbb{1}_v + \gamma_f \Delta z_t + \epsilon_{ft}$$

- where

$\Delta y_{ft}$: Percent change in the price of oil future on day $t$ with maturity $f$

- ★ 24 actively traded maturities $f = 1 \ldots 24$ months into the future
- ★ Price change derived using closing prices on day $t$ relative to $t-1$

$\alpha_{fm(t)}$: Maturity-by-month fixed effects

- ★ We focus on variation within a calendar month

$\mathbb{1}_v$: Dummy for June 24, 2015, the day the Urgenda v. Netherlands verdict was rendered

- ★ In sensitivity check we estimate a separate $\beta_f$ by maturity

$\Delta z_t$: Market movement on day $t$ (percent change of S&P500)

$\epsilon_{ft}$: Error term (clustered by day in baseline)

- ★ Errors of 24 maturities allowed to be correlated

# Step 4: Climate Policy Salience

$$\Delta y_{fm} = \alpha_{fq(m)} + \beta \ I_m + \theta \ R_m + \lambda \ E_m + \gamma_f \ \Delta z_m + \epsilon_{fm}$$

- where

$\Delta y_{fm}$: Percent change in the price of oil future during month $m$ with maturity $f$
  - ★ 24 actively traded maturities $f = 1 \ldots 24$ months into the future
  - ★ Price change derived using closing prices on last day of month $m$ relative to $m - 1$

$\alpha_{fq(m)}$: Maturity-by-quarter fixed effects
  - ★ We focus on variation within a quarter $q(m)$ - 3 data points per quarter

$I_m$: International climate policy index (standardized)

$R_m$: Renewable energy policy index (standardized)

$E_m$: Environmental policy index (standardized)

$\Delta z_m$: Market movement during month $m$ (percent change of S&P500)

$\epsilon_{fm}$: Error term (clustered by month)
  - ★ Errors of 24 maturities allowed to be correlated

# Step 4: Climate Policy Salience

$$\Delta y_{fm} = \alpha_{fq(m)} + \beta \; I_m + \theta \; R_m + \lambda \; E_m + \gamma_f \; \Delta z_m + \epsilon_{fm}$$

- where

$\Delta y_{fm}$: Percent change in the price of oil future during month $m$ with maturity $f$
  - ★ 24 actively traded maturities $f = 1 \ldots 24$ months into the future
  - ★ Price change derived using closing prices on last day of month $m$ relative to $m-1$

$\alpha_{fq(m)}$: Maturity-by-quarter fixed effects
  - ★ We focus on variation within a quarter $q(m)$ - 3 data points per quarter

$I_m$: International climate policy index (standardized)

$R_m$: Renewable energy policy index (standardized)

$E_m$: Environmental policy index (standardized)

$\Delta z_m$: Market movement during month $m$ (percent change of S&P500)

$\epsilon_{fm}$: Error term (clustered by month)
  - ★ Errors of 24 maturities allowed to be correlated

# Step 4: Climate Policy Salience

$$\Delta y_{fm} = \alpha_{fq(m)} + \beta\ I_m + \theta\ R_m + \lambda\ E_m + \gamma_f\ \Delta z_m + \epsilon_{fm}$$

- where

$\Delta y_{fm}$: Percent change in the price of oil future during month $m$ with maturity $f$
  - ★ 24 actively traded maturities $f = 1 \ldots 24$ months into the future
  - ★ Price change derived using closing prices on last day of month $m$ relative to $m-1$

$\alpha_{fq(m)}$: Maturity-by-quarter fixed effects
  - ★ We focus on variation within a quarter $q(m)$ - 3 data points per quarter

$I_m$: International climate policy index (standardized)

$R_m$: Renewable energy policy index (standardized)

$E_m$: Environmental policy index (standardized)

$\Delta z_m$: Market movement during month $m$ (percent change of S&P500)

$\epsilon_{fm}$: Error term (clustered by month)
  - ★ Errors of 24 maturities allowed to be correlated

# Step 4: Climate Policy Salience

$$\Delta y_{fm} = \alpha_{fq(m)} + \beta \ I_m + \theta \ R_m + \lambda \ E_m + \gamma_f \ \Delta z_m + \epsilon_{fm}$$

- where

$\Delta y_{fm}$: Percent change in the price of oil future during month $m$ with maturity $f$

- ★ 24 actively traded maturities $f = 1 \ldots 24$ months into the future
- ★ Price change derived using closing prices on last day of month $m$ relative to $m - 1$

$\alpha_{fq(m)}$: Maturity-by-quarter fixed effects

- ★ We focus on variation within a quarter $q(m)$ - 3 data points per quarter

$I_m$: International climate policy index (standardized)

$R_m$: Renewable energy policy index (standardized)

$E_m$: Environmental policy index (standardized)

$\Delta z_m$: Market movement during month $m$ (percent change of S&P500)

$\epsilon_{fm}$: Error term (clustered by month)

- ★ Errors of 24 maturities allowed to be correlated

# Step 4: Climate Policy Salience

$$\Delta y_{fm} = \alpha_{fq(m)} + \beta \ I_m + \theta \ R_m + \lambda \ E_m + \gamma_f \ \Delta z_m + \epsilon_{fm}$$

- where

$\Delta y_{fm}$: Percent change in the price of oil future during month $m$ with maturity $f$

- ★ 24 actively traded maturities $f = 1 \ldots 24$ months into the future
- ★ Price change derived using closing prices on last day of month $m$ relative to $m-1$

$\alpha_{fq(m)}$: Maturity-by-quarter fixed effects

- ★ We focus on variation within a quarter $q(m)$ - 3 data points per quarter

$I_m$: International climate policy index (standardized)

$R_m$: Renewable energy policy index (standardized)

$E_m$: Environmental policy index (standardized)

$\Delta z_m$: Market movement during month $m$ (percent change of S&P500)

$\epsilon_{fm}$: Error term (clustered by month)

- ★ Errors of 24 maturities allowed to be correlated

# Outline

# Climate Policy Salience

| | (1) | (2) | (3) | (4) |
|---|---|---|---|---|
| International Climate Negotiations | -0.918** | | | |
| | (0.385) | | | |
| Renewable Policy | 2.667** | | | |
| | (1.256) | | | |
| Environmental Policy | 0.306 | | | |
| | (0.942) | | | |
| Quarter x Year FEs | Yes | | | |
| Maturity x Quarter x Year FEs | No | | | |
| S&P 500 x Maturity | No | | | |
| Observations | 9240 | | | |

# Climate Policy Salience

| | (1) | (2) | (3) | (4) |
|---|---|---|---|---|
| International Climate Negotiations | -0.918** | | | |
| | (0.385) | | | |
| Renewable Policy | 2.667** | | | |
| | (1.256) | | | |
| Environmental Policy | 0.306 | | | |
| | (0.942) | | | |
| Quarter x Year FEs | Yes | | | |
| Maturity x Quarter x Year FEs | No | | | |
| S&P 500 x Maturity | No | | | |
| Observations | 9240 | | | |

# Climate Policy Salience

| | (1) | (2) | (3) | (4) |
|---|---|---|---|---|
| International Climate Negotiations | -0.918** | | | |
| | (0.385) | | | |
| Renewable Policy | 2.667** | | | |
| | (1.256) | | | |
| Environmental Policy | 0.306 | | | |
| | (0.942) | | | |
| Quarter x Year FEs | Yes | | | |
| Maturity x Quarter x Year FEs | No | | | |
| S&P 500 x Maturity | No | | | |
| Observations | 9240 | | | |

# Climate Policy Salience

| | (1) | (2) | (3) | (4) |
|---|---|---|---|---|
| International Climate Negotiations | -0.918** | | | |
| | (0.385) | | | |
| Renewable Policy | 2.667** | | | |
| | (1.256) | | | |
| Environmental Policy | 0.306 | | | |
| | (0.942) | | | |
| Quarter x Year FEs | Yes | | | |
| Maturity x Quarter x Year FEs | No | | | |
| S&P 500 x Maturity | No | | | |
| Observations | 9240 | | | |

# Climate Policy Salience

| | (1) | (2) | (3) | (4) |
|---|---|---|---|---|
| International Climate Negotiations | -0.918** | -0.918* | | |
| | (0.385) | (0.472) | | |
| Renewable Policy | 2.667** | 2.719* | | |
| | (1.256) | (1.533) | | |
| Environmental Policy | 0.306 | 0.252 | | |
| | (0.942) | (1.151) | | |
| Quarter x Year FEs | Yes | No | | |
| Maturity x Quarter x Year FEs | No | Yes | | |
| S&P 500 x Maturity | No | No | | |
| Observations | 9240 | 9193 | | |

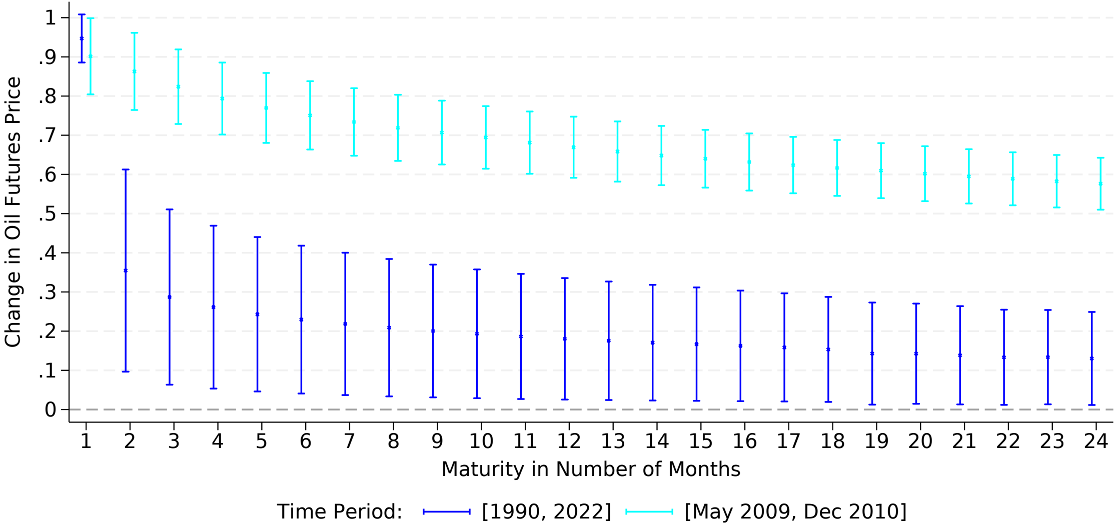
# Climate Policy Salience

| | (1) | (2) | (3) | (4) |
|---|---|---|---|---|
| International Climate Negotiations | -0.918** | -0.918* | -0.958** | |
| | (0.385) | (0.472) | (0.373) | |
| Renewable Policy | 2.667** | 2.719* | 2.571** | |
| | (1.256) | (1.533) | (1.234) | |
| Environmental Policy | 0.306 | 0.252 | 0.435 | |
| | (0.942) | (1.151) | (0.905) | |
| Quarter x Year FEs | Yes | No | Yes | |
| Maturity x Quarter x Year FEs | No | Yes | No | |
| S&P 500 x Maturity | No | No | Yes | |
| Observations | 9240 | 9193 | 9240 | |

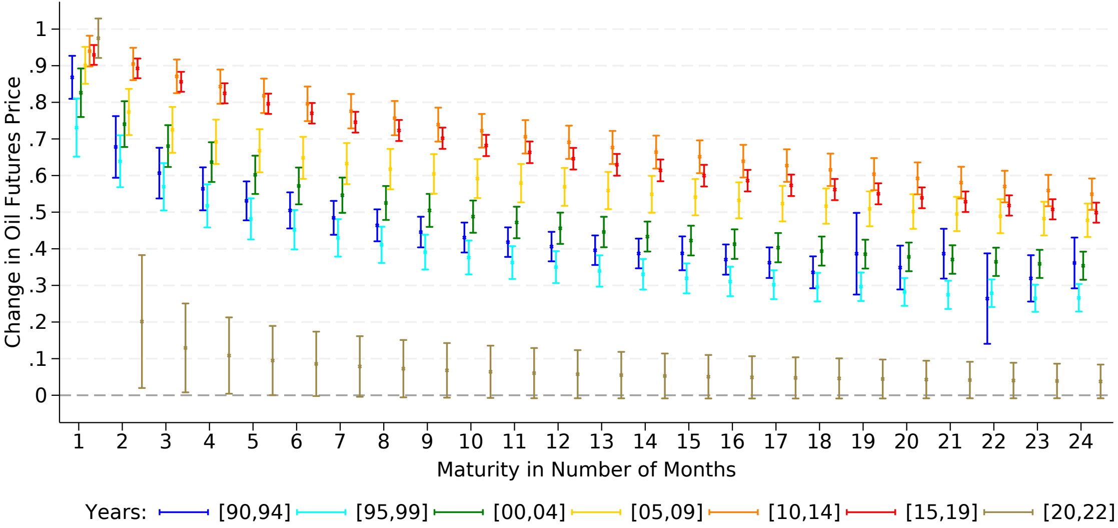
# Climate Policy Salience

| | (1) | (2) | (3) | (4) |
|---|---|---|---|---|
| International Climate Negotiations | -0.918** | -0.918* | -0.958** | -0.975** |
| | (0.385) | (0.472) | (0.373) | (0.453) |
| Renewable Policy | 2.667** | 2.719* | 2.571** | 2.581* |
| | (1.256) | (1.533) | (1.234) | (1.501) |
| Environmental Policy | 0.306 | 0.252 | 0.435 | 0.436 |
| | (0.942) | (1.151) | (0.905) | (1.096) |
| Quarter x Year FEs | Yes | No | Yes | No |
| Maturity x Quarter x Year FEs | No | Yes | No | Yes |
| S&P 500 x Maturity | No | No | Yes | Yes |
| Observations | 9240 | 9193 | 9240 | 9193 |

# Persistence of Oil Spot Price Shocks On Futures Prices



# Persistence of Oil Spot Price Shocks On Futures Prices



# Prediction Market and Oil Futures

| | (1) | (2) | (3) | (4) | (5) | (6) |
|---|---|---|---|---|---|---|
| | **A: Cutoffs for Prediction Market** | | | | | |
| Prediction Market | -3.43* | | | | | |
| | (1.87) | | | | | |
| Observations | 10072 | | | | | |
| Fixed Effects | 480 | | | | | |
| Clusters | 420 | | | | | |
| | **B: Cutoffs for Prediction Market and Google Trends** | | | | | |
| Prediction Market | | | | | | |
| Observations | | | | | | |
| Fixed Effects | | | | | | |
| Clusters | | | | | | |
| **Cutoff** $c$ **(**$\lvert\Delta x_t\rvert > c$**)** | 0 | 1 | 2 | 3 | 4 | 5 |

# Prediction Market and Oil Futures

| | (1) | (2) | (3) | (4) | (5) | (6) |
|---|---|---|---|---|---|---|
| | **A: Cutoffs for Prediction Market** | | | | | |
| Prediction Market | -3.43* | -3.68* | | | | |
| | (1.87) | (1.98) | | | | |
| Observations | 10072 | 2880 | | | | |
| Fixed Effects | 480 | 456 | | | | |
| Clusters | 420 | 120 | | | | |
| | **B: Cutoffs for Prediction Market and Google Trends** | | | | | |
| Prediction Market | | | | | | |
| Observations | | | | | | |
| Fixed Effects | | | | | | |
| Clusters | | | | | | |
| **Cutoff** $c$ **(**$\lvert\Delta x_t\rvert > c$**)** | 0 | 1 | 2 | 3 | 4 | 5 |

# Prediction Market and Oil Futures

| | (1) | (2) | (3) | (4) | (5) | (6) |
|---|---|---|---|---|---|---|
| | **A: Cutoffs for Prediction Market** | | | | | |
| Prediction Market | -3.43* | -3.68* | -3.49* | | | |
| | (1.87) | (1.98) | (1.97) | | | |
| Observations | 10072 | 2880 | 1920 | | | |
| Fixed Effects | 480 | 456 | 384 | | | |
| Clusters | 420 | 120 | 80 | | | |
| | **B: Cutoffs for Prediction Market and Google Trends** | | | | | |
| Prediction Market | | | | | | |
| Observations | | | | | | |
| Fixed Effects | | | | | | |
| Clusters | | | | | | |
| **Cutoff** $c$ **(**$\lvert\Delta x_t\rvert > c$**)** | 0 | 1 | 2 | 3 | 4 | 5 |

# Prediction Market and Oil Futures

| | (1) | (2) | (3) | (4) | (5) | (6) |
|---|---|---|---|---|---|---|
| | **A: Cutoffs for Prediction Market** | | | | | |
| Prediction Market | -3.43* | -3.68* | -3.49* | -3.89* | | |
| | (1.87) | (1.98) | (1.97) | (2.26) | | |
| Observations | 10072 | 2880 | 1920 | 1344 | | |
| Fixed Effects | 480 | 456 | 384 | 360 | | |
| Clusters | 420 | 120 | 80 | 56 | | |
| | **B: Cutoffs for Prediction Market and Google Trends** | | | | | |
| Prediction Market | | | | | | |
| Observations | | | | | | |
| Fixed Effects | | | | | | |
| Clusters | | | | | | |
| **Cutoff** $c$ **(**$\|\Delta x_t\| > c$**)** | 0 | 1 | 2 | 3 | 4 | 5 |

# Prediction Market and Oil Futures

| | (1) | (2) | (3) | (4) | (5) | (6) |
|---|---|---|---|---|---|---|
| | **A: Cutoffs for Prediction Market** | | | | | |
| Prediction Market | -3.43* | -3.68* | -3.49* | -3.89* | -6.83*** | |
| | (1.87) | (1.98) | (1.97) | (2.26) | (2.07) | |
| Observations | 10072 | 2880 | 1920 | 1344 | 912 | |
| Fixed Effects | 480 | 456 | 384 | 360 | 264 | |
| Clusters | 420 | 120 | 80 | 56 | 38 | |
| | **B: Cutoffs for Prediction Market and Google Trends** | | | | | |
| Prediction Market | | | | | | |
| Observations | | | | | | |
| Fixed Effects | | | | | | |
| Clusters | | | | | | |
| **Cutoff** $c$ **(**$\|\Delta x_t\| > c$**)** | 0 | 1 | 2 | 3 | 4 | 5 |

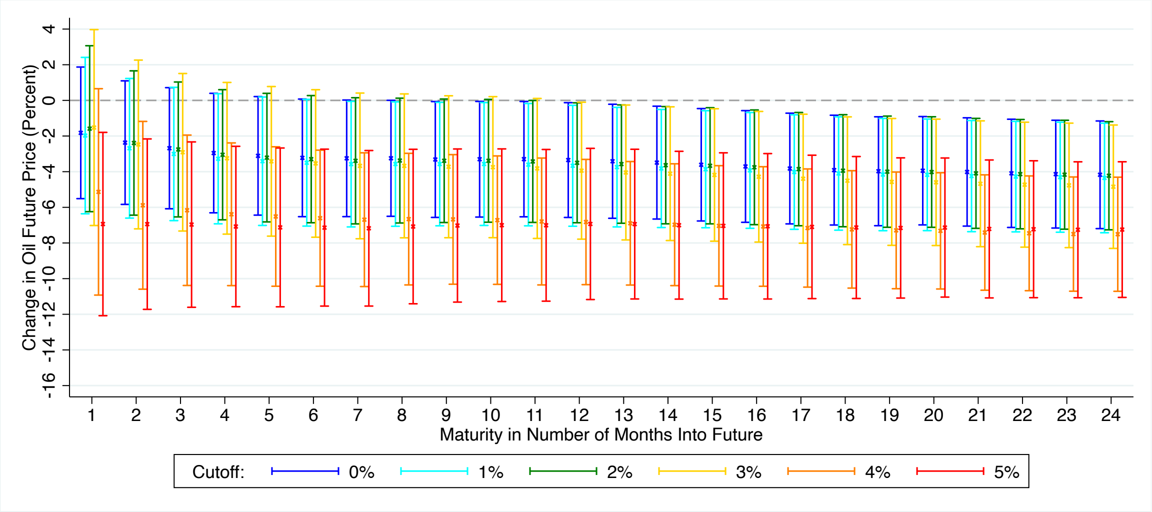
# Prediction Market and Oil Futures

| | (1) | (2) | (3) | (4) | (5) | (6) |
|---|---|---|---|---|---|---|
| | **A: Cutoffs for Prediction Market** | | | | | |
| Prediction Market | -3.43* | -3.68* | -3.49* | -3.89* | -6.83*** | -7.08*** |
| | (1.87) | (1.98) | (1.97) | (2.26) | (2.07) | (2.39) |
| Observations | 10072 | 2880 | 1920 | 1344 | 912 | 624 |
| Fixed Effects | 480 | 456 | 384 | 360 | 264 | 240 |
| Clusters | 420 | 120 | 80 | 56 | 38 | 26 |
| | **B: Cutoffs for Prediction Market and Google Trends** | | | | | |
| Prediction Market | | | | | | |
| | | | | | | |
| Observations | | | | | | |
| Fixed Effects | | | | | | |
| Clusters | | | | | | |
| **Cutoff** $c$ **(**$\lvert\Delta x_t\rvert > c$**)** | 0 | 1 | 2 | 3 | 4 | 5 |

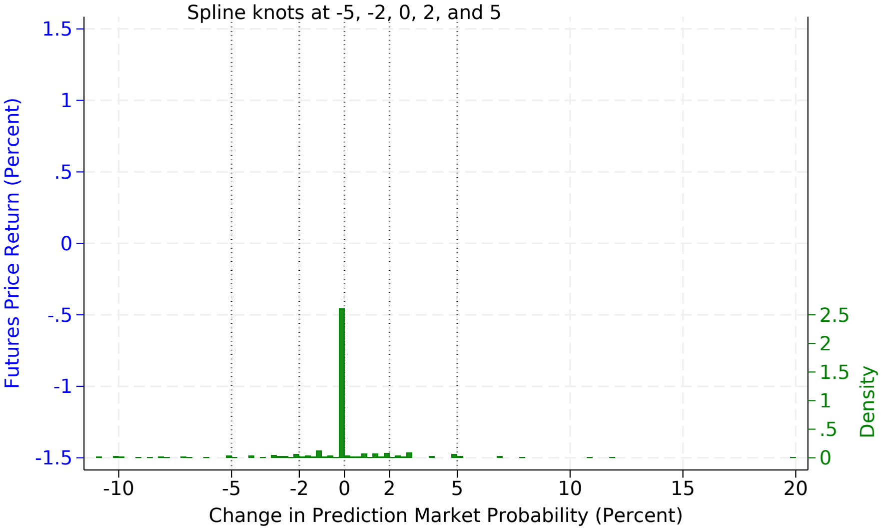
# Prediction Market and Oil Futures

| | (1) | (2) | (3) | (4) | (5) | (6) |
|---|---|---|---|---|---|---|
| | **A: Cutoffs for Prediction Market** | | | | | |
| Prediction Market | -3.43* | -3.68* | -3.49* | -3.89* | -6.83*** | -7.08*** |
| | (1.87) | (1.98) | (1.97) | (2.26) | (2.07) | (2.39) |
| Observations | 10072 | 2880 | 1920 | 1344 | 912 | 624 |
| Fixed Effects | 480 | 456 | 384 | 360 | 264 | 240 |
| Clusters | 420 | 120 | 80 | 56 | 38 | 26 |
| | **B: Cutoffs for Prediction Market and Google Trends** | | | | | |
| Prediction Market | -3.43* | -4.34* | -4.35* | -5.03** | -5.23** | -6.99** |
| | (1.87) | (2.55) | (2.39) | (2.43) | (2.38) | (2.97) |
| Observations | 10072 | 1992 | 1296 | 936 | 672 | 384 |
| Fixed Effects | 480 | 456 | 360 | 312 | 240 | 144 |
| Clusters | 420 | 83 | 54 | 39 | 28 | 16 |
| **Cutoff** $c$ **(**$\lvert\Delta x_t\rvert > c$**)** | 0 | 1 | 2 | 3 | 4 | 5 |

# Results By Maturity

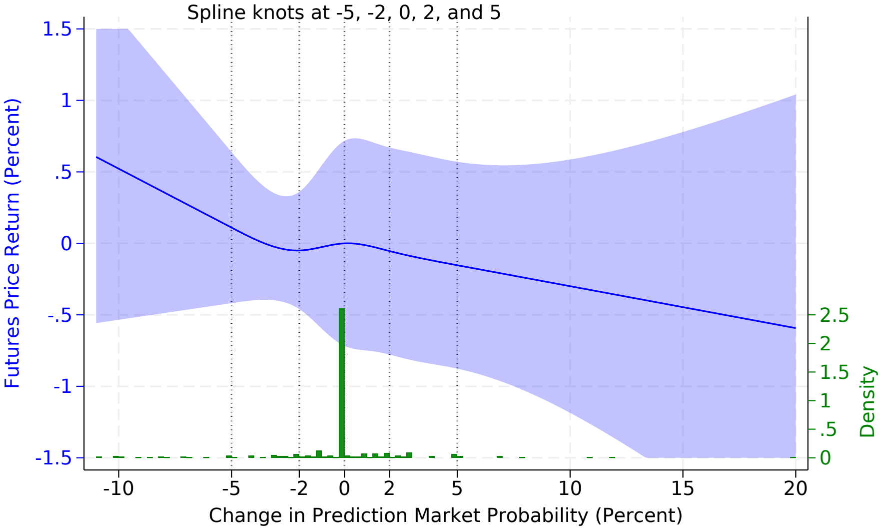


# Possible Nonlinear Response



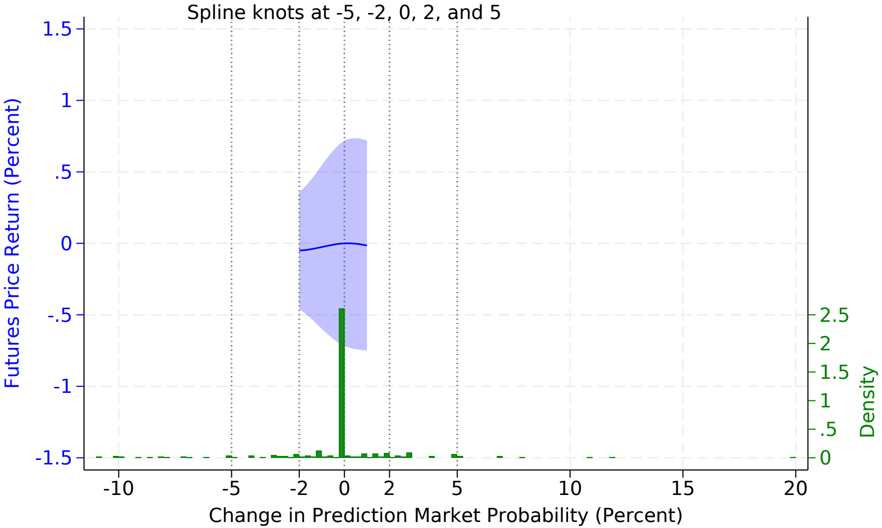

- Density
  - Observed changes
  - Mass at 0
  - Bid-ask spread

# Possible Nonlinear Response



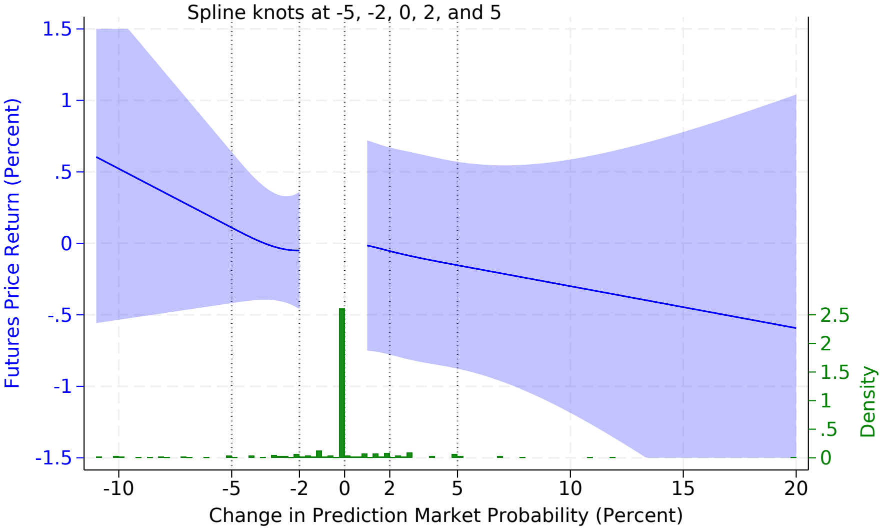

- Density
  - Observed changes
  - Mass at 0
  - Bid-ask spread
- Restricted cubic spline

# Possible Nonlinear Response




- Density
  - Observed changes
  - Mass at 0
  - Bid-ask spread
- Restricted cubic spline
- Flat in $[-2, 1]$

# Possible Nonlinear Response




- Density
  - Observed changes
  - Mass at 0
  - Bid-ask spread
- Restricted cubic spline
- Flat in $[-2, 1]$
- Linear in
  - $(-\infty, -2]$
  - $[1, \infty)$

# Prediction Market and Coal Futures

| | (1) | (2) | (3) | (4) | (5) | (6) |
|---|---|---|---|---|---|---|
| | **A: Cutoffs for Prediction Market** | | | | | |
| Prediction Market | -1.02 | -1.39 | -2.60 | -3.00 | -3.75* | -5.50* |
| | (1.63) | (1.66) | (1.81) | (1.89) | (1.99) | (2.91) |
| Observations | 10080 | 2880 | 1920 | 1344 | 912 | 624 |
| Fixed Effects | 480 | 456 | 384 | 360 | 264 | 240 |
| Clusters | 420 | 120 | 80 | 56 | 38 | 26 |
| | **B: Cutoffs for Prediction Market and Google Trends** | | | | | |
| Prediction Market | -1.02 | -4.12* | -4.55* | -4.96* | -5.22* | -8.45** |
| | (1.63) | (2.29) | (2.66) | (2.65) | (2.94) | (3.24) |
| Observations | 10080 | 1992 | 1296 | 936 | 672 | 384 |
| Fixed Effects | 480 | 456 | 360 | 312 | 240 | 144 |
| Clusters | 420 | 83 | 54 | 39 | 28 | 16 |
| **Cutoff** $c$ **(**$\lvert\Delta x_t\rvert > c$**)** | 0 | 1 | 2 | 3 | 4 | 5 |

# Urgenda v. Netherlands Ruling

| | (1) | (2) | (3) | (4) | (5) |
|---|---|---|---|---|---|
| $\mathbb{1}_v$ | -0.573** | | | | |
| | (0.276) | | | | |
| Observations | 6275 | | | | |
| Fixed Effects | 300 | | | | |
| Clusters | 251 | | | | |
| Years | [15,15] | | | | |

# Urgenda v. Netherlands Ruling

| | (1) | (2) | (3) | (4) | (5) |
|---|---|---|---|---|---|
| $\mathbb{1}_v$ | -0.573** | -0.618** | | | |
| | (0.276) | (0.260) | | | |
| Observations | 6275 | 31449 | | | |
| Fixed Effects | 300 | 1500 | | | |
| Clusters | 251 | 1258 | | | |
| Years | [15,15] | [13,17] | | | |

# Urgenda v. Netherlands Ruling

| | (1) | (2) | (3) | (4) | (5) |
|---|---|---|---|---|---|
| $\mathbb{1}_v$ | -0.573** | -0.618** | -0.653** | | |
| | (0.276) | (0.260) | (0.258) | | |
| Observations | 6275 | 31449 | 56515 | | |
| Fixed Effects | 300 | 1500 | 2700 | | |
| Clusters | 251 | 1258 | 2261 | | |
| Years | [15,15] | [13,17] | [11,19] | | |

# Urgenda v. Netherlands Ruling

| | (1) | (2) | (3) | (4) | (5) |
|---|---|---|---|---|---|
| $\mathbb{1}_v$ | -0.573** | -0.618** | -0.653** | -0.929*** | |
| | (0.276) | (0.260) | (0.258) | (0.281) | |
| Observations | 6275 | 31449 | 56515 | 181665 | |
| Fixed Effects | 300 | 1500 | 2700 | 8819 | |
| Clusters | 251 | 1258 | 2261 | 7538 | |
| Years | [15,15] | [13,17] | [11,19] | [90,19] | |

# Urgenda v. Netherlands Ruling

| | (1) | (2) | (3) | (4) | (5) |
|---|---|---|---|---|---|
| $\mathbb{1}_v$ | -0.573** | -0.618** | -0.653** | -0.929*** | -0.895*** |
| | (0.276) | (0.260) | (0.258) | (0.281) | (0.277) |
| Observations | 6275 | 31449 | 56515 | 181665 | 200539 |
| Fixed Effects | 300 | 1500 | 2700 | 8819 | 9719 |
| Clusters | 251 | 1258 | 2261 | 7538 | 8294 |
| Years | [15,15] | [13,17] | [11,19] | [90,19] | [90,22] |

# Outline

# Discussion

- Counterfactual: global oil consumption if US cap-and-trade policy had passed
  - Using the average long-term demand elasticity $\epsilon = -0.6$ from Hamilton (2009, Table 3)
  - Price coefficients from Permit Market table

# Discussion

| | (1) | (2) | (3) | (4) | (5) | (6) |
|---|---|---|---|---|---|---|
| | **A: Cutoffs for Prediction Market** | | | | | |
| Prediction Market | -3.43* | -3.68* | -3.49* | -3.89* | -6.83*** | -7.08*** |
| | (1.87) | (1.98) | (1.97) | (2.26) | (2.07) | (2.39) |
| Observations | 10072 | 2880 | 1920 | 1344 | 912 | 624 |
| Fixed Effects | 480 | 456 | 384 | 360 | 264 | 240 |
| Clusters | 420 | 120 | 80 | 56 | 38 | 26 |
| | **B: Cutoffs for Prediction Market and Google Trends** | | | | | |
| Prediction Market | -3.43* | -4.34* | -4.35* | -5.03** | -5.23** | -6.99** |
| | (1.87) | (2.55) | (2.39) | (2.43) | (2.38) | (2.97) |
| Observations | 10072 | 1992 | 1296 | 936 | 672 | 384 |
| Fixed Effects | 480 | 456 | 360 | 312 | 240 | 144 |
| Clusters | 420 | 83 | 54 | 39 | 28 | 16 |
| **Cutoff** $c$ ($\lvert\Delta x_t\rvert > c$) | 0 | 1 | 2 | 3 | 4 | 5 |

# Discussion

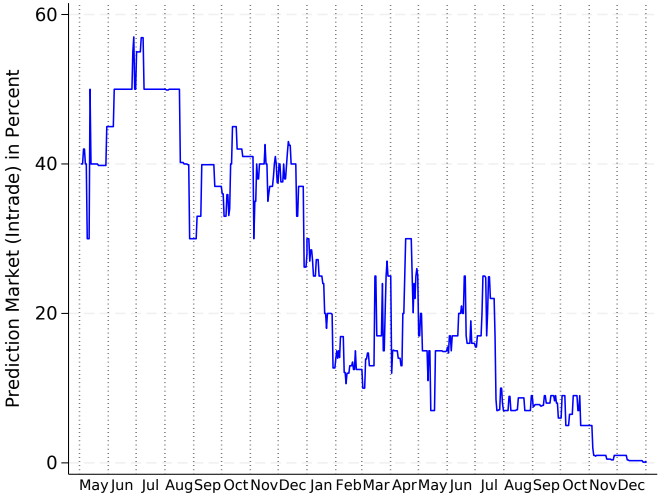
- Counterfactual: global oil consumption if US cap-and-trade policy had passed
  - Using the average long-term demand elasticity $\epsilon = -0.6$ from Hamilton (2009, Table 3)
  - Price coefficients from Permit Market table
  - Increase in global oil consumption $dQ = \epsilon dP =$ 2.0-4.2%

# Discussion

- Counterfactual: global oil consumption if US cap-and-trade policy had passed
  - Using the average long-term demand elasticity $\epsilon = -0.6$ from Hamilton (2009, Table 3)
  - Price coefficients from Permit Market table
  - Increase in global oil consumption $dQ = \epsilon dP =$ 2.0-4.2%

- Uncertainty itself has an effect
  - Additional oil consumption induced by the bill's deliberation
  - Starting with an undisturbed price path
  - Average short-term demand elasticity of $\epsilon = -0.26$ from Hamilton (2009, Table 3)
    - ★ As the probability of the law passing increases, the price is suppressed from undisturbed path
    - ★ As the bill collapses, it returns to undisturbed path
    - ★ We calculate $dQ = \epsilon dP$ daily and add the disturbances over May 2009 - December 2010

# Discussion




- Prices (cents)
  - Probability of law passing
- Initial above 50%
  - House passed bill 219–212
  - June 26, 2009
- Probability approached zero
  - Bill was abandoned

# Discussion

- Counterfactual: global oil consumption if US cap-and-trade policy had passed
  - Using the average long-term demand elasticity $\epsilon = -0.6$ from Hamilton (2009, Table 3)
  - Price coefficients from Permit Market table
  - Increase in global oil consumption $dQ = \epsilon dP =$ 2.0-4.2%
- Uncertainty itself has an effect
  - Additional oil consumption induced by the bill's deliberation
  - Starting with an undisturbed price path
  - Average short-term demand elasticity of $\epsilon = -0.26$ from Hamilton (2009, Table 3)
    - As the probability of the law passing increases, the price is suppressed from undisturbed path
    - As the bill collapses, it returns to undisturbed path
    - We calculate $dQ = \epsilon dP$ daily and add the disturbances over May 2009 - December 2010
    - Combined additional oil consumption are 7.7-26.69 million metric tons
    - Annual consumption is 4.4 billion tons

# Policy Implication for Carbon Tax

- Carbon tax
  - Almost entirely absorbed by producers
    - If tax was passed through to consumers, not all oil would be sold (Heal & Schlenker 2019)
    - Reduction in scarcity rents of oil producers
  - *Global* carbon tax would not regressive as cost born by oil producers
  - Even if there is no pass-through to consumers
    - Still changes the relative competitiveness of various fossil fuels (depending on carbon intensity)

# Policy Implication for Carbon Tax

- Carbon tax
  - Almost entirely absorbed by producers
    - ★ If tax was passed through to consumers, not all oil would be sold (Heal & Schlenker 2019)
    - ★ Reduction in scarcity rents of oil producers
  - *Global* carbon tax would not regressive as cost born by oil producers
  - Even if there is no pass-through to consumers
    - ★ Still changes the relative competitiveness of various fossil fuels (depending on carbon intensity)

- Agreement on minimum corporate tax (includes China and India)
  - Can the same group pass a minimum energy tax?

# Outline

# Conclusions

- Novel evidence on the "Green Paradox"' for climate change legislation
  - Climate bills that limit future oil use shift oil consumption from the future towards the present
- Daily shocks to the oil spot price
  - historically quickly phase out over time, i.e., maturities further into the future show less responsiveness to changes in oil spot prices
  - during the time period when a US climate bill was deliberated, the daily shocks to the spot price became much more persistent
- Monthly changes in oil futures respond to the salience of climate policy
  - negative relationship between the salience of international climate negotiations
  - positive relationship between the salience of renewable energy policy
    - ★ Market sees this as reduced pressure to limit fossil fuel consumption
- Daily future returns respond to changes in prediction market for climate bill
  - Effect bigger for larger prediction market changes when google trends show search activity
  - Effect increases for longer maturities
- Dutch court ruling lead to abnormal negative oil future return