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Pricing The Unknown: Evidence From Derivatives Markets On Corporate Environmental Targets In India

Option-Implied Tail Risk, Credibility Signals, and Climate-Policy Exposure in Listed Indian Firms

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Abstract

This study examined whether derivatives markets in India quantify the uncertainty embedded in corporate environmental targets and whether target credibility attenuates option-implied downside risk. Using firm-level events derived from standardised sustainability disclosures under the Business Responsibility and Sustainability Reporting (BRSR) framework, third-party target validation records from the Science Based Targets initiative (SBTi), and climate-policy milestones including India's Carbon Credit Trading Scheme (CCTS) and notified greenhouse gas emissions-intensity target rules, the study tested how option-implied volatility, volatility skew, and related risk-neutral tail measures responded to the introduction and revision of corporate emissions targets. A panel of listed Indian firms with actively traded derivatives was assembled, target characteristics were merged with daily contract-level options and futures data from the National Stock Exchange (NSE), and event-study and staggered-adoption difference-in-differences (DiD) estimators robust to heterogeneous treatment effects were applied. Endogeneity was addressed using quasi-exogenous credibility shocks induced by phased BRSR Core assurance requirements and, where feasible, instrumental variables exploiting policy-driven variation in climate compliance exposure. Credible targets were found to reduce implied volatility skew and variance risk premia, consistent with markets updating downward the probability of severe downside transition shocks. The paper contributes to climate finance by providing an India-specific framework connecting mandatory sustainability reporting with forward-looking derivative prices, and offers regulatory implications for disclosure standardisation, assurance design, and carbon-market architecture.

Keywords: *Corporate environmental targets, implied volatility, volatility skew, variance risk premium, climate transition risk, BRSR, BRSR Core assurance, India, event study, staggered DiD.*

I. INTRODUCTION

Motivation

Derivatives prices embed forward-looking information about the distribution of future asset returns, and option-implied volatility skew is widely interpreted as a market price for downside tail risk. The foundational option pricing models of Black and Scholes (1973) and Merton (1974) formalised the relationship between asset-price distributions and option values, motivating the use of implied volatility surfaces as market-implied measures of uncertainty. Within climate finance, Ilhan et al. (2021) demonstrated that option markets price climate-policy uncertainty and carbon-intensive business-model tail risks for US firms, implying that derivatives are particularly informative about transition states that are difficult to quantify through conventional equity price analysis.

India presents an analytically valuable setting because corporate sustainability disclosures have moved from fragmented voluntary reporting to standardised, regulator-backed formats within a short span. The Securities and Exchange Board of India (SEBI) introduced the Business Responsibility and Sustainability Reporting framework through a Board memorandum that emphasised quantifiable metrics, cross-firm comparability, and structured environmental disclosures including Scope 1 and Scope 2 greenhouse gas emissions (SEBI, 2021a). BRSR guidance further required entities to disclose specific commitments, goals, and targets, along with their baseline context and the organisational boundary to which they applied (SEBI, 2021b). More recently, the BRSR Core framework established a phased roadmap for reasonable assurance of key ESG metrics and formalised value-chain ESG boundaries covering the top upstream and downstream partners accounting for 75 percent of purchases and sales by value (BSE, 2023). This regulatory layering from voluntary reporting to mandatory filing to third-party assured disclosure created a sequence of credibility upgrades that can be exploited empirically.

On the climate-policy side, India's Carbon Credit Trading Scheme, notified under the Energy Conservation Act framework, defined a carbon credit as equivalent to one tonne of CO_2 equivalent, designated the Grid Controller of India Limited as the registry, and assigned trading oversight to the Central Electricity Regulatory Commission with trading conducted on registered power exchanges (Bureau of Energy Efficiency [BEE], 2023). Complementing this architecture, the Greenhouse Gas Emission Intensity Target Rules of 2025 and associated amendments identified obligated entities and specified compliance-year targets, creating measurable policy exposure heterogeneity across firms and sectors (Ministry of Environment, Forest & Climate Change [MoEFCC], 2025). Together, these developments mean that the question of how derivatives markets price corporate environmental target uncertainty is not only academically interesting but directly relevant to India's emerging carbon-market and transition-finance ecosystem.

Research Questions

This study addressed three empirical questions. First, do Indian derivatives markets respond to new information about corporate environmental targets measured through implied volatility level and skew when targets are disclosed in standardised formats and made available to investors through exchange filings? Second, does target credibility, operationalised through SBTi validation or BRSR Core assurance; reduce option-implied downside tail risk and the market price of variance risk relative to otherwise comparable unvalidated disclosures? Third, do climate-policy milestones particularly the implementation architecture for carbon credit trading and emissions-intensity compliance targets amplify derivatives-market sensitivity to target credibility among firms with greater regulatory exposure?

Empirical Contribution and Positioning

This study bridged three bodies of literature. The first is the climate risk pricing literature, which has documented that carbon emissions intensity commands an equity risk premium (Bolton &Kacperczyk, 2021) and that firm-level climate exposure measures derived from corporate communications are priced in equity markets (Sautner et al., 2023). The second is the derivatives-based tail risk and variance risk premium literature, which established the theoretical and empirical foundations for interpreting implied volatility skew and variance risk premia as measures of market-priced downside uncertainty (Bollerslev et al., 2009; Demeterfi et al., 1999). The third is the India-specific disclosure and investor reaction literature, which documented stock market responses to mandatory sustainability reporting under the BRSR framework (Pandey et al., 2024; Desai, 2024). The distinctive contribution of the present study is its focus on derivatives rather than cash equity prices, and its construction of a replicable pipeline that converts disclosed target characteristics into event-time and panel regressors directly linked to India's mandatory reporting architecture.

Prior evidence on ESG characteristics and option-implied tail risk provides direct methodological support. Shafer and Szado (2020) showed that better ESG practices are associated with lower implied volatility skew on individual equity options, consistent with markets perceiving stronger ESG firms as carrying lower downside tail risk. Ford et al. (2022) further demonstrated that environmental risk and ESG controversies are significant in short-term options-based sentiment measures. These studies established the empirical plausibility of the measurement approach adopted in the current paper and grounded the core hypothesis that credible environmental target disclosures reduce priced tail risk in options markets.

The methodological design drew on advances in causal inference for panel data. Brown and Warner (1985) and MacKinlay (1997) formalised best practices and inference considerations for event-study designs in finance. Sun and Abraham (2021) and Callaway and Sant'Anna (2021) demonstrated that conventional two-way fixed effects event-study estimators produce biased coefficients under staggered treatment adoption and heterogeneous treatment effects conditions that plausibly held in the present setting where different firms received credibility upgrades at different points in time. The study employed the corrected estimators from both papers. Goodman-Bacon (2021) provided further diagnostics on the decomposition of two-way fixed effects estimates under staggered adoption, and Bertrand et al. (2004) provided guidance on addressing serial correlation concerns in DiD designs with long panels.

II. REVIEW OF LITERATURE

2.1 Climate Risk Pricing and Transition Uncertainty

A central theme in climate finance is that transition risk carries both risk-premium and preference-discounting components. Bolton and Kacperczyk (2021) documented that investors demand higher expected returns from firms with greater carbon emissions, establishing a carbon premium in equity markets. Sautner et al. (2023) extended this analysis by constructing firm-level climate exposure measures from earnings call transcripts and showing that these measures are priced in equity valuations. Hong et al. (2019) argued that climate risks can impair market efficiency by generating slow-moving, hard-to-arbitrage information environments in which prices fail to fully reflect long-horizon physical and transition risks.

Option markets are particularly important for pricing tail and policy uncertainty channels. Ilhan et al. (2021) showed that the cost of downside option protection is significantly larger for firms with higher carbon intensity, and interpreted this as evidence that climate-policy uncertainty enters risk-neutral return distributions through the options market rather than through cash equity prices alone. This finding directly motivated the use of implied volatility skew as the primary dependent variable in the current study, as it captures the forward-looking tail-risk beliefs of market participants rather than backward-looking realised volatility.

2.2 Derivatives-Based Measures of Uncertainty and Tail Risk

The theoretical foundations for extracting uncertainty measures from options markets were established by Black and Scholes (1973) and Merton (1974), whose option pricing models linked the level of implied volatility to market-implied return uncertainty. Demeterfi et al. (1999) extended this framework by showing how variance and volatility swaps could connect option prices across strikes to a model-free implied variance measure. Bollerslev et al. (2009) introduced the variance risk premium defined as risk-neutral expected variance minus expected realised variance as a measure of investor compensation for variance risk, and showed empirically that this premium predicts expected equity returns.

Directly linking ESG characteristics to option-implied tail risk, Shafer and Szado (2020) demonstrated that firms with better ESG practices exhibit lower implied volatility skew, consistent with lower perceived downside tail risk. Ford et al. (2022) showed that environmental risk and ESG controversies generate significant signals in short-term options-based sentiment measures. These studies provided the global empirical precedent for the measurement strategy applied in the present paper, and supported the interpretation of smirk changes around disclosure events as reflecting genuine updates to market beliefs about downside transition risk.

2.3 Disclosure Mandates, Credibility, and India Evidence

Disclosure mandates create discrete information shocks by standardising what is revealed, when, and in what format, allowing researchers to exploit event-time variation. SEBI's BRSR framework was designed to enable cross-framework interoperability and comparability across firms, and explicitly contemplated the disclosure of specific commitments, goals, and targets including their baseline context and entity coverage (SEBI, 2021b). The subsequent BRSR Core framework added reasonable assurance requirements on a phased glide path, strengthening the credibility signal associated with disclosed metrics (BSE, 2023).

Empirical India-focused studies have documented investor reactions to mandatory sustainability reporting. Pandey et al. (2024) found significant stock market responses to mandatory sustainability disclosure requirements and showed that carbon intensity and ESG reputation moderated these reactions. Desai (2024) studied investor responses to BRSR adoption announcements and documented cumulative abnormal returns around key regulatory announcement dates. Both studies focused on cash equity markets. The present study extended this line of inquiry to derivatives markets, where forward-looking information about tail-risk beliefs is more directly observable.

2.4 Corporate Target Systems and Third-Party Validation

The Science Based Targets initiative provides a global target-setting and validation mechanism through which firms can have their emissions reduction targets independently validated against 1.5°C-aligned science-based criteria (SBTi, 2023). SBTi validation constitutes an externally observable credibility signal that is distinct from self-reported disclosures, providing a quasi-exogenous upgrade in target credibility that can be used for event-study identification. CDP operates a complementary global environmental disclosure system and provides granular emissions and net-zero target data through its dataset licensing programme (CDP, 2023). Together, SBTi validation records and CDP data allowed a triangulation strategy in which target claims in BRSR and annual reports were cross-checked against external validation and emissions records.

III. DATA AND SAMPLE DESIGN

3.1 Data Sources

Table 1 enumerates the primary data sources used in this study. Each dataset is described in terms of its content, coverage, frequency, and accessibility.

Table 1: Data Sources, Coverage, and Access Status

Dataset	What It Contains	Coverage & Frequency	Access & Notes
BRSR filings and sustainability/annual reports	Standardised ESG disclosures; structured fields for specific commitments, goals and targets, and performance context including baseline and entity coverage	Top 1,000 listed entities; annual (FY)	Mandatory BRSR applicability roadmap defined by SEBI; files disseminated via exchange and company reporting channels (SEBI, 2021a)
BRSR Core and updated BRSR formats	BRSR Core template with formulas for Scope 1 and Scope 2 emissions and intensity; phased reasonable assurance	Phased from FY 2023–24 onwards	Exchange circular summarises FY 2023–24 to FY 2026–27 glide path (BSE, 2023)

Dataset	What It Contains	Coverage & Frequency	Access & Notes
	and value-chain boundary definitions (75% purchases/sales)		
SBTi target status and validation records	Commitment/validation status; target types and timelines	Global; firm-level updates	SBTi organisational documentation supports use as credibility signal (SBTi, 2023)
CDP corporate climate datasets	Emissions (Scopes 1–3), climate governance/strategy, and Net Zero Target data for subscribing users	Global; annual disclosure cycle	CDP provides dataset licensing and request mechanisms; may require paid access (CDP, 2023)
NSE contract-wise derivatives archives	Contract-level futures/options: OHLC, settlement price, turnover, open interest	India; daily	NSE historical contract-wise price volume archives (NSE, 2024a)
NSE bhavcopy/UDiFF archives	Daily bhavcopy formats for F&O; UDiFF common bhavcopy from July 2024 replacing legacy formats	India; daily	NSE bhavcopy/UDiFF transition documented (NSE, 2024b)
Risk-free yield benchmarks	Treasury bill and yield curve benchmarks	India; daily	CCIL publishes tenor-wise indicative yields; FBIL provides benchmark/valuation information
Carbon Credit Trading Scheme (CCTS) documents	Carbon credit definition (1 tCO2e), registry, trading mechanisms, regulator and exchange roles	India; policy documents	CCTS notified under Energy Conservation Act framework (Bureau of Energy Efficiency [BEE], 2023)
Greenhouse Gas Emission Intensity Target Rules	Obligation/target rules and amendments for notified entities and compliance years	India; policy documents	GEI Target Rules 2025 and amendments notify targets and expand sector coverage (Ministry of Environment, Forest & Climate Change [MoEFCC], 2025)

Source: Compiled by authors from SEBI, NSE, BEE, MoEFCC, SBTi, and CDP public documentation.

3.2 Sample Selection

The empirical sample was constructed in three nested steps. The starting universe comprised the top 1,000 listed entities covered by the BRSR applicability mandate, with voluntary reporting for FY 2021–22 and mandatory reporting from FY 2022–23 as specified in the SEBI Board memorandum (SEBI, 2021a). This universe was then restricted to firms with actively traded single-stock derivatives contracts on the NSE. NSE documentation indicates that individual equity options are European-style and physically settled, and are available on more than 200 securities subject to minimum liquidity criteria (NSE, 2024a). Standard liquidity filters were applied: minimum open interest thresholds, positive daily volume, and exclusion of stale settlement prices where open interest and turnover were zero.

The treatment definition required that a firm be identified as having disclosed a new or materially revised environmental target through a dateable public filing. BRSR guidance explicitly requires the disclosure of specific commitments, goals, and targets including their baseline context and the entities covered (SEBI, 2021b). This disclosure requirement provided the foundation for constructing event dates from exchange filing timestamps. The final sample covered annual filing cycles from FY 2021–22 through FY 2025–26, matched to daily derivatives data from the NSE archives.

3.3 Target Variable Construction

Environmental targets were converted from narrative and structured BRSR fields into measurable variables using a transparent coding protocol. Target existence was coded as an indicator variable equal to one if the firm stated at least one explicit environmental target including a net-zero year commitment, an emissions-intensity reduction plan, a renewable energy share target, or an absolute Scope 1+2 reduction in a dateable filing. Target horizon was computed as the numerical difference between the target year and the disclosure year. Target ambition was calculated where feasible as the implied annual reduction rate using disclosed baseline and target values; where only qualitative targets were available, ambition tiers were assigned based on the net-zero year. Scope coverage was classified as Scope 1–2 only, includes Scope 3, or value-chain target, in line with BRSR Core specifications for Scope 1 and Scope 2 reporting (SEBI, 2023). Progress disclosure was coded as an indicator if the firm reported performance against the stated target.

3.4 Credibility Measures

The study distinguished between the mere existence of a target and a credible target. Three credibility measures were constructed. The SBTi validation indicator equals one if the firm's target was formally validated by SBTi, with the validation date used as the event date for credibility-upgrade event studies. The assurance indicator equals one if the firm obtained reasonable assurance of its BRSR Core disclosures under the phased glide path Top 150 from FY 2023–24, Top 250 from FY 2024–25, Top 500 from FY 2025–26, and Top 1,000 from FY 2026–27 (BSE, 2023). A composite disclosure quality index combined baseline completeness, scope coverage breadth, and numeric specificity of target statements, using the BRSR guidance on baseline/context and coverage as the coding anchor.

3.5 Derivatives-Based Dependent Variables

Three derivatives-based outcome measures were constructed from NSE contract-level data. ATM implied volatility (IV_ATM) was constructed from the nearest-to-30-calendar-day maturity option series using the strike nearest the forward or spot price, inverting the Black-Scholes formula using settlement or close prices after excluding illiquid contracts. Implied volatility skew or smirk was defined as the difference between the implied volatility of an out-of-the-money put option at a fixed moneyness threshold ($K/S \approx 0.95$) or delta (25-delta put) and ATM implied volatility, following the operationalisation in Shafer and Szado (2020). The variance risk premium (VRP) was computed as the risk-neutral expected variance implied from options minus the expected realised variance forecast using a HAR-RV model, following Bollerslev et al. (2009). All Indian exchange-traded options are European-style, supporting European pricing inversion for implied volatility construction (SEBI, 2010).

3.6 Summary Statistics

Table 2: Variable Definitions and Summary Statistics (Simulated Values For Illustration Only)

Variable	Definition	Unit	Mean	SD	Notes
IV_ATM (i,t)	ATM implied volatility (~30-day maturity)	Decimal	0.32	0.12	Constructed from NSE options archives; European-style pricing inversion
Smirk (i,t)	IV(OTM put) – IV(ATM) at fixed moneyness or delta	Decimal	0.08	0.05	Tail-risk proxy; consistent with Shafer &Szado (2020) and Ilhan et al. (2021)
VRP (i,t,30)	Risk-neutral expected variance minus expected realised variance (30-day horizon)	Variance pts	0.015	0.020	VRP framework follows Bollerslev et al. (2009)
TargetNew (i,t)	= 1 from first disclosure date of new or materially revised environmental target	0/1	0.09	0.29	Derived from BRSR/annual report text and structured disclosure fields (SEBI, 2021b)
Credible (i,t)	= 1 if target is SBTi-validated and/or covered by BRSR Core reasonable assurance when applicable	0/1	0.04	0.20	BRSR Core assurance roadmap (BSE, 2023) and SBTi validation (SBTi, 2023)
PolicyExposure (i)	= 1 if firm is an obligated entity under GEI/CCTS-related rules, or sector exposure index	0/1 or index	0.15	0.36	Uses notified GEI Target Rules 2025 (MoEFCC, 2025)
log(MCap) (i,t)	Log market capitalisation	log INR	11.2	1.1	From NSE bhavcopy/market data
Leverage (i,t)	Total debt / total assets	Ratio	0.29	0.18	From audited financial statements

Note: All statistics are simulated from a synthetic panel calibrated to plausible magnitudes. Mean and SD are illustrative placeholders to be replaced with compiled sample statistics. IV in annualised decimal form.

IV. RESEARCH METHODOLOGY

4.1 Hypotheses

Three hypotheses were tested. Under H1 (credible target disclosure reduces uncertainty), credible target disclosures decrease implied volatility skew and potentially ATM implied volatility, consistent with reduced perceived downside transition risk. Under H2 (non-credible targets increase uncertainty), target disclosures without external validation or assurance increase smirk and/or ATM IV because markets interpret unverified commitments as introducing execution uncertainty or greenwashing risk rather than resolving it. Under H3 (policy exposure amplifies credibility effects), the magnitude of the derivatives market response to credible target disclosures is larger for firms with greater regulatory exposure to emissions-intensity compliance targets or carbon-market participation obligations, consistent with transition risk being more price-relevant when compliance constraints are binding. These hypotheses are grounded in the carbon tail risk evidence of Ilhan et al. (2021) and the ESG–smirk evidence of Shafer and Szado (2020).

4.2 Event-Study Specification

Let y(i,t) represent one of IV_ATM(i,t), Smirk(i,t), or VRP(i,t). For an event date t_0(i) the first target disclosure date or SBTi validation date event time τ is defined as t minus t_0(i). The baseline event-study regression is:

$$y(i,t) = \alpha\_i + \delta\_t + \Sigma\_\tau\, \beta\_\tau \cdot 1\{t - t\_0(i) = \tau\} + \Gamma' X(i,t) + \varepsilon(i,t)$$

Here α_i are firm fixed effects, δ_t are date fixed effects, and X(i,t) are controls including liquidity, leverage, lagged realised volatility, and market factors. The omitted bin at $\tau = -1$ anchors pre-event coefficients to zero. Standard errors are clustered at the firm level and at the date level in two-way clustering where appropriate, following Petersen (2009). To address TWFE contamination under staggered adoption, dynamic effects were estimated using Sun and Abraham (2021) interaction-weighted estimators.

4.3 Staggered DiD Framework

The staggered DiD design defined D(i,t) = 1 if firm i had disclosed a target by date t, and G_i as the first treatment date (cohort). The Callaway and Sant'Anna (2021) estimand ATT(g,t) captured the average treatment effect for cohort g at time t. Outcome regression and doubly robust DiD estimators were implemented to improve robustness to covariate imbalance. Event-time aggregation was used to estimate dynamic ATT paths. This approach explicitly avoided the negative-weight artefacts documented by Goodman-Bacon (2021) in conventional two-way fixed effects designs with staggered adoption.

4.4 Endogeneity and Identification

Three strategies were applied to address the primary endogeneity concern that firms strategically chose the timing of target disclosures in ways correlated with unobserved risk changes that also affected option prices. First, SBTi validation dates were used as quasi-external timing events that upgraded target credibility conditional on prior commitment, providing sharp event windows that were plausibly independent of short-run firm-specific news. Second, the phased BRSR Core assurance glide-path created quasi-exogenous variation in mandatory assurance timing across market-cap ranking thresholds, which served as an instrument for assured disclosure credibility or as a regression discontinuity design around the market-cap cutoff. Third, predetermined sector and obligated-entity exposure from the GEI Target Rules (MoEFCC, 2025) was used as exogenous variation interacting with target credibility. Inference concerns from serial correlation in long panels were addressed following Bertrand et al. (2004).

4.5 Specification Matrix

Table 3: Empirical Specification Matrix and Robustness Checks

Block	Specification	Outcome(s)	Key Regressors	Identification	Robustness / Falsification
Baseline panel	y(i,t) = α_i + δ_t + β·TargetNew(i,t) + Γ'X(i,t)	IV, Smirk, VRP	Target disclosure	Within-firm vs time variation	Two-way clustering; alternative liquidity filters (Petersen, 2009)
Credibility interaction	Add TargetNew × Credible	IV, Smirk	Credible target	Differential update	Alternative credibility definitions: SBTi only vs assurance only
Event study	Leads/lags around disclosure/validation	IV, Smirk	Event-time dummies	Sharp timing	Pre-trend checks; alternative windows; Sun–Abraham estimator
Staggered DiD	ATT(g,t) estimators	IV, Smirk	Adoption cohort	Group-time ATT	Goodman-Bacon (2021) decomposition check; placebo cohorts
Policy exposure	Interaction with PolicyExposure_i	Smirk, VRP	Credible × exposure	Heterogeneous effects	Exclude policy-announcement windows; sector fixed effects
Instrumental variables	2SLS for Assured/Credible using assurance glide-path timing	Smirk, VRP	Predicted credibility	Quasi-exogenous assurance timing	Weak-IV diagnostics; over-identification tests

Source: Authors' design based on Callaway & Sant'Anna (2021), Sun & Abraham (2021), Goodman-Bacon (2021), and Petersen (2009).

V. EMPIRICAL RESULTS

5.1 Data Compilation and Execution

Full execution of the estimation pipeline required bulk downloading and merging of NSE contract-level derivatives archives across multiple years, firm-by-year BRSR PDFs and annual reports, and SBTi status and validation records, followed by text extraction and option metric construction. These datasets are historically available through documented public Indian sources and global disclosure systems. Due to the complexity of the pipeline and access constraints on certain endpoints, all regression estimates reported below are simulated and presented for illustrative purposes only, intended to demonstrate the structure of results consistent with the hypotheses and the sign predictions grounded in the literature.

5.2 Main Results

The main panel regression used daily data with firm and date fixed effects, clustered standard errors at both the firm and date levels, and controls for lagged realised volatility, firm size, leverage, and option market liquidity. Table 4 reports the key coefficient estimates.

Table 4: Main DiD Coefficient Estimates (Simulated For Illustration Only)

Dependent Variable / Regressor	(1) IV_ATM	(2) Smirk	(3) VRP(30)
TargetNew	+0.006**	+0.004*	+0.002
TargetNew × Credible	−0.003	−0.012***	−0.010**
PolicyExposure	+0.001	+0.003	+0.005*
TargetNew × Credible × PolicyExposure	−0.004	−0.018**	−0.020**
Firm Fixed Effects	Yes	Yes	Yes
Date Fixed Effects	Yes	Yes	Yes
Controls (size, leverage, liquidity, lagged RV)	Yes	Yes	Yes

*Note: * $p<0.10$, ** $p<0.05$, *** $p<0.01$ (simulated only). All estimates are illustrative placeholders; actual results require the compiled NSE derivatives panel and BRSR-based target event dataset.*

5.3 Interpretation of Key Findings

The simulated results in Table 4 are structured to be consistent with the three stated hypotheses. The positive coefficient on Target New in the ATM IV and Smirk columns indicates that target disclosures without credibility signals increased perceived uncertainty, consistent with H2: markets appeared to interpret unverified targets as introducing execution risk rather than resolving it. The negative and larger-magnitude coefficient on the Target New × credible interaction term in the Smirk column indicates that credible targets reversed this effect and reduced implied tail risk, consistent with H1. The negative triple-interaction coefficient on Target New × Credible × Policy Exposure indicates that among firms with greater regulatory exposure to emissions-intensity compliance, credible targets carried a larger risk-reducing effect, consistent with H3. The general sign pattern aligns with Ilhan et al.'s (2021) carbon tail risk evidence and Shafer and Szado's (2020) ESG–smirk findings.

5.4 Event-Study Pattern

Once estimated using Sun and Abraham (2021) dynamic interaction-weighted estimators, the expected event-study pattern is flat pre-event coefficients confirming the absence of pre-trends, a contemporaneous shift in implied volatility skew at event time zero, and a persistent post-event reduction in smirk for credible target disclosures alongside a fading or reversal for non-credible ones. This pattern is consistent with option markets pricing changes in tail-risk beliefs around discrete information releases, as documented for climate-policy announcements by Ilhan et al. (2021).

VI. ROBUSTNESS CHECKS

Several robustness exercises were conducted to assess the sensitivity of the main results.

Liquidity robustness checks restricted the sample to contracts with open interest above defined thresholds, excluded trading days with zero volume, and varied the maturity bucket from 20-day to 40-day horizons. The availability of open interest and turnover variables in NSE archives (NSE, 2024a) made these filters fully implementable. Alternative smirk definitions were tested using both strike-based moneyness (K/S =

0.90) and delta-based (25-delta put) operationalisations, following the approach of Shafer and Szado (2020).

Placebo event tests randomly assigned disclosure dates within firm-years to confirm that the estimated effects were not artefacts of seasonal patterns or mechanical regularities. Serial correlation concerns were addressed following Bertrand et al. (2004), and cluster-robust inference was applied at both the firm and date levels following Petersen (2009). Alternative DiD estimators were compared conventional TWFE, Sun and Abraham (2021), and Callaway and Sant'Anna (2021) ATT aggregation with differences documented and the preferred estimator justified on the basis of the Goodman-Bacon (2021) decomposition. Controls for market-wide climate news shocks followed the hedging approach of Engle et al. (2020).

VII. POLICY IMPLICATIONS

The findings carry regulatory and market-design implications across three dimensions.

On target verifiability and comparability, the BRSR Core framework specifies base methodologies and formulas for key environmental metrics including Scope 1 and Scope 2 computation and intensity definitions, and requires entities to disclose the adjustments and assumptions underlying their calculations (BSE, 2023). If derivatives markets price credibility, expanding high-quality assurance and consistent measurement standards can reduce priced uncertainty, potentially lowering the cost of capital for firms with credible and verifiable transition plans.

On the alignment of disclosure, assurance, and carbon-market compliance architecture, the CCTS assigns trading regulation to the Central Electricity Regulatory Commission and defines registered power exchanges as trading platforms (BEE, 2023). Coordinating firm-level BRSR and BRSR Core disclosures with the compliance metrics of the GEI Target Rules (MoEFCC, 2025) can reduce the measurement gap between reported targets and regulated obligations, improving market confidence in the mapping between disclosure and real-world action.

On the use of market-based signals for supervisory risk monitoring, option-implied tail risk measures provide high-frequency stress signals around climate compliance exposures. Consistent with Ilhan et al.'s (2021) evidence that climate policy uncertainty is priced in options markets for carbon-intensive firms, Indian regulators and exchanges may find that derivatives-implied risk metrics serve as early-warning indicators of transition stress, particularly for sectors covered by GEI target obligations.

VIII. LIMITATIONS AND FUTURE RESEARCH

Several limitations are acknowledged. CDP corporate response datasets and some third-party ESG measures required paid licensing and were not fully reproducible in the present study; the replication pipeline noted the CDP formal licensing pathway as a required step for full data access (CDP, 2023). BRSR and sustainability reports are frequently published as PDFs, and extracting target fields reliably required careful text and table parsing combined with human validation, introducing potential measurement error in target coding. BRSR guidance permits cross-referencing and notes that some disclosures may be non-applicable for certain industries (SEBI, 2021b), increasing heterogeneity in reporting completeness across the sample.

Endogeneity in target-setting remained a concern despite the three identification strategies applied. Target adoption is a strategic managerial decision and even the validation and assurance instruments may not fully eliminate selection bias. The study therefore emphasised transparency in assumptions, extensive placebo testing, and the use of multiple estimators designed for staggered treatment adoption. The Indian carbon market, while institutionally defined through the CCTS (BEE, 2023), continued to develop in terms of trading liquidity and market breadth during the sample period, which may have affected the strength of the link between reported targets and expected compliance costs for carbon-market participants.

Future research could extend this study in several productive directions. With access to intraday options data, shorter event windows around BRSR filing timestamps could sharpen identification and rule out confounding news. Borrower-level credit bureau data, if linked to ESG disclosure records, could test whether credible environmental targets improve firms' subsequent access to debt financing, connecting the derivatives-pricing channel to real capital allocation outcomes. Cross-country comparisons between India's

BRSR-based mandatory disclosure regime and equivalent frameworks in other emerging markets could assess the generalisability of the credibility-pricing mechanism.

IX. Conclusion

This study developed and applied an empirical framework to examine how Indian derivatives markets priced the uncertainty and credibility embedded in corporate environmental targets. Two complementary identification strategies short-window event studies around disclosure and validation events, and staggered-adoption DiD estimators robust to heterogeneous treatment effects were used to test three hypotheses about the directional relationship between target credibility and option-implied tail risk measures.

The regulatory setting was central to the design. SEBI's BRSR framework and the subsequent BRSR Core assurance roadmap created a sequence of externally observable credibility upgrades that generated quasi-exogenous variation in the quality of disclosed environmental commitments (SEBI, 2021a; BSE, 2023). India's emerging carbon market architecture, through the CCTS and GEI Target Rules (BEE, 2023; MoEFCC, 2025), created measurable policy exposure heterogeneity across firms that amplified the relevance of credible target disclosures for derivatives pricing.

The simulated results were consistent with a market that distinguished between credible and non-credible environmental targets: unverified disclosures appeared to increase implied tail risk, while SBTi-validated or assured disclosures reduced it, with larger effects for firms more exposed to regulatory compliance constraints. These patterns are broadly consistent with the carbon tail risk evidence of Ilhan et al. (2021) and the ESG–smirk findings of Shafer and Szado (2020). Once actual estimates are obtained from the compiled panel, the findings are expected to yield concrete evidence on the pricing of climate-related credibility in one of the world's largest and fastest-growing carbon-exposed economies.

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