Climate Risk Premium: Evidence from Commodity Options

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Abstract

This paper investigates the pricing of climate-related risks in the commodity derivatives market. Leveraging a proprietary dataset of “brown” and “green” iron ore options traded on the Singapore Exchange, we document the existence of significant climate-specific variance and skewness risk premiums. Our analysis reveals a nonlinear, inverted U-shaped relationship between climate policy uncertainty and these risk premiums: low-to-moderate uncertainty elevates premiums by destabilizing market expectations, whereas extreme uncertainty suppresses them by reducing market activity. We also find that the impact of climate policy uncertainty is asymmetric, with sustained levels having a stronger impact than transient shocks. These effects are concentrated in short-maturity options, highlighting the transitional nature of policy-introduced risks. By employing a novel dual-differencing methodology, our study provides a direct and robust measure of climate-specific risk premium, advancing the understanding of climate risk pricing in commodity derivatives and offering valuable insights for policymakers and investors.

Keywords: climate risk, risk premium, climate policy uncertainty, commodity options

1 Introduction

Climate change has emerged as one of the most urgent global challenges of the 21st century, with significant ramifications for economies, societies, and financial markets worldwide. It poses both physical risks, such as extreme weather events, and transition risks linked to evolving policy, regulatory, and technological responses aimed at mitigating climate change. According to the World Economic Forum's Global Risks Report 2023,[1] environmental threats dominate the top ten global risks over the coming decade, with "failure to mitigate climate change" ranked as the most severe. As practitioners and researchers increasingly acknowledge the necessity of adapting to these complex and evolving risks, understanding how climate-related risks are priced in financial markets has become a central inquiry in financial economics.

The notion of a "climate risk premium" has gained notable attention in both theoretical and empirical finance research over the past decade. Theoretical consensus suggests that assets associated with high carbon emissions or environmental harm ("brown" assets) should command a positive climate risk premium, whereas assets aligned with sustainable, climate-friendly activities ("green" assets) should earn on average negative climate risk premiums (e.g., Engle et al., 2020; Pástor, Stambaugh, and Taylor, 2021; Pedersen, Fitzgibbons, and Pomorski, 2021; Hsu, Li, and Tsou, 2023).[2] This distinction arises because brown assets are more vulnerable to climate-related risks, while green assets are viewed as hedges against such risks. Consequently, green assets attract strong demand from climate-conscious investors, resulting in lower expected returns. However, empirical evidence remains mixed. Some studies find that climate-related risks adversely affect brown assets through various channels, including depressed prices, heightened volatility, increased downside tail risk, and elevated costs of capital (e.g., Bolton and Kacperczyk, 2021, 2023; Seltzer, Starks, and Zhu, 2022; Ilhan, Sautner, and Vilkov, 2021; Chava, 2014), aligning

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[1] `www.weforum.org/publications/global-risks-report-2023/`

[2] In this paper, we focus exclusively on the environmental (E) component of ESG (see Starks (2023)). Accordingly, we define "green" as climate-friendly and "brown" as climate-unfriendly.

with standard risk compensation theory. In contrast, others report insignificant or even contrary effects (e.g., Görgen et al., 2020; Bauer et al., 2022; Ardia et al., 2023; Byrd and Cooperman, 2018; Monasterolo and De Angelis, 2020; Bernardini et al., 2021; Duan, Li, and Wen, 2021; In, Park, and Monk, 2019; Zhang, 2024), suggesting that the pricing of climate-related risks in financial markets may be more nuanced than initially posited.

Several factors likely account for these conflicting results. Differences in empirical methodologies, such as backward- or forward-looking designs or event studies, can yield divergent results. The choice of impact measures, whether focusing on asset prices, volatility, downside risk, or the cost of capital, can also influence conclusions. Moreover, the distinction between physical and transition climate risks, as well as the variety of asset classes examined (e.g., equities, corporate bonds, or real estate), adds further complexity. Finally, the evolving nature of investor awareness and practices introduces additional challenges in interpreting these findings, as market perceptions and strategies related to climate risks continue to develop.

A key impediment to advancing this literature is the challenge of cleanly isolating climate-related risk premiums in the presence of confounding firm-specific or asset-specific characteristics unrelated to climate concerns. This difficulty in achieving standardized measurement constrains cross-study comparisons and underscores the necessity for research that clarifies how climate-related risks are incorporated into asset prices. This study addresses this challenge by examining the climate risk premium within the commodity derivatives market, leveraging a unique empirical setting on the Singapore Exchange (SGX). Our primary objective is to determine whether climate-related distinctions between green and brown iron ore options result in divergent forward-looking risk premiums. To this end, we conduct a novel comparative assessment of the term structure of risk-neutral variance and skewness derived from the brown options relative to their green counterparts.

Our study tackles three challenges prevalent in the empirical climate finance literature. First, we address the concern of endogeneity (Jahmane and Gaies, 2020), which is particularly pronounced in equity markets where the classification of green vs. brown stocks is often ambiguous and confounded by firm-specific characteristics. To mitigate this, our research utilizes a proprietary dataset from the Singapore Exchange (SGX) featuring two distinct iron ore option contracts: the lower-grade SGX TSI Iron Ore CFR China (62% Fe Fines) and the higher-grade SGX MB Iron Ore CFR China (65% Fe Fines). We classify the former as brown because its underlying asset requires more carbon-intensive processing, while the latter is classified as green due to its association with lower climate-related risks. Crucially, these contracts share identical specifications, including contract size, denomination, and expiration conventions, and differ almost exclusively in the environmental impact of the underlying asset. This unique empirical setting allows us to directly measure exposure to climate risks, circumventing the need for complex control variables and mitigating biases from confounding factors common in equity-focused studies.

Second, climate risk is a relatively recent and evolving phenomenon that might not have been fully recognized or priced in financial markets 10-15 years ago. As a result, historical data are often limited, and traditional econometric techniques that rely on extensive data series often struggle to yield robust estimates of the climate risk premium (Dennis and Mayhew, 2002; Bakshi, Kapadia, and Madan, 2003; Jiang and Tian, 2005). Recognizing that backward-looking models may inadequately capture such emerging risks, Svartzman et al. (2021) advocate for forward-looking assessments of climate-related financial risks. We tackle this by leveraging the inherent forward-looking nature of options, which embed market expectations and perceptions of future price volatility and downside tail risks (Christoffersen, Jacobs, and Chang, 2013). Our use of option-implied measures thus offers more efficient and reliable estimates of climate-related premiums compared to those derived solely from historical data.

Third, the option-based framework we employ facilitates a novel dual-differencing approach to identify and isolate the climate risk premium. This method delivers a clean and efficient indicator of market perceptions of climate-related risks through two distinct steps.

The first step, consistent with established options literature, defines the overall risk premium for each asset as the difference between its option-implied risk-neutral measure ($\mathbb{Q}$) and the physical measure ($\mathbb{P}$). The primary difficulty at this stage is the accurate estimation of the physical measure and ensuring that the resulting premium captures the specific risk of interest — in this case, climate-related risk. The methodological novelty emerges in the second step. By differencing the overall risk premium of the brown asset from that of the green asset, we effectively cancel out any common, unobserved components of their respective physical measures and other shared, non-climate-related risk factors. This dual-differencing process, which first derives individual premiums for both brown and green assets and then differentiates them, enables us to isolate a net premium directly attributable to the differential climate-related attributes of the two contracts. This approach overcomes the common estimation challenges associated with physical measures and avoids the definitional ambiguities of green versus brown assets that are typical in more heterogeneous settings, such as equity markets.

Our initial results confirm that the iron ore options market embeds a positive and statistically significant climate risk premium. We find that less sustainable brown options exhibit higher climate variance risk premium (VRP) and skewness risk premium (SRP) than their green counterparts. This aligns with theoretical predictions (Pástor, Stambaugh, and Taylor, 2021; Pedersen, Fitzgibbons, and Pomorski, 2021; Hsu, Li, and Tsou, 2023) and corroborates empirical evidence of a carbon premium in other asset classes like equities (e.g., Bolton and Kacperczyk, 2021, 2023; Faccini, Matin, and Skiadopoulos, 2023).

We then examine the drivers of these premiums, focusing on climate policy uncertainty in China, the primary destination market for the underlying commodity and the world's leading importer and producer of iron ore. Our analysis reveals a nonlinear, inverted U-shaped relationship for both climate VRP and SRP: the climate risk premium increases with low-to-moderate levels of uncertainty but declines as uncertainty becomes extreme. This suggests an interplay between demand for risk compensation and a real options effect where extreme uncertainty suppresses hedging activity. Initially, heightened uncertainty demands greater compensation for perceived risks. However, as uncertainty reaches extreme levels, investors often become more cautious, delay decision-making, or adopt alternative hedging strategies, thereby mitigating its impact on risk premiums.

We further document that this relationship is multifaceted. Although daily changes in policy uncertainty also influence the climate VRP, their impact is less pronounced than that of sustained uncertainty levels. This observation suggests that investors place greater emphasis on persistent uncertainty rather than transient shocks. In line with this interpretation, we do not observe significant effects of daily uncertainty fluctuations on the climate SRP. Furthermore, our results indicate that market participants respond more strongly to increases in uncertainty than to comparable decreases, highlighting the asymmetric role that climate policy uncertainty plays in shaping investor behavior and risk assessments.

Notably, these effects are concentrated in short-maturity contracts. This is consistent with the conventional view that policy- or regulation-driven climate risks are transitional in nature and are more pronounced over shorter horizons, whereas physical climate risks, which evolve gradually, affect longer-term time frames (Stroebel and Wurgler, 2021). Taken together, these findings shed new light on how investors interpret and manage climate-related risks across different financial markets and under varying uncertainty regimes.

Finally, we explore the dynamics of climate risk premiums along the time-to-maturity dimension, taking advantage of the risk premium term structure. We find that both the climate VRP and SRP are significantly higher for long-maturity options and generally increase with time-to-maturity, suggesting that the compensation investors demand for bearing climate risk grows with the time horizon. These findings are consistent with prior literature on the term structure of variance risk premiums, such as Egloff, Leippold, and Wu (2010) and Aït-Sahalia, Karaman, and Mancini (2020), while uniquely isolating and documenting this behavior in climate-specific risk premiums.

Our study makes several key contributions to the climate finance literature. First, we overcome the endogeneity challenge that has long impeded empirical research in the literature. By exploiting a unique empirical setting with two iron ore option contracts on the Singapore Exchange that are nearly identical except for their underlying climate-related attributes, we obtain a direct and robust estimate of the climate risk premium in the commodity derivatives market. This empirical setting circumvents the need for complex controls and mitigates biases from confounding factors, a common problem in equity-focused studies.

Second, we capitalize on the inherently forward-looking nature of options markets to develop a novel methodological framework for identifying and isolating the climate risk premium.[3] The proposed dual-differencing strategy effectively distinguishes the climate-specific component by first deriving overall risk premiums from risk-neutral and physical measures for both green and brown options, and subsequently differencing these premiums. This approach delivers a clean and efficient measure of market perceptions of climate-related risks, offering a more reliable alternative to methodologies that rely on subjective rating systems or narrow event windows.

Third, to the best of our knowledge, this study is the first to document the existence of a climate risk premium specifically within *commodity options markets* by directly comparing green and brown contracts. This extends the scope of climate finance research beyond traditional asset classes such as equities (e.g., Ramelli, Ossola, and Rancan, 2021; Bolton and Kacperczyk, 2021, 2023; Faccini, Matin, and Skiadopoulos, 2023), bonds (e.g., Huynh and Xia, 2021; Baker et al., 2022; Seltzer, Starks, and Zhu, 2022), and real estate (e.g., Giglio et al., 2021; Bernstein, Gustafson, and Lewis, 2019; Baldauf, Garlappi, and Yannelis, 2020). While Wang (2024) explores carbon risk pricing in commodity *futures*, our options-based analysis focuses on forward-looking variance and skewness risk premiums,

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[3] Our approach is related to Ilhan, Sautner, and Vilkov (2021), who also leverage risk-neutral measures from options to examine carbon risk pricing. However, our focus on commodity markets rather than equities is a key differentiating feature.

providing a different lens on how climate concerns are priced. Moreover, our approach, centered on the direct comparison of two nearly identical contracts differing mainly in their environmental attributes, offers a distinct methodology for isolating this premium. Furthermore, while similar option-implied measures have been employed to assess carbon risk in equity markets (Ilhan, Sautner, and Vilkov, 2021), demonstrating this phenomenon in the commodity options market offers new evidence on the breadth of climate risk pricing. Commodity markets possess unique characteristics, are fundamental to industrial processes with significant carbon footprints (such as steel production from iron ore), and may price climate risks differently due to distinct participant bases and underlying risk exposures. Documenting this premium in such a context, using our specific green vs. brown comparative framework, therefore extends the empirical evidence of climate risk pricing to a new and economically significant asset class.

Finally, our research offers important implications for policymakers and regulators. By demonstrating that climate policy uncertainty affects risk premiums in a nonlinear and asymmetric fashion, our findings suggest that clearer and more predictable policy guidelines could help stabilize market expectations. Such transparency and consistency in environmental regulations are vital for reducing uncertainty, facilitating more efficient climate risk pricing, and ultimately encouraging greater investment in sustainable assets.

The remainder of the paper is organized as follows. Section 2 introduces our data and details the methodologies used to construct option-implied measures. In Section 3, we discuss our dual-differencing strategy for isolating climate risk premiums. Section 4 reports the empirical findings, and Section 5 concludes the paper.

2 Data and Option-implied Measures

In this section, we begin by describing the iron ore option contracts that form the basis of our analysis. We then present our data sources, detail the data cleaning and filtering procedures, and explain the construction of the option-based measures employed in this study.

2.1 SGX Iron Ore Option Contracts

The estimation of climate risk premiums from commodity option prices centers on two specific iron ore option contracts traded on the Singapore Exchange (SGX). Strategically located within the Asia-Pacific region, SGX has established itself as a prominent trading hub for a wide array of commodities, efficiently catering to the growing demand driven by expanding infrastructure and industrial capabilities in emerging markets. Iron ore, in particular, is a critical input in steel production and thus serves as a foundational element of the global economy. Reflecting its pivotal role, SGX has handled over one billion megatons (10^{15} tons) of iron ore annually since 2015, underscoring the exchange's significant role as a nexus for global commodity transactions.

SGX lists two types of iron ore option contracts: the SGX TSI Iron Ore CFR China (62% Fe Fines) options and the SGX MB Iron Ore CFR China (65% Fe Fines) options. These derivative contracts are structured as options on futures, with their respective underlying assets being actively traded iron ore index futures on SGX. A key differentiating factor between the two contracts is the grade of iron ore they represent. Higher-grade (65% Fe) iron ore requires a smaller quantity of material to produce the same volume of steel as the lower-grade (62% Fe) variant. This distinction not only contributes to energy savings but also reduces reliance on coke, a coal-based, high-carbon input integral to iron ore smelting. Since the iron and steel industry is the world's largest industrial source of carbon emissions (IEA, 2007), the use of higher-grade iron ore can have meaningful environmental implications by curbing carbon-intensive processes. Beyond its environmental implications, combustion of coke also produces by-products detrimental to human health. According to the U.S. Environmental Protection Agency (EPA), chronic exposure to coke oven emissions can lead to conjunctivitis, severe dermatitis, respiratory and digestive system lesions, and an increased risk of cancer.[4] Recognizing these environmental and health considerations, the 65% Fe Fines iron ore is regarded as a more environmentally and socially sustainable alternative to the 62% Fe Fines variety. Therefore, options on the 65% Fe Fines iron ore are considered “greener” relative to their 62% Fe Fines counterparts.

Despite the distinctions in their environmental implications, both options share identical contract specifications. Each contract corresponds to one lot of the underlying futures contract, representing 100 tons of iron ore, and both are denominated in U.S. Dollars. The minimum price fluctuation (tick size) is set at $0.01. Additionally, both contracts have expiration dates that coincide with the last trading day of their respective expiry months.[5]

2.2 Data

Our primary data source consists of iron ore option contract data from the Singapore Exchange. The dataset includes daily observations for each contract, with expiration year and month, strike price, and settlement price, all denominated in U.S. Dollars. The sample period extends from January 1, 2022, to December 31, 2022. Due to the agreement with the data provider, we are only able to obtain data for such a time period, and we acknowledge that the one-year sample period is a limitation of this study.

Following standard practices in the options literature, we apply standard filters to refine our options data. We exclude deep out-of-the-money options, defined as contracts with strike prices more than 20% above or below the underlying index value. We also restrict the sample to options with maturities ranging from 30 to 500 days. Furthermore, we remove any observations that violate the following no-arbitrage conditions:

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[4] See `www.epa.gov/sites/default/files/2016-09/documents/coke-oven-emissions.pdf`.

[5] For more details, see `www.sgx.com/derivatives/products/iron-ore`.

$$max[0, S - Ke^{-r\tau}] \leq C \leq S \tag{1}$$

$$max[0, Ke^{-r\tau} - S] \leq P \leq Ke^{-r\tau} \tag{2}$$

where S is the value of the underlying, K is the option strike price, r is the corresponding U.S. Treasury yield, τ is the time to maturity. C and P are the price for call options and put options, respectively.

To ensure a balanced and meaningful comparison, we conduct a matching procedure that pairs each 65% Fe Fines option observation with a corresponding 62% Fe Fines option. The matching criteria include trading date, option type, maturity, and the nearest strike price. This process yields 3,662 matched pairs of option-day observations, providing a well-aligned sample for our comparative analysis. By pairing observations with closely matched characteristics, we obtain a more accurate assessment of the climate risk premium embedded in sustainable iron ore options.

Table 1 reports the summary statistics of the filtered and matched option sample. For both iron ore grade contracts, the statistics (i.e., mean, standard deviation, and median) for calls and puts are closely aligned for the strike price, time-to-maturity, and implied volatility.

Table 1. Option sample statistics

This table reports the summary statistics of our filtered contract sample.

		Strike price			Time-to-maturity			Implied volatility		
	Option type	mean	std	median	mean	std	median	mean	std	median
62% Fe Fines	Call	118.53	8.30	118.00	237.37	133.68	231.00	0.36	0.10	0.34
	Put	116.86	5.48	117.00	257.61	127.71	260.00	0.56	0.10	0.55
65% Fe Fines	Call	121.00	7.58	120.54	237.37	133.68	231.00	0.37	0.13	0.35
	Put	119.65	5.02	120.54	257.61	127.71	260.00	0.52	0.09	0.51

We also obtain the daily closing prices for the underlying iron ore indexes—specifically, the MB Iron Ore CFR China (65% Fe Fines) index and the STI Iron Ore CFR China (62%

Fe Fines) index—from Refinitiv. Additionally, we collect the U.S. Treasury yields from the Federal Reserve Economic Data (FRED). To explore the drivers of the climate risk premiums, we collect the daily China Climate Policy Uncertainty index value from Ma et al. (2023). To account for broader global climate risk sentiment, we include the Physical Risk Index (PRI) and the Transition Risk Index (TRI) from Bua et al. (2024). Also from Refinitiv, obtain the daily closing prices for the ten largest publicly listed steel producers in the Asia-Pacific region, ranked by their steel production in 2021. Production data of these companies is sourced from the World Steel Association.[6] To capture for the overall financial market uncertainty, we obtain the daily VIX index value from Cboe Global Markets.

2.3 Option-based Measures

Using our matched data sample, we compute two key option-based variables: implied variance and implied skewness. Implied variance captures the market's perception of future price fluctuation, reflecting overall price risk. Implied skewness offers insights into the market's expectations regarding the likelihood of large price drops relative to price increases, serving as a measure of downside tail risk. Together, these variables provide a comprehensive understanding of the risk dynamics embedded in iron ore options, enabling us to assess the value of protection against various risks and estimate the climate risk premium.

To compute the option implied volatility (IV), we invert the Black and Scholes (1973) option pricing formula. Implied skewness (IS) captures the asymmetry of the risk-neutral distribution of returns, calculated using the model-free methodology proposed by Bakshi, Kapadia, and Madan (2003). This measure reflects the relative cost of protection against downside risk (left tail events) compared to upside risk (right tail events) in the distribution of underlying iron ore prices. Higher values of implied skewness indicate that protection against downside risks is less expensive than protection against upside risks,

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[6] https://worldsteel.org

suggesting that investors prioritize hedging adverse price movements on the downside.

For each day t and maturity τ, we compute IS for both brown 62% Fe options and green 65% Fe options as:

$$IS_{t,\tau} = \frac{e^{r\tau} W_{t,\tau} - 3\mu_{t,\tau} e^{r\tau} V_{t,\tau} + 2\mu_{t,\tau}^3}{(e^{r\tau} V_{t,\tau} - \mu_{t,\tau}^2)^{3/2}} \tag{3}$$

where $V_{t,\tau}$ is the price of variance contracts; $W_{t,\tau}$ is the price of cubic contracts; r is the prevailing risk free rate with the corresponding maturity (linearly interpolated if option maturity does not match available federal rates' terms); $\mu_{t,\tau}$ is the risk neutral mean of the underlying return.[7] For the two iron ore options, separately, we further drop the observations where the estimated IS is more than four standard deviations away from the sample mean.

3 The Dual-differencing Identification Approach

To identify and isolate the climate risk premium, we employ a novel dual-differencing approach. This strategy unfolds in two steps. The first step defines the overall risk premium for a given asset (green or brown), and the second stage isolates the component of this premium that is attributable specifically to climate risks.

Following the standard options literature (See, e.g., Bollerslev, Tauchen, and Zhou, 2009; Bekaert and Hoerova, 2014; Bollerslev, Todorov, and Xu, 2015; Bollerslev, Li, and Zhao, 2020; Chow et al., 2020; Finta and Ornela, 2022), the overall variance and skewness risk premiums (VRP and SRP, respectively) for an asset are defined as the difference between its risk-neutral ($\mathbb{Q}$) and physical ($\mathbb{P}$) probability measures.[8] For either the brown

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[7] For a more detailed explanation, please refer to Bakshi, Kapadia, and Madan (2003).

[8] Note that some studies define the variance risk premium (VRP) as the difference between the physical ($\mathbb{P}$) and risk-neutral ($\mathbb{Q}$) probability measures e.g., Bakshi, Kapadia, and Madan (2003), Carr and Wu (2009), Jacobs and Li (2023). Under this definition, the VRP is typically negative, reflecting the premium that variance buyer pay to obtain large positive payoff from variance swaps during periods of market turmoil effectively serving as insurance against the volatility.

or green options, these are:

$$\begin{aligned} VRP &= Var^{\mathbb{Q}} - Var^{\mathbb{P}} \\ SRP &= Skew^{\mathbb{Q}} - Skew^{\mathbb{P}} \end{aligned} \tag{4}$$

where Var and $Skew$ are the variance and skewness of the underlying asset's returns, respectively.

The second difference contrasts the overall risk premiums of the brown assets with those of the green assets to derive the climate-specific premiums. Formally, the climate-specific variance risk premium ($VRP_{Climate}$) is:

$$\begin{aligned} VRP_{Climate} &= VRP_{Brown} - VRP_{Green} \\ &= (Var^{\mathbb{Q}}_{Brown} - Var^{\mathbb{P}}_{Brown}) - (Var^{\mathbb{Q}}_{Green} - Var^{\mathbb{P}}_{Green}) \\ &= (Var^{\mathbb{Q}}_{Brown} - Var^{\mathbb{Q}}_{Green}) - (Var^{\mathbb{P}}_{Brown} - Var^{\mathbb{P}}_{Green}) \end{aligned} \tag{5}$$

And the climate-specific skewness risk premium ($SRP_{Climate}$) is:

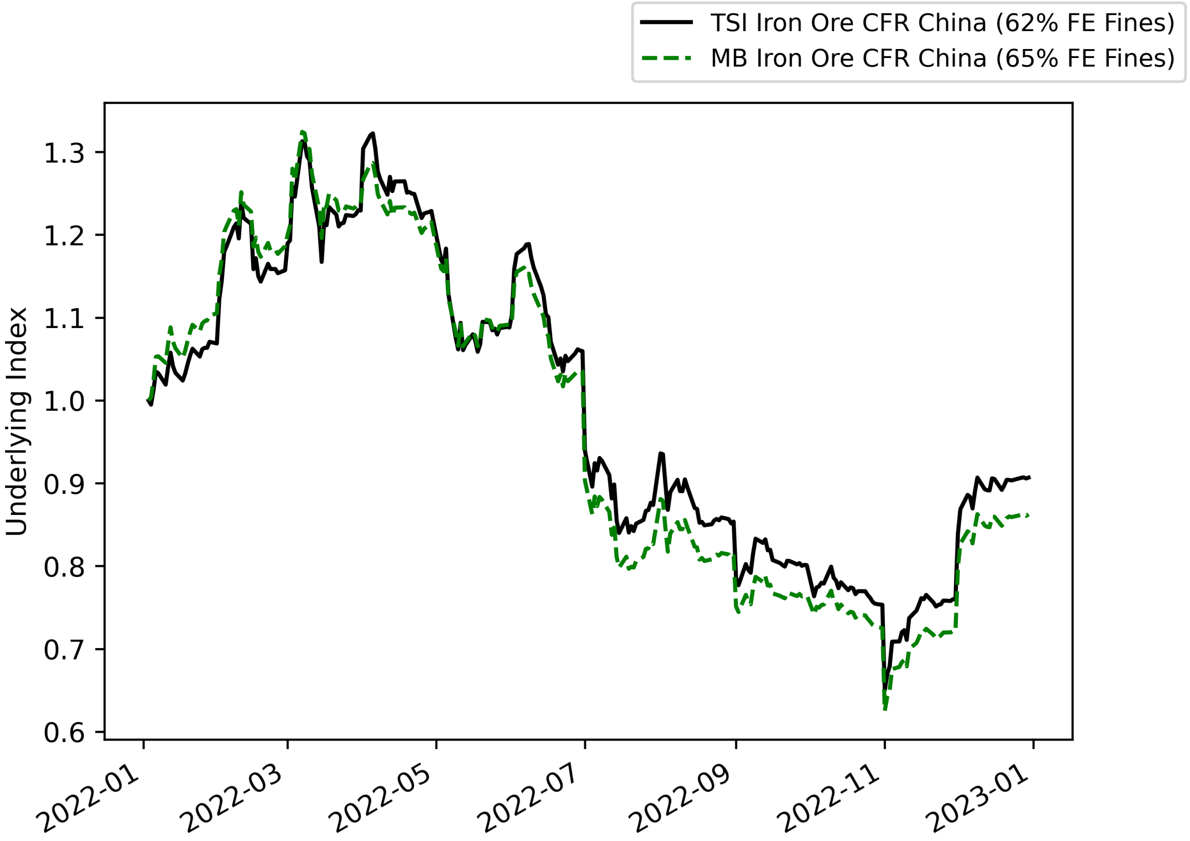
$$\begin{aligned} SRP_{Climate} &= SRP_{Brown} - SRP_{Green} \\ &= (Skew^{\mathbb{Q}}_{Brown} - Skew^{\mathbb{P}}_{Brown}) - (Skew^{\mathbb{Q}}_{Green} - Skew^{\mathbb{P}}_{Green}) \\ &= (Skew^{\mathbb{Q}}_{Brown} - Skew^{\mathbb{Q}}_{Green}) - (Skew^{\mathbb{P}}_{Brown} - Skew^{\mathbb{P}}_{Green}) \end{aligned} \tag{6}$$

While risk-neutral variance and skewness ($Var^{\mathbb{Q}}$ and $Skew^{\mathbb{Q}}$) can be derived directly from option prices as implied variance (IV^2) and skewness (IS), estimating their physical counterparts is notoriously challenging due to their sensitivity to factors such as data frequency, sample periods, and the alignment of historical versus forward-looking information (e.g., Bliss and Panigirtzoglou, 2004; Jacobs and Li, 2023).

Our identification strategy addresses this challenge by assuming that the physical return distributions of the two underlying iron ore indexes exhibit indistinguishable variance and skewness. We provide strong empirical support for this assumption. As shown in Figure 1, the standardized daily prices of the two iron ore indexes follow highly similar patterns, suggesting comparable physical return distributions. More formally, Table 2 presents statistical tests on the standard deviation and skewness of the two return series. While minor economic differences exist, the tests confirm their statistical similarity. We find no statistically significant differences between the two series in their standard deviation or skewness, as indicated by the high p-values for these comparisons.[9]

Figure 1. Iron ore underlying index

This figure plots the daily prices of the two underlying indexes, standardized by the price at the beginning of our sample period. The underlying index for the brown 62% Fe option is the TSI Iron Ore CFR China index, and the underlying index for the green 65% Fe option is the MB Iron Ore CFR China index.



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[9] For standard deviations, we use F-tests. For skewness, we resample the moment measure using a Jackknife Bootstrap approach and then apply t-tests.

Table 2. Underlying index return distribution

This table reports the annualized standard deviation and skewness of the 62% Fe index returns (column 1) and the 65% Fe index returns (column 2). Column (3) shows the difference between the two return series, and column (4) reports the p-value testing the hypothesis that the return distribution moments equal to zero. We use F-test to test the difference in standard deviation. For the differences in skewness, we resample these moments using the Jackknife Bootstrap method and then run the t-test for mean difference.

	62% Fe Index (1)	65% Fe Index (2)	Difference (3)	p-value (4)
Standard Dev.	0.371	0.352	0.019	0.799
Skewness	-0.640	-0.953	0.313	0.423

The statistical indifference provides strong support for our assumption that the second and third moments of physical distributions for the two indexes are effectively indistinguishable ($Var^{\mathbb{P}}_{Brown} \cong Var^{\mathbb{P}}_{Green}$ and $Skew^{\mathbb{P}}_{Brown} \cong Skew^{\mathbb{P}}_{Green}$). Adopting this key assumption is powerful because it circumvents the need to estimate the physical measures directly. Under this condition, the physical-measure components in Equations (5) and (6) cancel out. Consequently, the climate-specific variance and skewness risk premiums can be cleanly estimated by simply differencing the option-implied measures (i.e., IV^2 and IS) between brown and green options:

$$VRP_{Climate} = IV^2_{Brown} - IV^2_{Green} \tag{7}$$

$$SRP_{Climate} = IS_{Brown} - IS_{Green} \tag{8}$$

These are the direct and robust measures of the climate risk premiums that we use in our subsequent empirical analysis.

4 Empirical Results

In this section, we present and discuss the results of our empirical analyses, examining the climate risk premiums from both a temporal perspective and with respect to time-to-maturity.

4.1 Climate Risk Premiums

We begin our empirical analysis by investigating how climate risks are reflected in the pricing of iron ore options. Specifically, we compare the unconditional averages of option-implied variance (IV^2) and skewness (IS) estimated from the brown (traditional 62% Fe) and green (sustainable 65% Fe) iron ore option prices. Note that the differences in these option-implied moments represent the climate risk premiums embedded in the market's pricing structure.

Table 3. Positive climate risk premiums

This table presents the average values for implied variance (IV^2) and model-free implied skewness (IS) for traditional 62% Fe and "greener" 65% Fe iron ore options. The risk premium (column 3) represents the differences in these measures between the two categories, while the p-values (column 4) indicate the statistical significance of the observed differences.

	62% Fe (1)	65% Fe (2)	Climate Risk Premium (3)	p-value (4)
Implied Variance (IV^2)	0.217	0.206	0.011	0.000
Model-free Implied Skewness (IS)	6.556	0.099	6.457	0.000

The results, presented in Table 3, show that the average implied variance for brown options is 0.217, significantly higher than the 0.206 for green options. This yields a positive climate variance risk premium ($VRP_{Climate}$) of 0.011 ($p < 0.01$). This finding indicates that market participants anticipate greater future price volatility for the brown underlying asset and, consequently, are willing to pay a higher premium for insurance against the volatility of the brown iron ore.

Similarly, the second row of Table 3 reveals a large and statistically significant climate skewness risk premium ($SRP_{Climate}$) of 6.457 ($p < 0.01$), driven by the substantial difference in implied skewness (IS) between the brown (62% Fe) and green (65% Fe) iron ore options. This result indicates that the underlying brown iron ore returns exhibit higher upward potential in the risk-neutral distribution than the green ones. As a result, investors demand a higher premium to compensate for the relatively higher downside tail risk, or limited upside potential, associated with the green iron ores.

A potential concern in the specification of the climate risk premiums in Equations (7) and (8) is that it could be affected by differences in processing costs or machinery requirements between 62% and 65% iron ore. However, as documented by Nicholas and Basirat (2022), the processing procedures and blast furnace equipment employed for these two grades of iron ore are essentially identical, thereby alleviating this concern.

In summary, the results in Table 3 demonstrate that climate-related risks are a significant factor in the iron ore options market. These results align with the recent findings on the pricing of climate risks in the equity options market (Cao et al., 2023; Ilhan, Sautner, and Vilkov, 2021). This consistency underscores the pervasive influence of climate-related risks on asset pricing across different financial instruments and markets.

4.2 Drivers of Climate Variance Risk Premium

Having established the existence of a climate risk premium, we now analyze its key drivers. This section investigates the determinants of the climate variance risk premium ($VRP_{Climate}$), with a specific focus on the role of climate policy uncertainty in China. Our investigation is motivated by prior research demonstrating that policy uncertainty significantly affects financial markets, leading investors to demand higher risk premiums (See, e.g., Pástor, Stambaugh, and Taylor, 2021; Pástor and Veronesi, 2013; Kelly, Pástor, and Veronesi, 2016). The focus on China is crucial, as it is the primary destination for the underlying iron ore and dominates the global market, accounting for 66.1% of worldwide import volume. This market concentration reinforces the pivotal role of China's climate policies in influencing the pricing of these iron ore options.[10] In addition, these option contracts are tailored for China's iron ore market, as the underlying indexes track the Chinese iron ore prices.

To measure climate policy uncertainty, we employ the daily China Climate Policy Un-

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[10] As of 2021, the year of our analysis. See the Observatory of Economic Complexity, https://oec.world/en/profile/hs/iron-ore?yearSelector1=2021

certainty ($CCPU$) index developed by Ma et al. (2023). This index shares methodological similarities with Engle et al. (2020), who construct a U.S.-based uncertainty measure through textual analysis of news articles. However, the $CCPU$ index improves upon traditional policy uncertainty metrics, which often rely solely on keyword counting, by employing a deep learning model that automatically identifies complex linguistic patterns indicative of climate policy uncertainty. This approach reduces potential biases associated with manual keyword selection, offering a more accurate and nuanced measure of climate policy uncertainty.

In our regression analysis, we also include several control variables to isolate the effect of policy uncertainty. First, to account for industry-specific dynamics, we incorporate the performance of the steel production industry, which has a substantial carbon footprint and is highly vulnerability to climate regulations. We measure this using the production-weighted daily returns of the ten largest publicly listed steel producers in the Asia-Pacific region, ranked by production output in 2021.[11] Second, to control for aggregate market volatility, we include daily changes in the VIX index. Finally, to account for broader global climate risk sentiment, we include the Physical Risk Index (PRI) and the Transition Risk Index (TRI) from Bua et al. (2024).

Table 4 presents the summary statistics for these independent variables. Notably, Augmented Dickey-Fuller (ADF) tests, reported in the final column, confirm that all variables used in our analysis are stationary, which supports the validity of our subsequent regression models.

For our regression analysis, we begin by estimating the following OLS model to examine the determinants of the climate risk premium:

$$RP_{Climate} = c + \beta_1 CCPU + \beta_2 Ret_{pw} + \beta_3 Ret_{pw}^2 + \beta_4 \Delta VIX + \beta_5 PRI + \beta_6 TRI + \varepsilon \quad (9)$$

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[11] The list of firms includes prominent names, such as China Baowu Group, Ansteel Group, and Nippon Steel Corporation, among others. These companies' production data is obtained from the World Steel Association (www.worldsteel.org).

Table 4. Independent variables summary statistics

This table presents the summary statistics for the Independent variables used in this paper. The independent variables include the China Climate Policy Uncertainty Index ($CCPU$) from Ma et al. (2023)p; Ret_{pw} represents the production-weighted stock return of the 10 largest publicly listed steel producers in the Asia-Pacific region. ΔVIX is the daily change in the VIX index; the global climate Physical Risk Index (PRI) and Transition Risk Index (TRI) from Bua et al. (2024). The last column reports the Augmented Dickey-Fuller (ADF) test statistics. The sample period covers the year 2022. Note: *p<0.1; **p<0.05; ***p<0.01.

	count (1)	mean (2)	std (3)	min (4)	25% (5)	50% (6)	75% (7)	max (8)	ADF (9)
CCPU	238	1.015	0.282	0.311	0.840	0.981	1.175	1.943	-4.261***
Ret$_{pw}$	238	-0.001	0.016	-0.067	-0.010	0.000	0.008	0.050	-14.902***
ΔVIX	238	0.064	1.721	-3.160	-1.007	-0.270	0.910	6.500	-12.381***
PRI	238	-0.002	0.026	-0.051	-0.021	-0.001	0.012	0.104	-17.543***
TRI	238	-0.001	0.029	-0.065	-0.023	0.002	0.020	0.068	-3.722***

In this model, the dependent variable, $RP_{Climate}$, is the option-based climate variance or skewness risk premium defined in Section 3. The independent variables include our primary variable of interest, the China Climate Policy Uncertainty ($CCPU$) index, along with controls for steel industry performance (Ret_{pw}) and its squared term (Ret^2_{pw}), market volatility (ΔVIX), global physical climate risk index (PRI), and global transition climate risk index (TRI).

The regression results for the climate variance risk premium ($VRP_{Climate}$) are presented in Table 5. Column (1) shows that the coefficient on $CCPU$ is positive and significant (0.028, p<0.01), indicating that rising climate policy uncertainty in China increases the climate VRP in the iron ore commodity market. Interpreting the estimated coefficient, a 1% increase in $CCPU$ corresponds to a 2.58% increase in the climate variance risk premium relative to the sample average.[12] This finding aligns with Kelly, Pástor, and Veronesi (2016), who document that investors demand greater compensation for risks associated with unpredictable policy environments. Notably, the coefficients for the global climate risk controls, the Physical Risk Index (PRI) and Transition Risk Index (TRI), are not statistically significant. This result underscores the localized nature of the risk premium drivers, suggesting that investors in SGX iron ore options, for whom China is the primary

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[12] The economic magnitude is computed as 1% $\times$ $CCPU$ mean (1.015) $\times$ coefficient (0.028) divided by the climate VRP mean (0.011).

destination market, are more attuned to specific, regional policy uncertainty ($CCPU$) than to broader global climate risk measures.

Table 5. Climate variance risk premium

This table presents the regression results for the option-implied climate variance risk premium ($VRP_{Climate}$). The independent variables in the different models include the China Climate Policy Uncertainty Index ($CCPU$) from Ma et al. (2023), its squared value ($CCPU^2$), and its first difference ($\Delta CCPU$). Ret_{pw} represents the production-weighted stock return of the 10 largest publicly listed steel producers in the Asia-Pacific region, while Ret_{pw}^2 represents its squared value. The analysis also includes two dummy variables: 1_{Short}, which equals 1 for options with a time-to-maturity shorter than 250 days and 0 otherwise, and $1_{\Delta CCPU \geq 0}$, which equals 1 if $\Delta CCPU \geq 0$ and 0 otherwise. ΔVIX is the daily change in the VIX index; the global climate Physical Risk Index (PRI) and Transition Risk Index (TRI) from Bua et al. (2024). The sample period covers the year 2022. The table reports coefficient estimates with standard errors provided in parentheses. Note: $^{*}p<0.1$; $^{**}p<0.05$; $^{***}p<0.01$.

	Dependent variable: Climate VRP					
	(1)	(2)	(3)	(4)	(5)	(6)
$CCPU$	0.028^{***}	0.227^{***}	0.002			
	(0.005)	(0.030)	(0.007)			
$CCPU^2$		-0.086^{***}				
		(0.013)				
$CCPU \times 1_{Short}$			0.052^{***}			
			(0.009)			
$\Delta CCPU$				0.009^{**}	-0.000	-0.024^{**}
				(0.004)	(0.006)	(0.011)
$\Delta CCPU \times 1_{Short}$					0.018^{**}	
					(0.009)	
$\Delta CCPU \times 1_{\Delta CCPU \geq 0}$						0.047^{***}
						(0.015)
1_{Short}			-0.061^{***}		-0.007^{***}	
			(0.010)		(0.003)	
$1_{\Delta CCPU \geq 0}$						0.004
						(0.004)
Ret_{pw}	-0.135	-0.062	-0.140	-0.159	-0.161	-0.221^{**}
	(0.101)	(0.100)	(0.100)	(0.102)	(0.102)	(0.104)
Ret_{pw}^2	-0.826	-1.898	0.266	-3.352	-3.016	-2.696
	(4.681)	(4.625)	(4.641)	(4.717)	(4.708)	(4.710)
ΔVIX	-0.001	-0.001	-0.001	-0.002^{**}	-0.002^{**}	-0.002^{**}
	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)
PRI	-0.009	-0.017	-0.009	-0.015	-0.016	-0.024
	(0.068)	(0.067)	(0.067)	(0.068)	(0.068)	(0.068)
TRI	-0.091^{*}	-0.096^{*}	-0.084	-0.089	-0.086	-0.067
	(0.055)	(0.054)	(0.055)	(0.056)	(0.056)	(0.056)
$Intercept$	-0.019^{***}	-0.128^{***}	0.011	0.011^{***}	0.014^{***}	0.003
	(0.005)	(0.017)	(0.007)	(0.001)	(0.002)	(0.003)
Observations	1786	1786	1786	1786	1786	1786
R^2	0.025	0.050	0.044	0.009	0.015	0.015
Adjusted R^2	0.022	0.046	0.040	0.006	0.010	0.011

Drawing on Svartzman et al. (2021), who note that climate change can have nonlinear effects on financial markets, we extend our baseline model to test for such a relationship. Column (2) of Table 5 presents the results after incorporating a squared term for $CCPU$.

We find that the coefficient on $CCPU^2$ is negative and statistically significant (-0.086, p<0.05), while the coefficient on $CCPU$ remains positive. This result indicates an inverted U-shaped relationship: as climate policy uncertainty rises, it initially increases the climate VRP, but beyond a certain threshold, further increases in uncertainty reduce the premium. This nonlinear pattern can be interpreted as an interplay between two economic forces. At low-to-moderate uncertainty, rising ambiguity about future policy destabilizes market expectations and increases demand for hedging, thus elevating the VRP. At extreme levels of uncertainty, however, a real options effect may dominate, as investors adopt a "wait-and-see" approach, reducing market activity and lowering the demand for risk hedging, which consequently decreases the VRP. (See Dixit and Pindyck, 1994)

We next examine the temporal dimension of this relationship. Climate policy risks are often considered transitional, in contrast to the long-term nature of physical risks (Stroebel and Wurgler, 2021; Campiglio et al., 2023). To test this, we introduce a dummy variable, 1_{Short}, which equals 1 for options with maturities of 250 days or fewer (48.8% of the sample) and 0 for contracts with maturities longer than 250 days (51.2% of the sample). The results in column (3) of Table 5 show a positive and significant interaction term ($CCPU \times 1_{\text{Short}}$), while the coefficient on $CCPU$ itself becomes insignificant. This finding suggests that investor sensitivity to climate policy uncertainty is predominantly concentrated in short-maturity option contracts.

Our analysis thus far has focused on sustained uncertainty proxied by the CCPU level. To distinguish between the impacts of persistent uncertainty and immediate shocks, we next analyze the impact of the first difference of the CCPU index ($\Delta CCPU$). This measure not only offers statistical advantages by removing trend components but also has a clear economic meaning, reflecting the markets reaction to daily policy news. The results in columns (4) and (5) of Table 5 show that $\Delta CCPU$ has a positive but statistically weaker influence (0.009, $p < 0.10$) on the climate VRP compared to the sustained CCPU level. This effect is stronger for short-maturity options. The key takeaway is that persistent uncertainty is a more significant driver of risk pricing than daily shocks are. This muted response to daily policy news in the commodity options market contrasts sharply with the pronounced overreactions often observed in equity markets, which can be driven by flight-to-safety behavior or investor overreaction (e.g., Barberis, Shleifer, and Vishny, 1998; Bollerslev, Li, and Xue, 2018; Pástor and Veronesi, 2013).

Finally, we explore potential asymmetries in the market's response. We incorporate a dummy variable for days with rising uncertainty ($\Delta CCPU \geq 0$) and an interaction term ($\Delta CCPU \times 1_{\Delta CCPU \geq 0}$). The results in column (6) of Table 5 reveal a positive and significant interaction term, indicating that an increase in policy uncertainty has a more pronounced effect on the climate VRP than a comparable decrease. This finding points to greater risk aversion when climate policy uncertainty is on the rise. In contrast, a reduction in policy uncertainty appears to have a less pronounced effect on climate VRP.

4.3 Drivers of Climate Skewness Risk Premium

This section mirrors the preceding analysis to examine the drivers of the option-implied climate skewness risk premium ($SRP_{Climate}$), with the results presented in Table 6. Our analysis begins with the linear relationship between the China Climate Policy Uncertainty (CCPU) index and the climate SRP. Column (1) of Table 6 shows a significant negative relationship, suggesting that, on average, greater policy uncertainty leads to a lower skewness risk premium. The estimated coefficient is -1.018 (p<0.01), suggesting that a 1% increase in CCPU results in a 16.0 bps decrease in climate skewness risk premium, with respect to the sample average.[13] This result may appear counterintuitive, as higher uncertainty is generally expected to increase the price of protection against extreme outcomes, thereby raising the cost of downside protection and ultimately leading to a higher SRP (Bollerslev, Li, and Xue, 2018; Kelly, Pástor, and Veronesi, 2016; Bali, Brown, and Tang, 2017).

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[13] The economic magnitude is computed as 1% × CCPU mean (1.015) × coefficient (-1.018) / Climate SRP mean (6.457).

Table 6. Climate skewness risk premium

This table presents the regression results for the option-implied climate skewness risk premium ($SRP_{Climate}$). The independent variables in the different models include the China Climate Policy Uncertainty Index ($CCPU$) from Ma et al. (2023), its squared value ($CCPU^2$), and its first difference ($\Delta CCPU$). Ret_{pw} represents the production-weighted stock return of the 10 largest publicly listed steel producers in the Asia-Pacific region, while Ret_{pw}^2 represents its squared value. The analysis also includes two dummy variables: 1_{Short}, which equals 1 for options with a time-to-maturity shorter than 250 days and 0 otherwise, and $1_{\Delta CCPU \geq 0}$, which equals 1 if $\Delta CCPU \geq 0$ and 0 otherwise. ΔVIX is the daily change in the VIX index; the global climate Physical Risk Index (PRI) and Transition Risk Index (TRI) from Bua et al. (2024). The sample period covers the year 2022. The table reports coefficient estimates with standard errors provided in parentheses. Note: *p<0.1; **p<0.05; ***p<0.01.

	Dependent variable: Climate SRP					
	(1)	(2)	(3)	(4)	(5)	(6)
$CCPU$	-1.018***	6.601***	-0.177			
	(0.299)	(1.843)	(0.405)			
$CCPU^2$		-3.277***				
		(0.782)				
$CCPU \times 1_{Short}$			-1.701***			
			(0.568)			
$\Delta CCPU$				0.053	0.246	1.006
				(0.276)	(0.373)	(0.700)
$\Delta CCPU \times 1_{Short}$					-0.427	
					(0.527)	
$\Delta CCPU \times 1_{\Delta CCPU \geq 0}$						-1.577*
						(0.905)
1_{Short}			0.070		-1.727***	
			(0.625)		(0.152)	
$1_{\Delta CCPU \geq 0}$						-0.030
						(0.253)
Ret_{pw}	-16.344***	-13.560**	-16.707***	-16.120**	-16.524***	-14.069**
	(6.255)	(6.261)	(6.016)	(6.291)	(6.067)	(6.399)
Ret_{pw}^2	-510.836*	-551.835*	-456.085	-444.612	-362.123	-463.515
	(289.384)	(288.213)	(278.552)	(290.220)	(279.969)	(290.431)
ΔVIX	0.120**	0.157***	0.131**	0.149**	0.162***	0.151**
	(0.060)	(0.060)	(0.057)	(0.059)	(0.057)	(0.060)
PRI	-0.086	-0.399	0.741	0.705	1.509	1.107
	(4.177)	(4.159)	(4.018)	(4.205)	(4.057)	(4.220)
TRI	3.082	2.883	2.843	2.504	2.451	1.901
	(3.405)	(3.389)	(3.275)	(3.433)	(3.312)	(3.470)
$Intercept$	7.626***	3.463***	7.572***	6.529***	7.362***	6.720***
	(0.335)	(1.048)	(0.449)	(0.092)	(0.115)	(0.186)
Observations	1786	1786	1786	1786	1786	1786
R^2	0.015	0.025	0.090	0.009	0.080	0.011
Adjusted R^2	0.012	0.021	0.086	0.006	0.075	0.006

To investigate this relationship further, we introduce a squared term for $CCPU$ in column (2), revealing a significant nonlinear effect. The coefficients for $CCPU$ and $CCPU^2$ are 6.601 ($p<0.01$) and -3.277 ($p<0.01$), respectively. This suggests an inverted U-shaped relationship that parallels our findings for the climate VRP. At lower levels of uncertainty, rising policy ambiguity is associated with a higher climate SRP, consistent with a standard risk-return framework where greater uncertainty about tail events requires a larger premium. However, beyond a certain threshold, extreme uncertainty appears to diminish the SRP. This may occur because the complexity of forecasting future regulatory outcomes becomes so great that the pricing of downside risks becomes less sensitive to further increases in uncertainty. Noteworthily, consistent with the results for the climate VRP, the global climate risk indices (PRI and TRI) are also not statistically significant drivers of the climate SRP across the specifications in Table 6. This reinforces our conclusion that the pricing of climate risk in this market is predominantly influenced by China-centric policy uncertainty rather than global risk sentiment.

We then explore the other dimensions of this relationship in Columns (3) - (6) of Table 6. As shown in Column (3), the effects of CCPU on the climate SRP are concentrated in short-maturity options, suggesting the market perceives the influence of policy uncertainty on skewness risk as primarily a short-term phenomenon. Turning to Columns (4) - (5), which use the first difference of the CCPU index ($\Delta CCPU$) as the main explanatory variable, we find no statistically significant relationship with the climate SRP. This lack of significance, in contrast to the weak effect found for the climate VRP, implies that daily fluctuations in uncertainty are perceived as too transitory to affect investors' longer-term expectations regarding skewness risk. Market participants appear to rely on sustained levels of uncertainty, rather than short-lived shocks, to inform their views on the pricing of skewness risk. Finally, in column (6), a marginally significant coefficient on the interaction term ($\Delta CCPU \times 1_{\Delta CCPU \geq 0}$) suggests that increases in policy uncertainty attract greater investor attention and have a stronger influence on the climate SRP than comparable decreases do.

4.4 Climate Risk Premiums and Option Time-to-maturity

A key advantage of using options is the ability to analyze the term structure of risk premiums. In this section, we examine how the climate VRP and SRP evolve with options' time-to-maturity. Our results in Tables 5 and 6 provide some initial evidence: the coefficient on the 1_{Short} dummy variable is mostly negative and statistically significant, implying that, on average, long-maturity options command a higher climate risk premium than their short-maturity peers.

To explore this relationship in greater detail, we plot the average daily climate VRP and SRP against time-to-maturity in Figure 2. Panel A, which displays the VRP, clearly illustrates an upward-sloping trend, confirming that the climate VRP increases with the option's maturity. Furthermore, the plot also shows that the premiums extracted from short-maturity options (particularly those under 120 days) fluctuate much more than those from long-maturity options.

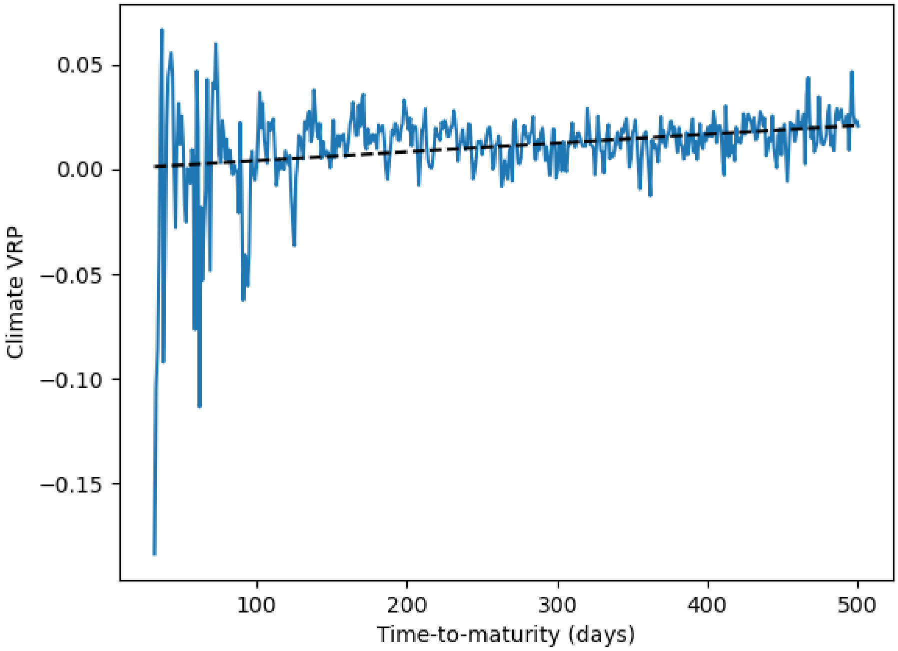
A similar, though more nuanced, trend is observed for the climate SRP in Panel B of Figure 2. First, the average climate SRP remains positive across all maturities, consistent with the unconditional premium documented in Section 4.1. Second, the overall pattern shows that the climate SRP generally increases with time-to-maturity, though there appears to be a short-term decline for maturities under 150 days before the upward trend resumes.

Our findings provide insights into the literature on the term structure of variance risk premiums, a field where results vary by asset class and definition. For instance, Egloff, Leippold, and Wu (2010) find a positive and increasing term structure for equity index swap variance rates, while Aït-Sahalia, Karaman, and Mancini (2020) and Jacobs and Li (2023) document declining term structures for variance risk premiums in equity and energy markets, respectively. Our study extends this line of inquiry by addressing a new dimension of this topic. While prior studies have documented the term structure of the overall vari-

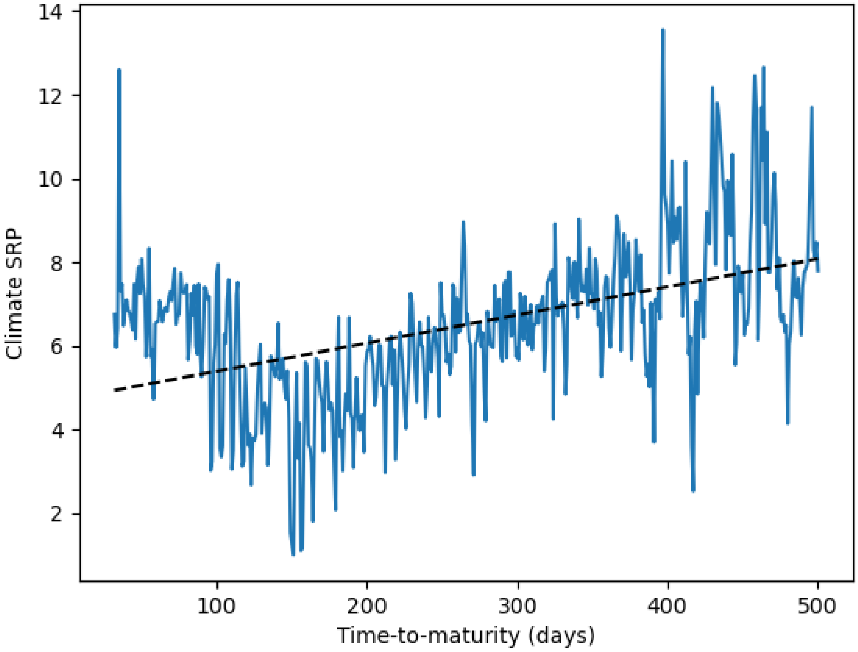
Figure 2. Climate Risk Premiums and Option Time-to-maturity

The figure plots the average climate variance risk premium and climate skewness risk premium for each option time-to-maturity in Panel A and Panel B, respectively. The dotted line represents the fitted value of the corresponding climate risk premium regressed on option time to maturity.

Panel A: Climate variance risk premium



Panel B: Climate skewness risk premium



ance risk premium, our study is the first to isolate and analyze the term structure of the climate-specific component of this premium. By documenting this phenomenon in commodity options, we extend this inquiry to a new asset class where such risks are highly material. This focus provides added value on risk pricing. In contrast to the declining term structures for the overall VRP found in other markets, we identify a clear, upward-sloping pattern for both the climate VRP and SRP, suggesting that the compensation investors demand for bearing climate-related risks grows as the time horizon lengthens, a key insight for understanding the long-term financial implications of climate change.

5 Conclusion

While the existence of a climate risk premium remains a topic of debate in the finance literature, this study provides robust evidence of such premiums within the commodity derivatives market. By leveraging a unique empirical setting, featuring otherwise identical green and brown iron ore option contracts, we demonstrate that climate-related risks are a significant determinant of financial asset prices. Our findings indicate that, on average, carbon-intensive brown options command higher climate variance and skewness risk premiums than their greener counterparts, in line with theories predicting greater risk compensation for assets more vulnerable to climate risks.

Our analysis of the drivers of these premiums reveals a multifaceted relationship with climate policy uncertainty, particularly in China. We find a nonlinear, inverted U-shaped effect: low-to-moderate uncertainty elevates premiums by destabilizing market expectations, while extreme uncertainty suppresses them as investors tend to adopt a more cautious, “wait-and-see” approach aligned with the real options theory. Furthermore, we show that the pricing of risk is more sensitive to sustained uncertainty levels than to transient daily shocks, and that the market reacts more strongly to increases in uncertainty than to comparable decreases. These effects are concentrated in short-maturity options, highlighting the market's perception of policy-related risks as primarily transitional.

By employing a novel dual-differencing methodology, our research addresses a key identification challenge in the empirical literature, yielding a direct and robust measure of the climate risk premium without relying on subjective ESG ratings or narrow event windows. This extends the study of climate finance to the commodity options market, a new and economically significant asset class. Ultimately, our findings have important implications for policymakers, suggesting that transparent and predictable policy guidance is crucial. Reducing uncertainty can stabilize markets, foster more efficient risk pricing, and encourage the sustainable investment needed to meet global climate objectives.

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