# Markets, Metals and Melting Points:

## deriving market expectations of global warming from commodity prices

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# Background on existing work

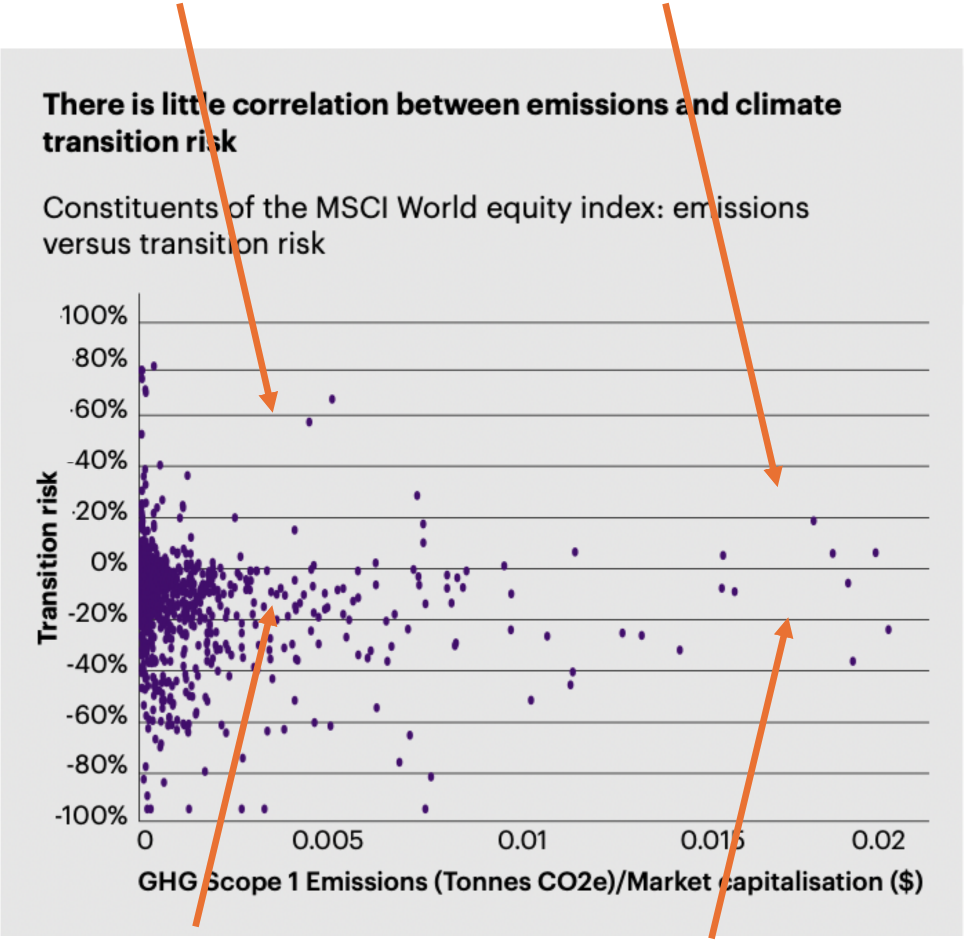
- Rich tradition of central banks extracting information from financial market prices
- Current approaches to deriving expectations of global warming focus on the level of emissions embodied in firms' activities (e.g., MSCI implied temperature increases)
- Academic literature assess the degree to which emissions explain stock returns: **but results are quite mixed**
- Increasing recognition of the role that some commodities will play in enabling the transition to lower emissions

# Our approach (1)

- We avoid taking emissions as a proxy of firms' prospects under climate transition. Emissions don't correlate well with firms' profitability under transition to net zero
- We look instead at commodities that are likely to play a crucial role in enabling transition: copper, nickel, cobalt
- The more weight market participants attach to a timely, ambitious and credible transition, the higher demand for – and prices of – these commodities

Low emitting, transition gainers (wind, solar manufacturers)

High emitting, transition gainers (copper, lithium miners)




Low emitting, transition losers (software supplier to O&G)

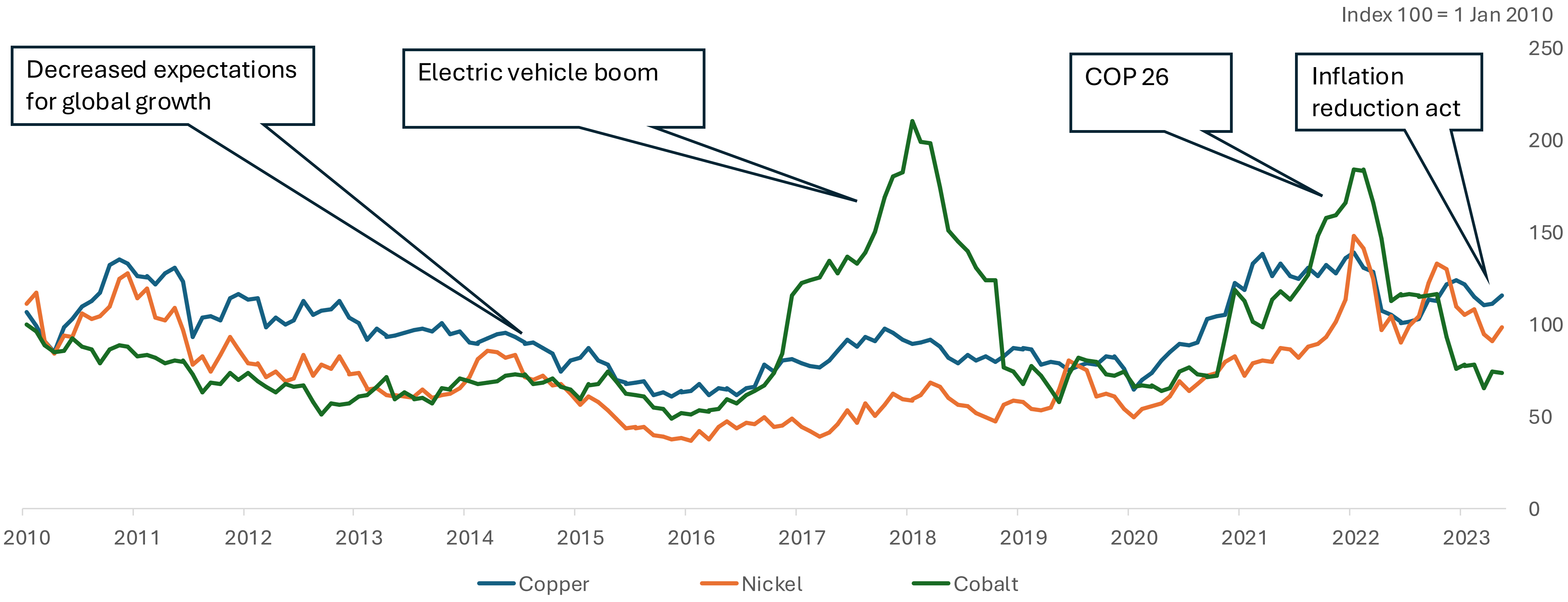
High emitting, transition losers (oil, coal)

# Our approach (2)

1. Consider historical prices of transition-critical commodities
2. Isolate changes in these prices that are due to climate transition
3. Take these ‘adjusted commodity prices’ and fit a model of future global temperatures
4. Leaves us with changes in market-implied expectations of global temperatures in 2050

# Data

**Monthly prices of three transition-critical commodities**



# Isolating the effect of climate transition on commodity prices

## Other factors found to affect commodity prices

- Better prospects for economic growth increase commodity prices
- Lower interest rates reduce commodity prices by increasing:
  - Present value of commodities for use in end products
  - Incentives of speculators
  - Incentives to hold inventories
- Geopolitical tensions can prompt changes in expected supply

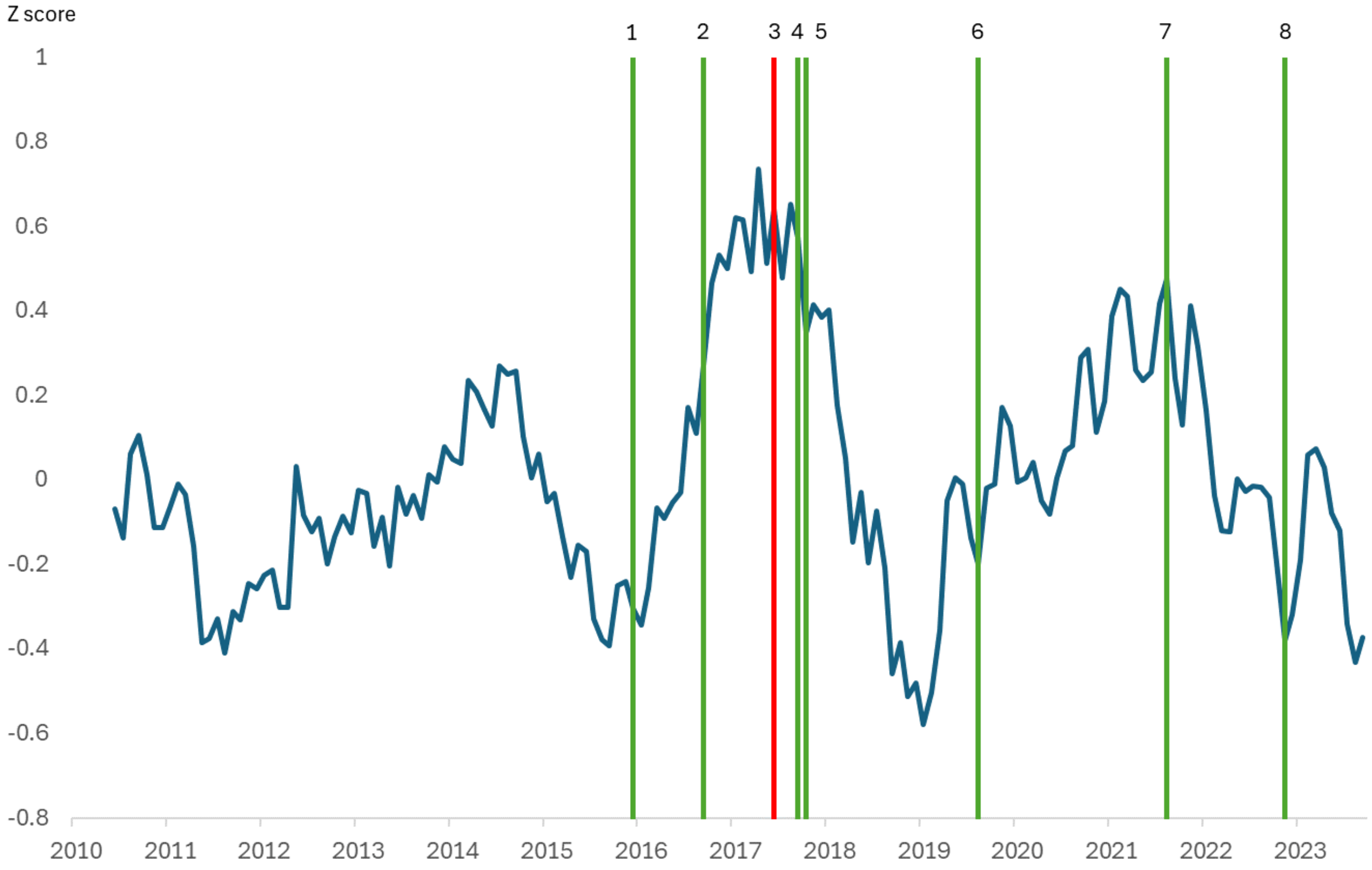
## We use a sign-restricted VAR model to isolate the effects of climate transition

- Identifies 'structural shocks' in the data based on the directional co-movement of different variables

| | Structural shock | | |
|---|---|---|---|
| | Increase in economic output | Increase in interest rates | **Climate transition** |
| **Prices of transition critical commodities (copper, nickel cobalt)** | All increase | All decrease | **All increase** |
| **Economic output** | Increases | Unrestricted | **Unrestricted** |
| **US one-year interest rate** | Unrestricted | Increases | **Unrestricted** |
| **Oil price** | Increases | Decreases | **Decreases** |

Robustness checks: (1) we check the response of commodity prices if oil is removed from the model (same directional response that is less strong) and (2) the response of gold to the climate transition shock (insignificant)

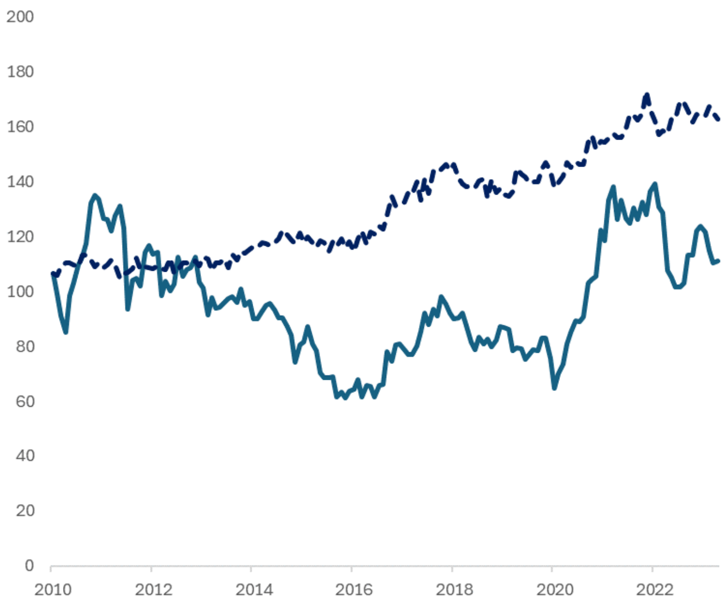
# Structural shocks related to climate transition



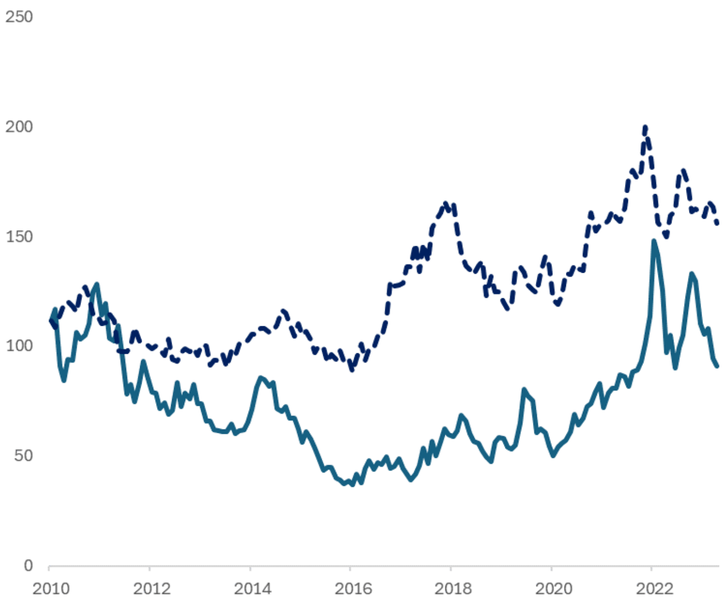

| # | Date | Event | Assumed impact on climate transition |
|---|---|---|---|
| 1 | 12 Dec 2015 | Paris Agreement | Positive |
| 2 | 3 Sep 2016 | Ratification of Paris Agreement | Positive |
| 3 | 1 June 2017 | US withdrawal from Paris Agreement | Negative |
| 4 | 10 Sep 2017 | Chinese government commitment to EV | Positive |
| 5 | 1 Oct 2017 | Formation of EU Battery Alliance | Positive |
| 6 | 15 Aug 2019 | EU Green deal | Positive |
| 7 | 31 Oct 2021 | COP 26 | Positive |
| 8 | 17 Oct 2022 | US Inflation Reduction Act | Positive |

# Series of ‘adjusted prices’ that reflect climate transition

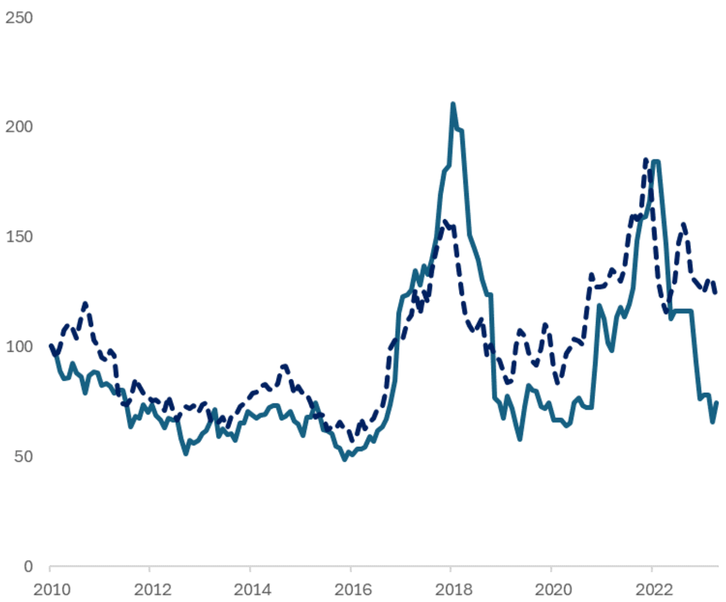
## Copper




## Nickel




## Cobalt



# A model of adjusted commodity prices as a function of global temperatures

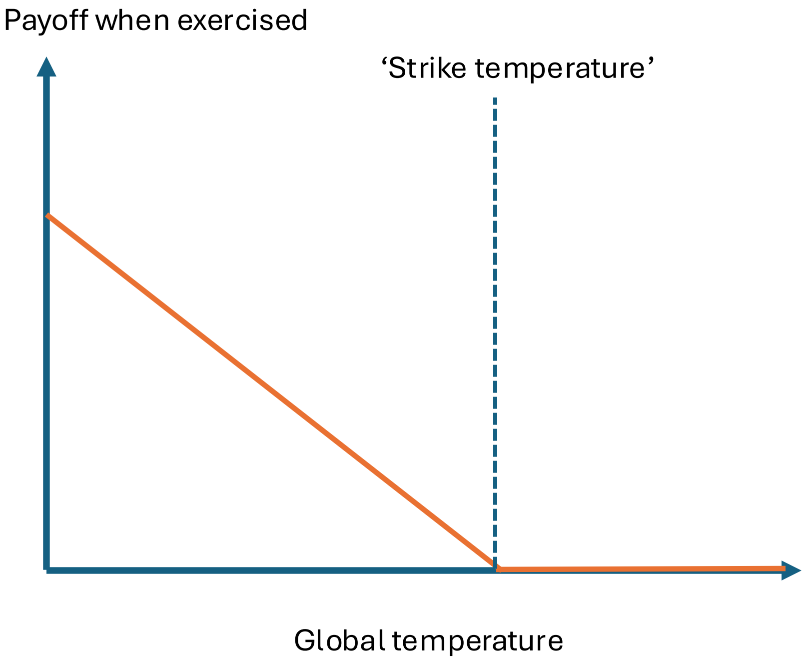
- View transition-critical commodities as put options on global temperatures
- Strike price is equal to some (high) future value of global temperatures – *below which the commodity has value in transition*
- The more ambitious/credible markets perceive NZ transition, the lower future temperatures, the more commodities worth
- Commodity *i* has value:

$$|K_i - S_t|^+$$

where $k_i$ is the strike temperature, and $S_t$ is the future evolution of actual temperatures

- Option is perpetual (non-perishable good)
- Present value has closed-form formula

**Payoff of a hypothetical perpetual put option, struck on underlying value of global temperatures**



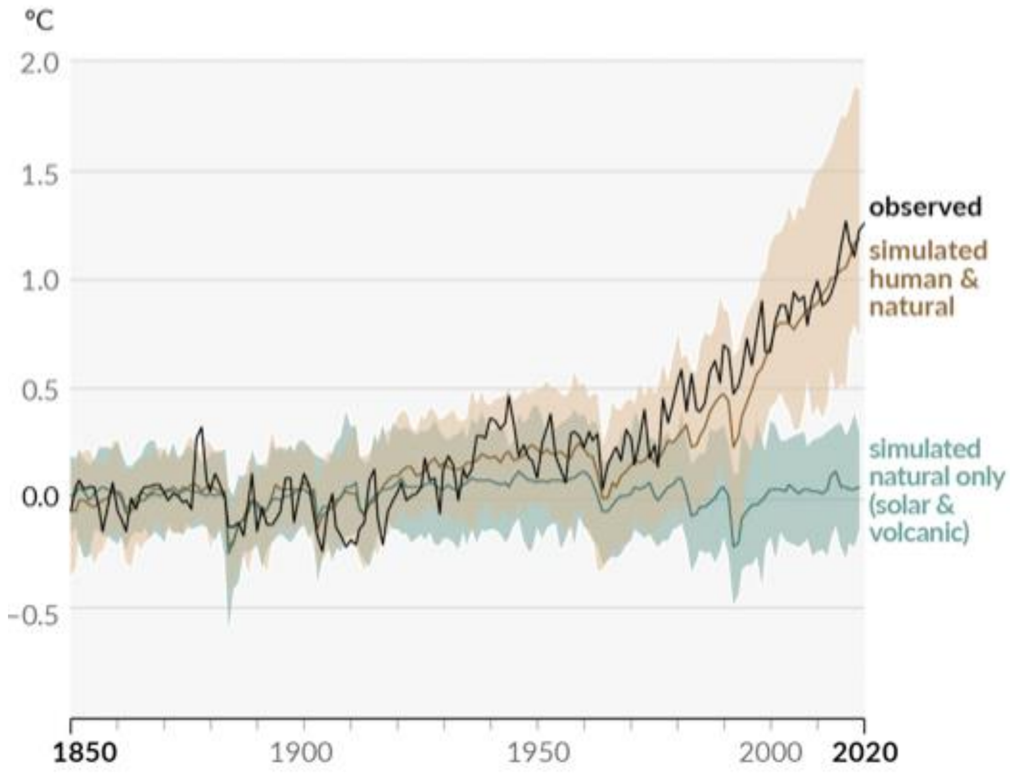
# A stochastic process for global temperatures

- Global temperatures are the underlying ‘instrument’ of our ‘option’
- It’s hard to know what process to use to capture temperatures!
- We observe recent exponential increase in, and random innovations around, temperature
- We assume a geometric Brownian motion

$$\frac{dS_t}{S_t} = \mu dt + \sigma dZ$$

- Matches rough behaviour we observe over past few decades (chart)
- Plenty of scope to make this more complex!

**Global earth surface temperature (annual average)**



# Estimating the model

(1) Calibrate the modelled price of each commodity in 2023

- Modelled price of commodity *i* is $\rho_i f(S, Ki, r, \mu, \sigma)$
- Set $(\mu, \sigma)$ to match real-world predicted temperature increase (from IPCC report)
- Find $\rho_i$ so that modelled price of commodity matches that in January 2023

(2) Fit model to historical prices

- Monthly price of each of four commodities, 2010-23
- Each month, find drift and volatility of temperature $(\mu, \sigma)$ that minimises RMSE across observed/model prices
- Time series of the market-expected mean/variance of temperatures in 2050

(3) Estimate the strike prices

- Repeat the procedure in (2) for different commodity strike temperatures,

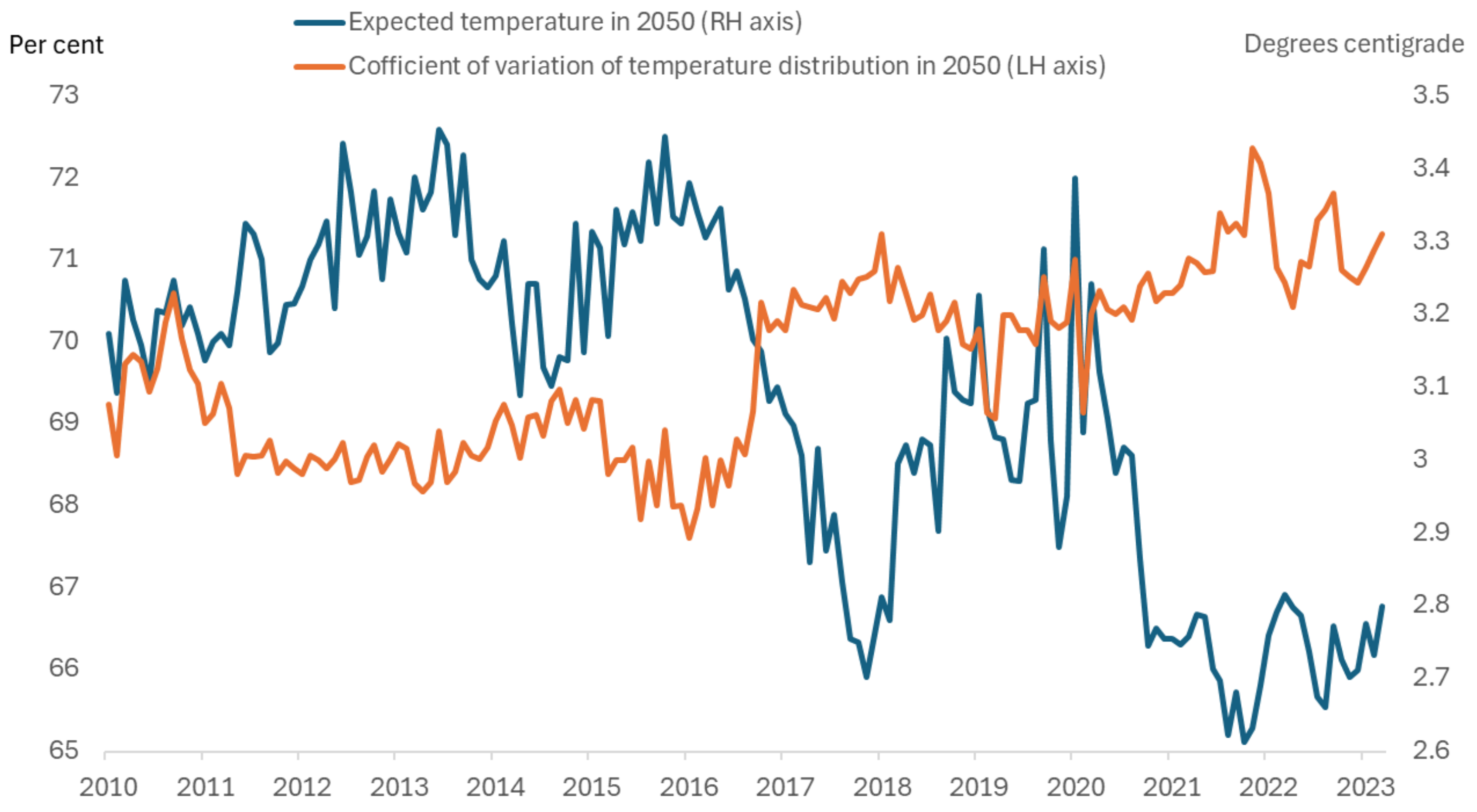
$$(K_1, K_2\ K_3\ , K_4)$$

- Search (numerically) for the strike prices that minimise the average RMSE error between the modelled and fitted prices, summed across all time periods.

(4) Gives us a single time series of mean/variance of expected temperatures in 2050

- In each period, expected/variance of temperatures is that which best fits commodity prices in that period
- Final observation (for January 2023) matches the IPCC forecast

# Results: estimated distribution of global temperatures in 2050

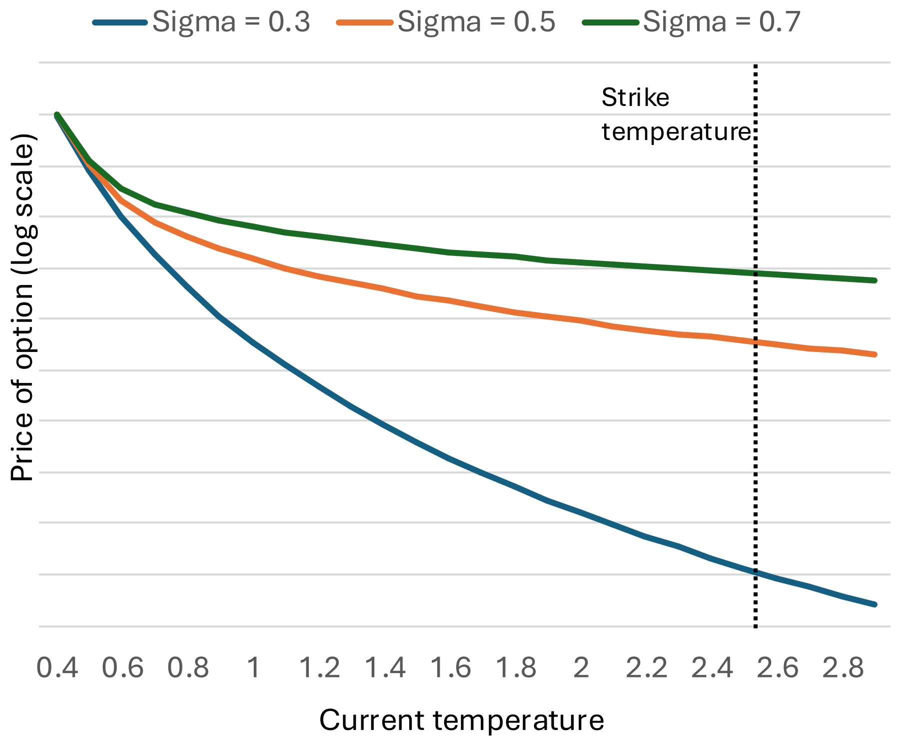



- Market expectations of global warming have decreased a little since 2010 (troughed in 2022)
- ...but have increased a little since ('ESG backlash?'; Retraction of commitments?)
- Expectations are volatile and variance has increased recently. Is transition credible?

# One extra insight

- Recall: literature struggles to distinguish between prices of high/low emitters – **why?**
- Options value higher for lower temperatures (in-the-money option is worth more!)
- But look at the option's delta – sensitivity of price to temperature (chart)
- **This is lower if (i) underlying is more volatile; and (ii) as time to expiry increases (particular when the option is out the money)**
- Climate change is the ultimate deep-out-the money long expiry option.
- Even if emissions did proxy risk/return, no wonder we don't see a difference in prices

**The present value of a hypothetical perpetual put option as a function of underlying global temperature in 2050**

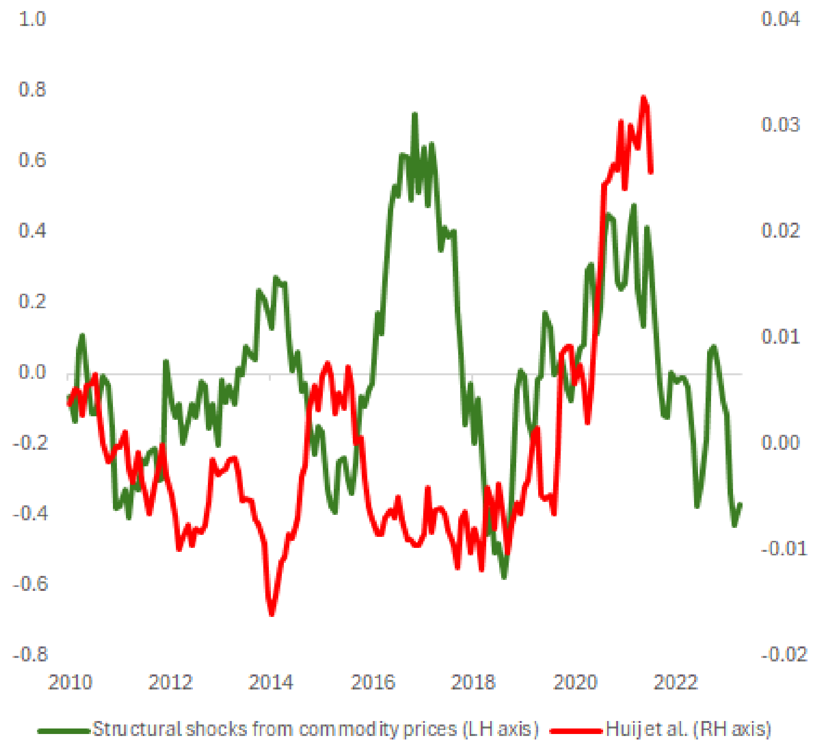


# Comparison with measures of climate risk

**Measures of climate risk from the literature**

| Paper | Name of index | Type | Description |
|---|---|---|---|
| Gorgen et al (2020, 'Carbon risk', working paper | Brown-Minus-Green (BMG) portfolio returns | Equity market prices | Value of portfolio long 'brown' firms and short 'green' firms |
| Huij et al. (2024), 'Carbon Beta: A Market-Based Measure of Climate Transition Risk Exposure', WP | Pollutive-Minus-Clean (PMC) portfolio returns | Equity market prices | Difference in value between portfolios of most vs least polluting firms |
| Engle et al (2020), 'Hedging climate change news', Review of Financial Studies | Wall Street Journal (WSJ) climate change news index | News | Intensity of climate-related news in the WSJ |
| Bua et al (2024), 'Transition versus physical climate risk pricing in European financial markets: a text-based approach', The European Journal of Finance | Physical and Climate Risk indices based on text-based approaches from Reuters News articles | News | Intensity of media coverage related to physical and transition risks |

**Huija et al (financial markets climate risk measure)**




- There is little correlation between our measure and those based on equities / news
- Which is unsurprising given they are measuring different things
- One exception is the period between 2018 and 2021

# Summary slide

- Model of commodity prices as ‘options’ on future global temperatures
- Negates the need to take emissions as a proxy for firms’ prospects under climate transition
- Strip out factors that affect commodity prices besides climate transition
- Derive market expectations of the future mean and variance of global temperatures in 2050
- Global temperature expectations have fallen a little…
- …but have increased recently, and are highly volatile