Voluntary Disclosures and Climate Change Uncertainty: Evidence from CDS Premiums*

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Abstract

We examine the effect of voluntary climate risk disclosure on Credit Default Swap (CDS) premiums. We develop a structural model, in which climate-related disclosures serve as an information source reducing climate change uncertainty. The model predicts a negative relation between the informativeness of climate risk disclosure and the CDS premium, and asymmetric effects of positive and negative disclosure tone on the CDS premium. Using climate risk measures quantified from earnings call transcripts, we provide evidence supporting these predictions with causality. Our study suggests that climate risk is priced in the CDS market, where investors pay attention to climate risk disclosures.

JEL Classification: G10, G12, G14, G24, G32

Keywords: Climate change, voluntary disclosure, climate risk, CDS premium, informational uncertainty.

"Over the generations, the SEC has stepped in when there's significant need for the disclosure of information relevant to investors' decisions." — Gary Gensler, Chair of the U.S. Securities and Exchange Commission.

1 Introduction

An increasingly important issue in financial markets and regulation is understanding how the voluntary disclosure of climate risk is reflected in asset prices. The U.S. SEC has recently proposed a mandate for public companies to disclose climate risks in 10-K reports,[1] in addition to the currently adopted voluntary disclosure of the climate risks that have a material impact to their business operations (SEC, 2010). How financial markets and investors can benefit from the voluntary disclosure of climate risks is best understood within the context of the way that the risk disclosure facilitates the dissemination of information and that the information reduces noise in asset prices.

Climate finance is a significant topic of interest to investors, researchers, and regulators, alike (Hong et al., 2020; Giglio et al., 2021). Krueger et al. (2020) survey data that institutional investors consider the financial implications of climate risk in their portfolios. Institutional investors list regulatory changes associated with climate risk among the top factors that materialize in climate finance. Large investment management firms (e.g. BlackRock and State Street) actively seek to reduce carbon emissions from underlying firms in which they hold significant positions (Azar et al., 2021). Given the increasing attention on climate risk, both voluntary and mandatory disclosures of climate risk have significant financial implications for investors and corporations (Christensen et al., 2021; Krueger et al., 2021). It has been documented that there is still some underreaction of asset prices to climate risks (Hong et al., 2019), reinforcing the need for high-quality disclosure on climate risks.

[1] https://www.sec.gov/news/statement/gensler-climate-disclosure-20220321.

This paper examines the effect of voluntary climate risk disclosures on single-name CDS premiums. We are particularly interested in how the informativeness and tone, which is an interesting feature unique to voluntary disclosures (e.g., earnings call), of the climate risk disclosures, affect CDS premiums through the channel of uncertainty reduction. Thanks to some unique features of CDS contracts, the CDS market provides a cleaner setting to test the channel, compared to the equity and corporate bond markets. For example, unlike the equity market, CDS contracts have a term structure that allows us to empirically distinguish an uncertainty effect from a risk effect. Also, the fact that the CDS market is more liquid than the corporate bond market (see Longstaff et al., 2005) allows us to stay away from illiquidity issues that unnecessarily complicate the tests.

To guide our analysis, we develop a model that analytically incorporates climate news-induced noise into CDS pricing as a form of informational friction. Specifically, we build our model based on the Leland (1994) classic structural credit risk model framework. We incorporate a noise process, following Johnson (2004), to represent the effect that idiosyncratic climate change news obscures the true value of the firm's assets. The level of noisiness impacts CDS pricing through the parameter uncertainty effect of Pástor and Veronesi (2003). Disclosure informativeness lowers noisiness, therefore reducing uncertainty and tightening CDS spreads. Our model has a novel specification featuring an interplay between informativeness and tone of climate risk disclosures. The tone (positive *or* negative) of the disclosures not only adds clarity to the disclosures and improves the informativeness, but also captures the real impact of climate risk-related shocks on the true value of firm assets. To the best of our knowledge, we are the first to incorporate the tone of disclosures into a structural model.

Building on this interplay, our model predicts positive and negative disclosure tone has asymmetric effects on the CDS premiums. Intuitively, a positive tone strongly decreases the CDS premium by reducing informational friction and positively impacting the firm value. However, the negative tone does not have a clear impact on the CDS premium: in the same vein as the positive tone effect, the negative tone also reduces informational frictions, which would result in a tightening of CDS spreads; however, at the same time it has a negative real impact on the firm value (e.g., poor response to climate change and/or little or no sustainability efforts), which would result in a widening of CDS spreads. The net impact on the CDS premium depends on which force dominates the other; therefore, its direction is unclear.

To universally capture the effects of informativeness and tone of climate change disclosures, we propose a climate change uncertainty measure that aggregates informativeness and tone into a single quantity. Within our model, the CDS premium is negatively related to this measure analytically. Our model also predicts that when the overall noisiness of climate change news becomes lower or the overall informational setting improves, the effect of this uncertainty measure on the CDS premium becomes less prominent. Based on the model's predictions, we develop five testable hypotheses for our empirical study: 1) CDS premium decreases with the informativeness of climate risk disclosures; 2) CDS premium decreases with a positive tone of climate risk disclosures, but has a mixed relationship with negative tone; 3) the climate change uncertainty increases the CDS premium level but flattens the CDS curve; 4) the impacts of climate change uncertainty on the CDS level and slope become lower when the public climate risk awareness rises; 5) the effects of climate change uncertainty on the CDS level and slope become less prominent or even change direction for firms with lower analyst dispersion and less specific disclosures.

One challenge of the empirical analysis in climate finance is to quantify firm-level climate risk disclosures and their tone. A firm-level proxy of the disclosure is needed to identify the cross-sectional variation in the climate risk uncertainty over a reasonably long period to cover an entire business cycle. We use a recently developed method based on textual analysis from the 10-K report and the earnings call transcript (Loughran and McDonald, 2016; Hassan et al., 2019). We select the firm-level climate risk and sentiment measures of Sautner et al. (2022) to proxy the voluntary disclosure of the climate change-related bigrams captured from the quarterly earnings calls of the public firms. The climate risk measure is an aggregated numerical value reflecting the climate change topics covering physical risks, opportunities, and regulatory changes.

Consistent with our theoretical model's implications, we find evidence that the voluntary climate risk disclosures reduce the CDS premium level, supporting the notion that the disclosures reduce the uncertainty about climate change's impact on firms' business (Hypothesis 1). We empirically verify the asymmetric effect of climate change disclosures' positive and negative tone on the CDS premium (Hypothesis 2). We construct an empirical proxy for the climate change uncertainty measure and use it to show that climate change uncertainty increases the CDS premium level and flattens the CDS curve (Hypothesis 3), ruling out an alternative risk-based explanation. Importantly, we offer difference-in-difference evidence of causality that eases concerns about biased estimates due to endogeneity. Using the Paris Agreement in December 2015 as an interacting variable, we also find evidence supporting the notion that the impacts of climate change uncertainty on the CDS level and slope diminish with reducing noisiness in the overall climate change news (Hypothesis 4). We also confirm that the impacts of climate change uncertainty on the CDS term structure level and slope depend on informational frictions in the overall information environment measured by analyst dispersion (Hypotheses 5a and 5b). Our empirical results are generally consistent with the theoretical framework we developed.

The rest of this paper is organized as follows. Section 2 discusses the related literature and our incremental contributions. Section 3 develops our theoretical model and testable hypotheses for the empirical study. We introduce the data and summary statistics in section 4 and provide corresponding empirical results in section 5. Section 6 concludes the paper. The appendix contains the proofs.

2 Literature review

In the theory aspect, this paper contributes to the growing literature studying the effect of informational friction on asset pricing. Specifically, the model we develop offers novelty to the theoretical literature on structural models with implications for climate risk disclosures. For example, Heinle and Smith (2017) model the price effects of investors' uncertainty about the variance of a firm's cash flows and show that risk disclosure decreases the firm's cost of capital by reducing variance uncertainty. We extend the classic Leland (1994)-type of structural model by introducing climate news related information frictions into the pricing of credit risk. Our model is closely related to Duffie and Lando (2001) who show informational friction introduces an added premium to CDS premium, especially the short-term ones. We use a more parsimonious noise setting due to Johnson (2004). This allows for analytical solutions in pricing even with persistence in noise which is not available under Duffie and Lando (2001)'s setting. We then extend the framework further by incorporating both informativeness and tone of climate risk disclosures into the structural model and offer novel insights on their effects on the CDS premium. To the best of our knowledge, we are the first to incorporate both informativeness and tone of disclosures into a structural model.

Our study also relates to several areas in the empirical climate finance literature. The main theme of our paper fits into the fast-growing literature examining the impact of climate-related risks on various asset classes. On the equity market, Bolton and Kacperczyk (2021) find a higher premium in the cross-sectional U.S. stock returns, and known risk factors cannot explain the premium. Ilhan et al. (2021b) show that climate policy uncertainty is priced in the options market in the format of downside tail risk. They identify a tail risk premium for firms with high fossil energy dependence. In addition, institutional investors and banks screen the firms based on their potential environmental concerns, leading to a higher required return on the cost of capital and higher bank loan rates (Chava, 2014). On the bond market, Corporate bond holders seem to underreact to carbon risk, as the corporate bonds from high carbon emission firms yield lower returns (Duan et al., 2021).[2] It is shown that both the issuing cost and initial yield of municipal bonds are affected by climate change exposure (e.g., sea-level change impact), especially for long-term maturity bonds Painter (2020). In the meantime, there is no evidence that green bonds have a premium over regular bonds with similar characteristics (Tang and Zhang, 2020; Larcker and Watts, 2020). The green bond issuance is more of a signaling effect (Flammer, 2021).

The CDS market is tightly related to the equity, option, and corporate bond markets. On one hand, there is a robust link between the CDS premiums and the out-of-money equity put options (Cao et al., 2010; Carr and Wu, 2011). The single-name CDS premiums reflect the tail risk and are expected to be related to the carbon tail risk identified from the equity options market (Ilhan et al., 2021b). On the other hand, CDS and corporate bonds are tied to the underlying assets' credit risk. The CDS premiums are expected to be synchronized with the corporate bond yields, where there is a negative or insignificant premium from the climate change exposure (Cao et al., 2022; Larcker and Watts, 2020). We focus on disentangling the uncertainty-CDS premium relation in the setting where the climate change risk related discussion by the firm managers may affect the CDS premiums. We provide results on the effects of the tone in addition to the informativeness of voluntary climate risk disclosures on CDS premiums through a novel channel related to climate change uncertainty reduction. This novelty is a unique contribution to the literature and offers a complementary understanding of the relationship between disclosures and the cost of capital.

Our paper also contributes to the literature on the role of information disclosure in reducing financial risk uncertainty (Bochkay et al., 2022) by proposing a climate risk disclosure based uncertainty measure. Morgan (2002) provides evidence showing that

[2]The corporate bond market has started to recognize climate risks. Huynh and Xia (2021) construct corporate bonds' exposure to climate risk news, and find that bonds with high climate-risk news beta earn lower future returns. Corporate bonds from high carbon emission firms have higher illiquidity, and the bond funds suffer higher outflows when their exposure to carbon emission risk is high (Cao et al., 2022).

credit rating agencies disagree more often over more opaque financial intermediaries and argues that pushing self-disclosure can reduce the opacity. Akins (2018) finds that better disclosure quality results in less uncertainty about credit risk measured by disagreement among the credit rating agencies. Dye and Hughes (2018) theoretically argues that firms' propensity to disclose the information increases in the firm managers' information precision. Bochkay and Joos (2021) find that analysts' reliance on disclosure tone is almost three times greater when macroeconomic uncertainty is high. Bonsall and Miller (2017) show that less readable financial disclosures are associated with more significant bond rating agency disagreement and a higher cost of debt. Griffin and Jaffe (2022) argue that one of the critical challenges for a climate risk disclosure mandate is designing a climate disclosure framework to affect market volatility by reducing uncertainty. However, if it overlaps existing ESG disclosure systems, it could increase rather than reduce market uncertainty. In a survey of institutional investors regarding their opinions about climate disclosure, Ilhan et al. (2021a) find that respondents strongly believe that climate risk disclosure is essential. Our work is close to Wang (2021) in discussing the effect of the tone of risk disclosures on CDS premium, but ours is more specific on the climate change risk disclosures and the corresponding sentiment. In Donovan et al. (2021), the discussion in Management's Discussion and Analysis has prediction power on credit events. To the best of our knowledge, our study is the first to combine the informativeness and tone of climate risk disclosures into an aggregate measure of climate change uncertainty.

A precursor to our paper is Kölbel et al. (2022), which examines the impact of regulatory climate risk disclosures on the term structure of CDS premiums. Although we both study the relationship between climate risk disclosures and CDS premiums, there are key differences that set us apart distinctly and highlight the contributions of our new insights in presence of their findings. More concretely, Kölbel et al. (2022) focus on regulatory/mandatory disclosure (10-K reports) of climate risks and cannot unconditionally reject the hypothesis that climate risk disclosure does not affect CDS spreads, while we look at voluntary disclosure (from earnings call transcripts) of climate risks and find that it indeed has a lowering effect on CDS premiums through an uncertainty reduction channel (our Hypotheses 1 and 3) with affirmative *causal* evidence, which Kölbel et al. (2022) do not even attempt to address. Kölbel et al. (2022) find no convincing results on the sentiment/tone of their 10-K disclosure measures. In contrast, we find empirical results on voluntary disclosure tone consistent with the notion that tone is a crucial variable for understanding the role of disclosure in reducing climate change-related uncertainty. Also, to explain their empirical findings, Kölbel et al. (2022) argue disclosures of physical risk reduce uncertainty while those of transition risk increase uncertainty without a formal model. Here, we develop a formal model and demonstrate rigorously that disclosures with positive and negative tone have asymmetric effects on uncertainty reduction. Overall, Kölbel et al. (2022) focus on the climate change risk channel of mandatory disclosures' effect on CDS premiums and provide time-period sensitive results, while our study focuses on the climate risk uncertainty channel of voluntary disclosures' effect on CDS premiums and provides stronger and more general results.

3 Model and Hypotheses Development

In this section, we first develop an extended structural CDS pricing model featuring informational frictions. We then develop various testable hypotheses for the later empirical study based on the model's predictions.

3.1 CDS pricing with structural model

Similar to Cai et al. (2020), we start with the classical structural credit risk model framework Duffie and Lando (2001) and Hackbarth et al. (2006), and assume that the true value of firm i, $V_i(t)$, follows a Geometric Brownian Motion (GBM) under the risk-neutral measure, that is:

$$dV_i(t)/V_i(t) = rdt + \sigma_i dZ_i(t),$$

where σ_i is the constant asset volatility for a firm i, and $Z_i(t)$ is a standard Brownian Motion under the risk-neutral measure. Similar to Leland (1994), Duffie and Lando (2001), and Chen (2010), we further assume the firm has a console debt which pays coupon with a rate of c_i as long as the firm is solvent. For simplicity, we assume no tax payment in the model.[3]

The firm's default is modeled as the first time $V_i(t)$ touches a default boundary (Black and Cox, 1976). So, the risk-neutral default (PD) probability can be computed using the first passage time density of $V_i(t)$. Denote B_i as the endogenous default boundary of firm i which is invariant of t and given by $B_i = {}^{2c_i}/_{(\sigma_i^2+2r)}$ (see Leland, 1994). The default time $\tau_i = \inf\{t : V_i(t) \leq B_i\}$ is then the first time that the firm value, $V_i(t)$, reaches the default (lower) boundary B_i. By Zhou (2001), the risk-neutral probability of default at time t with a longer-term T is defined as $PD_i(t, T) = Prob(t < \tau_i < T)$, with specification

$$PD_i(t,T) \quad = \quad N(-d_1^i) + \exp\left(\frac{-2\gamma_i \log(V_i(t)/B_i)}{\sigma_i^2}\right) N(-d_2^i), \tag{1}$$

where $N(\cdot)$ is the cumulative density function of the normal distribution, $d_1^i = \frac{\log(V_i(t)/B_i)}{\sigma_i\sqrt{T-t}} + \frac{\gamma_i\sqrt{T-t}}{\sigma_i}$, $d_2^i = d_2^i - \frac{2\gamma_i\sqrt{T-t}}{\sigma_i}$, and $\gamma_i = r - \frac{\sigma_i^2}{2}$. From Duffie and Lando (2001), the CDS premium of firm i debt with quarterly fixed-leg payment and maturity T is given by:

$$CDS_i(t,T) = \frac{4(1-R_i)\mathbb{E}_t\left[e^{-r(\tau_i-t)}\mathbb{1}_{\{\tau_i<T\}}\right]}{\sum_{j=1}^{4(T-t)} e^{-r\frac{j}{4}}\mathbb{E}_t\left[\mathbb{1}_{\{\tau_i>t+j/4\}}\right]}, \tag{2}$$

where R is the recovery rate of the notional amount in the event of default and $\mathbb{E}_t(\cdot)$

[3] A major contribution of the Leland (1994) and Leland and Toft (1996) structural credit risk model was their incorporation of taxes and bankruptcy costs to identify the optimal capital structure. Although it is largely abstracted in our analysis, in relation to business cycle variation and macroeconomic conditions, the capital structure has been extensively studied in the literature within the structural credit risk model framework, see, e.g., Chen (2010) and Chen et al. (2018).

is the conditional expectation under the risk-neutral measure at time t. We can rewrite eq. (2) as:

$$CDS_i(t,T) = \frac{4(1-R)\int_t^T e^{-r(s-t)}\frac{\partial PD_i(t;s)}{\partial s}ds}{\sum_{j=1}^{4(T-t)} e^{-rj/4}\left[1-PD_i(t,t+j/4)\right]}. \quad (3)$$

Since the CDS position is approximately equivalent to a long position in a put option of firm value $V_i(t)$ (Carr and Wu, 2011), we know $CDS_i(t,T)$ is a convex function of $V_i(t)$.

3.2 Uncertainty and disclosures with tone

We model the firm-level climate risk-related shocks as a noise process obscuring the true value of the firm assets. The volatility of this noise process is *inversely* related to the informativeness of climate change-related disclosures, as it mitigates uncertainty. This modeling assumption is consistent with evidence found in Lang and Lundholm (1996); Hope (2003); Bonsall and Miller (2017); Akins (2018). The overall tone (positive *or* negative) of the disclosures, which adds clarity to the disclosures and improves the informativeness, captures the real impact of climate risk-related shocks on the true value of the firm assets. Specifically, when the tone is positive, e.g., climate change creates opportunities (negative, e.g., climate change imposes burdens) for the firm, adverse climate risk news translates into real positive (negative) shocks to the firm's assets' true value.

More concretely, following Johnson (2004), we assume the noise process $\eta_i(t)$ has the following dynamic:

$$d\eta_i(t) = -\theta_i\eta_i(t)dt + \sigma_{\eta_i}dW(t). \quad (4)$$

where σ_{η_i} controls the dispersion of the noise while θ_i controls the persistence of the noise, and $W(t)$ is a standard Brownian motion common to all firms under the risk-neutral measure and captures the shocks stem from overall climate risk news. Its correlation with $Z_i(t)$ is ρ_i. The investors in the market do not directly observe the firm value $V_i(t)$; instead they observe a noisy version $\widetilde{V}_i(t) = V_i(t)e^{\eta_i(t)}$. In this setting, the observed firm value with noise has the following dynamic:

$$\frac{d\widetilde{V}_i(t)}{\widetilde{V}_i(t)} = \left[r - \frac{\sigma_i}{2} + \frac{\widetilde{\sigma}_i}{2} - \theta_i \eta_i(t) \right] dt + \widetilde{\sigma}_i d\widetilde{Z}_i(t), \tag{5}$$

where

$$\widetilde{\sigma}_i d\widetilde{Z}_i(t) = \sigma_i dZ_i(t) + \sigma_{\eta_i} dW(t), \text{ and } \widetilde{\sigma}_i = \sqrt{\sigma_i^2 + \sigma_{\eta_i}^2 + 2\sigma_i \sigma_{\eta_i} \rho_i}. \tag{6}$$

Although when $\rho_i < 0$, the negative correlation offsets the noise dispersion to some extent, it is sensible to assume that the overall volatility of the observed firm value is always greater than that of the true firm value due to the added noise. Therefore, we require $\widetilde{\sigma}_i > \sigma_i$. In other words, the following condition is imposed:

$$\widetilde{\sigma}_i > \sigma_i \Leftrightarrow \sigma_{\eta_i} > -2\sigma_i \rho_i. \tag{7}$$

Here, $\eta_i(t)$ per se is firm-specific informational frictions arising from climate risk news, therefore the level of $\eta_i(t)$ should be taken as uninformative about the true firm value $V_i(t)$. However, the shocks to the noise $\eta_i(t)$ are correlated with those to the true firm value $V_i(t)$. In other words, climate risk news induces both informational frictions (via $\eta_i(t)$) and real impacts (via ρ_i) on the firm value. Keeping this intuition in mind, we now explain how climate risk disclosures and their tone can be modeled under our setting.

Disclosure tone The tone of disclosure is captured by ρ_i. When $\rho_i > 0$ ($\rho_i < 0$), the tone is negative (positive). The intuition can be understood as follows: in the case of a negative tone, bad news of climate change, which is a negative shock ($dW_t < 0$) driving η_i downwards, is likely to result in a negative shock to the true firm value, i.e., $dZ_i(t) < 0$ due to $\rho_i > 0$; in the case of a positive tone, bad news of climate change likely results in a positive shock to the true firm value, i.e., $dZ_i(t) > 0$ due to $\rho_i < 0$.

Climate risk disclosures The volatility of $\eta_i(t)$, σ_{η_i}, captures the uncertainty around shocks arising from news of climate risk. The higher is σ_{η_i} the greater the noise dispersion. As mentioned above, σ_{η_i} as a measure of uncertainty is reversely related to the informativeness of climate risk disclosures. Furthermore, disclosure tone (either positive or negative) adds clarity and improves disclosure informativeness, therefore reducing uncertainty (see, e.g., Bochkay and Joos, 2021; Mayew and Venkatachalam, 2012). In light of this intuition, we specify σ_{η_i} as:

$$\sigma_{\eta_i} = \phi\sigma_i\left(1 - cr_i\right)\left(1 - \rho_i^2\right), \tag{8}$$

where $\phi > 0$ is a scaling parameter that measures information environment and is common to firms within the same information environment, and $0 < cr_i < 1$ is a general measure of disclosure's informativeness without tone information. Given this specification, eq. (7) translates into:

$$\phi\left(1 - cr_i\right)\left(1 - \rho_i^2\right) + 2\rho_i > 0 \Rightarrow \rho_i > -\frac{\sqrt{1 + \phi^2\left(1 - cr_i\right)^2} - 1}{\phi\left(1 - cr_i\right)}. \tag{9}$$

By the results in Liptser and Shiryaev (2013, Theroem 12.1), the investors' belief about $\log V_i(t)$ given the historical value of $\widetilde{V}_i(t)$ set is normally distributed. The results are summarized in Proposition 1.

Proposition 1. *Given $\widetilde{V}_i(t)$ and assuming the prior distribution is normal, the optimal posterior belief about $\log V_i(t)$ is normally distributed with mean $\hat{v}_i(t) \equiv \mathbb{E}\left(\log V_i(t)|\mathcal{F}_t\right)$ and steady-state variance ω_i where $\mathcal{F}_t = \left\{\left(\widetilde{V}_i(s)\right) : 0 \leq s \leq t\right\}$. $\hat{v}_i(t)$ follows*

$$d\hat{v}_i(t) = (r - \sigma_i^2/2)dt + \sigma_i dZ_i^I(t), \tag{10}$$

where $Z_i^I(t)$ is a Standard Brownian motion with respect to $\mathcal{F}_t$ under the risk-neutral measure.

The parameter ω_i is given by

$$\omega_i = \frac{\sigma_i^2}{\theta_i}\left(\sqrt{1+\phi^2\left(1-cr_i\right)^2\left(1-\rho_i^2\right)^2+2\phi\rho_i\left(1-cr_i\right)\left(1-\rho_i^2\right)}-1\right). \tag{11}$$

Proof. See Appendix A. □

Based on eq. (11), we can explicitly quantify the impact of disclosure informativeness and tone on the precision of the investors' inference measured by (inverse of) ω_i. First, if we assume σ_{η_i} is purely driven by cr_i, then the precision clearly increases with cr_i. The result is formalized in Proposition 2.

Proposition 2. *Given condition (9), if $cr_i > cr_j$ and all else are equal, then $\omega_i < \omega_j$.*

Proof. See Appendix A. □

Second, when all else is equal, it is trivial to see that the precision increases with the absolute value of ρ_i, when $\rho_i < 0$, i.e., the positive tone always improves the precision. However, how ρ_i affects the precision is unclear when $\rho_i > 0$. In other words, the impact of a negative tone on precision is unclear. The intuition is that negative tone (positive ρ_i) directly increases the total variance (see eq. (6)), but at the same time improves the disclosure informativeness (see eq. (8)), which indirectly decreases the total variance. The net impact on the precision depends on which force dominates the other; therefore, its direction is unclear. The results are formalized in Proposition 3.

Proposition 3. *When all else are equal, if $\rho_i < \rho_j < 0$, then $\omega_i < \omega_j$; if $\rho_i > 0$, the relation between ρ_i and ω_i is non-monotonic.*

Proof. See Appendix A. □

The above results are shown in Figure 1. We fix $\sigma_i = 0.3$, $\theta_i = 0.2$ and $\phi = 1$, and set cr_i to four different levels separately [0.01, 0.2, 0.4, 0.6]. The key insights from Propositions 2 and 3 are visualized: overall, when cr_i increases the whole curve of $\sqrt{\omega_i}$

goes down, indicating improvement in the precision of the investors' inference. This is also the case for disclosure tone when it is positive ($\rho_i < 0$). However, from the curves, we can observe a non-monotonic relation between ρ_i and ω_i when the disclosure tone is negative ($\rho_i > 0$), highlighting the opposing effects on the precision brought by negative tone via direct and indirect channels mentioned above.

[Insert Figure 1 here]

3.3 CDS pricing with informational frictions

When pricing a firm i's CDS, the investors know the firm has not defaulted. Therefore, the investors' information set is $\mathcal{F}_t \cup \mathbb{1}_{\{\tau_i < t\}}$. $V_i(t)$ which is relevant to the investors only when $\tau_i > t$. Therefore, combined with Proposition 1 we have that, given $\mathcal{F}_t \cup \mathbb{1}_{\{\tau_i < t\}}$ from the investors' perspective, $V_i(t) > B_i$ and $\log V_i(t)$ follows a truncated normal distribution of which the PDF is

$$f(x; \hat{v}_i(t), \sqrt{\omega_i}, B_i) = \frac{1}{\sqrt{\omega_i}} \frac{\varphi\left(\frac{x - \hat{v}_i(t)}{\sqrt{\omega_i}}\right)}{1 - N\left(\frac{\log(B_i) - \hat{v}_i(t)}{\sqrt{\omega_i}}\right)}, \tag{12}$$

where $x > \log(B_i)$ and $\varphi(\cdot)$ is the PDF of the normal distribution.

3.3.1 CDS premium

The law of iterated expectations implies that the investors' pricing function for $\widehat{CDS}_i(t, T)$ is given by (Pástor and Veronesi, 2003)

$$\widehat{CDS}_i(e^{\hat{v}_i(t)}; t, T) = \int_{\log B_i}^{\infty} CDS(e^x; t, T) f(x; \hat{v}_i(t), \sqrt{\omega_i}, B_i) dx. \tag{13}$$

Therefore, the investors' CDS pricing function with informational friction $\widehat{CDS}_i(t, T)$ is the average of their pricing function under perfect information $CDS(V_i(t); t, T)$ for all possible values of $V_i(t)$, weighted by the current probabilities assigned to each $V_i(t)$. The convexity of $CDS(V_i(t); t, T)$ with respect to $V_i(t)$ leads to the following corollary:

Corollary 1. *For $\chi > B_i$, $\widehat{CDS}_i(\chi; t, T) > CDS_i(\chi; t, T)$.*

Since ω_i measures the uncertainty about the investors' posterior belief about $V_i(t)$, it increases the CDS premium. This effect is summarized in the following corollary:

Corollary 2. *For $\chi > B_i$, $\widehat{CDS}_i(\chi; t, T) - CDS_i(\chi; t, T)$ increases with ω_i.*

We visualize the impacts of cr_i and ρ_i on the CDS premium in Figure 2 using the same numerical setting in Figure 1. Given Corollary 2, as shown in Figure 2 the key insights from Propositions 2 and 3 are also applicable to the CDS premium: overall, cr_i increases CDS premiums, and negative ρ_i and positive ρ_i have an asymmetric impact on CDS premiums.

[Insert Figure 2 here]

3.3.2 Informational frictions vs volatility risk: the slope of the CDS curve

From Corollary 2, we know that the CDS premium increases with ω_i through the informational friction channel shown in eq. (13). From the common sense of credit derivative pricing (Carr and Wu, 2011), we know that CDS premium increases with σ_i too through the volatility risk channel. The effects of ω_i and σ_i on the CDS premium are shown in Figure 3a. Clearly, the informational friction channel of ω_i is hardly distinguished from the volatility risk channel of σ_i when only looking at their effect on the CDS premium.

[Insert Figures 3 and 4 here]

Based on common sense, we also know that volatility risk has a more significant positive impact on longer-term CDS premiums due to the amplifying effect of maturity, therefore the slope of CDS term structure increases with volatility. In contrast, the uncertainty induced by informational frictions has a more significant impact on shorter-term CDS premiums (Duffie and Lando, 2001), therefore the information frictions tend to flatten the CDS curve in general, i.e., the short end of the curve rises *relative* to the long end. Our model confirms this and visualizes this in Figure 4. These two distinct effects of ω_i and σ_i on the slope of the CDS curve are contrasted in Figure 3b. Although the effects of both the informational friction channel of ω_i and the volatility risk channel of σ_i are indistinguishable on the CDS premium level, they set themselves apart distinctly from each other when it comes to affecting the slope of the CDS curve.

After establishing the relation between ω_i and the slope of the CDS curve, in Figure 5 we further show the impacts of cr_i and ρ_i on the slope. Since ω_i decreases with cr_i, we see that overall cr_i decreases the slope. However, no monotonic patterns are predicted by the model with regard to the relation between ρ_i and the slope.

[Insert Figure 5 here]

3.3.3 Information environment and climate change uncertainty

It is helpful to aggregate cr_i and ρ_i into one measure within our model. Since our model predicts that the imprecision measure ω_i is proportional to:

$$(1 - cr_i)^2 \left(1 - \rho_i^2\right)^2 + 2\rho_i \left(1 - cr_i\right) \left(1 - \rho_i^2\right), \tag{14}$$

we define (14) as a climate change uncertainty measure, which we term 'CC Uncertainty'. CC Uncertainty measures investors' uncertainty about the firm's true value arising from climate change-related news. It provides a convenient way to aggregate information from the general informativeness of climate risk disclosures and the tone of such disclosures. By construction, CC Uncertainty$_i$ is negatively correlated with cr_i, capturing the key notion that climate risk disclosures *reduce* the firm's climate change uncertainty the investors face; at the same, CC Uncertainty$_i$ is non-linearly related with ρ_i, reflecting the fact that positive tone and negative tone have *asymmetric* effects on precision in the firm value inference as discussed in Proposition 3.

Given CC Uncertainty$_i$, the imprecision measure ω_i in eq. (11) can be rewritten as:

$$\omega_i = \frac{\sigma_i^2}{\theta_i}\left(\sqrt{1+\phi^2\left(\text{CC Uncertainty}_i\right)+2\phi\rho_i\left(1-cr_i\right)\left(1-\rho_i^2\right)\left(1-\phi\right)}-1\right). \tag{15}$$

As mentioned above, ϕ measures the information environment and is common to firms within the same information environment. From eq. (15), we see that the impact of CC Uncertainty on imprecision is very much controlled by ϕ. Therefore, our model quantifies CC Uncertainty's effect on the CDS premium in different information environments.

To this end, we set ϕ to be 0.85 and 1.4 in our numerical examples to represent low informational and high information friction environments, respectively. Within each environment, we vary cr_i and ρ_i to generate varying CC Uncertainty$_i$ while keeping other parameters constant. The numerical illustrations are shown in Figure 6.

[Insert Figure 6 here]

From Figure 6, we find that by transiting from a high informational friction environment to a low one, the positive impact of CC Uncertainty on the CDS premium is reduced significantly. The effect of CC Uncertainty on the slope even changes direction in high and low informational friction environments. These results echo the effect of ω_i on the CDS level and slope shown in the left panels of Figure 3, indicating how much climate risk disclosures can affect and how they affect the CDS premium depending on the overall information environment. This has essential empirical and policy implications for understanding the interplay between overall climate change policies, e.g., the Paris Agreement, and firm-level climate risk disclosure practice. This is also important for understanding why climate change uncertainty is priced differently in CDS for firms with different degrees of analysts' disagreement. We explore these empirical implications and develop various hypotheses in the following subsection.

3.4 Hypotheses development

We summarize the testable hypotheses in this subsection based on the model predictions to guide the later empirical study. In climate change news-induced uncertainty, imprecision in investors' inference of the firm value imposes an overpricing effect on CDS premiums (Corollaries 1 and 2). Our model predicts that disclosures on climate risks increase the precision (Proposition 2), while negative and positive disclosure tone has an asymmetric impact on the precision (Proposition 3). These results lead us to Hypotheses 1 and 2.

Hypothesis 1. *CDS premium decreases with disclosures on climate risks;*

Hypothesis 2. *CDS premium decreases with a positive disclosure tone but has an insignificant correlation with a negative disclosure tone.*

We argue that disclosures on climate risks affect the CDS premium via the informational friction channel, i.e., the uncertainty reduction effect, rather than the volatility risk channel. Using the theoretical results in section 3.3.2, we test Hypothesis 3 to rule out the alternative explanation of the volatility risk channel.

Hypothesis 3. *CDS premium increases with the CC Uncertainty, while the slope of the CDS curve decreases with it.*

The information environment measure, ϕ, can be related to the overall noisiness of climate change news. As the public awareness of climate risks rises, climate change news creates less noise, i.e., ϕ becomes smaller. This leads to Hypothesis 4.

Hypothesis 4. *As the public becomes more aware of climate risks, the impact of CC Uncertainty on CDS premium level and slope in Hypothesis 3 becomes lower.*

The parameter ϕ can also be considered as an external uncertainty factor common within certain firms. For example, firms with high analyst dispersion tend to be in industries with hard-to-value fundamentals, and firms with good disclosure practices tend to provide more specifics in their disclosures. Guided by the results in Figure 6, we propose Hypotheses 5a and 5b.

Hypothesis 5a. *The positive impact of CC Uncertainty on the CDS premium is stronger (weaker) among firms with high (low) analyst dispersion and low (high) disclosure specificity.*

Hypothesis 5b. *The impact of CC Uncertainty on the slope of the CDS curve is negative with a larger magnitude (positive with a smaller magnitude) among firms with high (low) analyst dispersion and low (high) disclosure specificity.*

4 Data and descriptive statistics

In this section, we describe the data used in the empirical analysis. We justify the empirical data choice on cross-sectional climate risk disclosure proxies in section 4.1. The CDS data description and controls are provided in section 4.2. Section 4.3 provides the summary statistics and correlations of the key variables used in the empirical study.

4.1 Cross-sectional climate risk disclosures

The hypothesis testing on the theoretical framework requires a firm-level proxy for underlying firms' climate risk disclosure. We select the firm-level climate change exposure and sentiment developed Sautner et al. (2022) as the proxies of the cross-sectional climate risk disclosures and their tone. This climate change measure is constructed using textual analysis of the earnings conference calls and builds on the methodology originally used to analyze political risk Hassan et al. (2019).

When building the climate change exposure, a (short) list of bigrams directly related to climate change is determined first. Then, an algorithm used to identify the keywords related to the list of the bigrams is executed, based on the methodology described King et al. (2017). This step provides a large set of bigrams related to the climate change discussion in the corresponding textual universe. The exposure and sentiment measures are constructed based on this set of bigrams related to the climate change discussion.

We use the climate change exposure (*CR Exposure*) of Sautner et al. (2022), which measures how frequently the specified bigrams appear in a given transcript, as our climate risk disclosure variable, CR Disclosure. We use Sautner et al. (2022)'s climate change sentiment (*CR Sentiment*), which counts the number of climate change bigrams after conditioning on the presence of the positive and negative tone words in Loughran and McDonald (2011), as our climate risk disclosure tone variables, CR Positive Tone and CR Negative Tone.

4.2 CDS premiums and controls

The pricing data on single-name CDS contracts are retrieved from Markit, a leading credit market data service provider. We use the five-year CDS premium as the key-dependent variable in the empirical study, as the five-year contract is usually the most liquid maturity on the single-name CDS premium curve (see Chen et al., 2010). We then use the difference between ten-year and one-year CDS premiums to measure the slope of the CDS term structure, as a measure of the long-term credit risk compared to the short-term. We identify 1,073 unique actively traded CDS firms from 2002Q1 to 2020Q4. A firm is counted as an actively traded CDS firm in a given quarter if at least 15 daily five-year CDS premiums are observed during the month. Within the same sample period, we collect about 158,000 firm-month observations on CDS premiums.

To examine the conditional effect of climate risk disclosure and corresponding disclosure tone on the credit spread, we include the standard independent variables that are related to default risk in the literature (see, e.g., Collin-Dufresn et al., 2001; Duffie et al., 2007; Davies, 2008; Ericsson et al., 2009; Duan et al., 2012; Bali et al., 2021).

- Risk-free rate: The three-month Treasury bill rate is used to incorporate business cycle information into the empirical framework. It is easier for firms to refinance their existing debt at a lower cost when interest rates are low. On the other hand, lower interest rates on the long end of the yield curve may signal recessions, which are coincidental with more frequent default events. We include the ten-year Treasury note rate to capture the term structure of the yield curve.

- Individual stock return: This is the lagged one-year return on a firm's stock, negatively correlated with the firm's leverage and default probability. The firm-level stock return also reflects the idiosyncratic risk of the firm.

- Stock index return: The lagged one-year S&P 500 index return serves as a systematic risk factor, and is expected to have a negative relationship with default events.

- Rating: the long-term S&P credit rating on the firm. The credit rating is closely related to the default risk and thus the credit spread.

- Idiosyncratic stock volatility (IVOL). IVOL is estimated by regressing daily individual stock returns on the Fama-French three factors and then computing the annualized standard deviation of the regression residuals. IVOL is expected to correlate positively with the likelihood of default.

- Leverage Ratio: the book leverage ratio of the firm is directly related to the firm's solvency. The leverage ratio correlates theoretically and empirically positively with a credit spread.

- Firm size: The logarithm of a firm's total assets. Larger firms tend to be less likely to default.

- Market-to-book ratio: The ratio of the market value of assets to the book value of assets. Traditionally, this has been viewed in the literature as a proxy for financial distress and, therefore, we predict that it should be negatively related to CDS premiums and probability of default (see, e.g., Griffin and Lemmon, 2002).

- Net Income/Asset ratio (ROA): The ratio between net income and total assets. Negatively related to the default probability.
- Analyst coverage: the unique number of financial analysts who provide the underlying firm's earnings per share (EPS) forecast.
- Analyst dispersion: the root of the sum squared error term of the analyst forecast on the firm's EPS.
- E-Score: logarithm of the environmental score based on Refinitiv ESG rating.
- GHG Scope 1: logarithm of the scope 1 greenhouse gas emission (GHG).

The CDS premium data is then merged with the firm-level climate risk disclosure measures and other control variables. A detailed description of how the key independent covariates are constructed is presented in Table 1.

[Insert Table 1 here]

4.3 Summary statistics

Table 2 summarizes the main variables used in the empirical study. The five-year CDS premium has a mean of 188 basis points and a median value of 95 basis points, indicating that the spread is heavily skewed to the right. The CDS slope has a mean of 107 basis points. The average firm in our sample has total assets of $13.7 billion (the logarithm of total assets, in units of $1 million, is equal to 9.53), a market-to-book ratio of 1.61, and a net income equal to 1.0% of total assets. As for the controls related to the capital market, the average 3-month Treasury rate is about 132 basis points, the average 10-year Treasury rate is about 304 basis points, and the S&P500 index return has an average of 0.8% per month. An average firm has an annualized idiosyncratic stock volatility of 23.2%, and a monthly stock return of 0.6%. The average environmental score is 0.58 with a standard deviation of 0.32.

[Insert Table 2 here]

Turning to the correlations among the covariates in Table 3, The CDS premium is negatively associated with the climate change disclosure proxy and the positive disclosure tone. The CDS premium is positively related to climate change uncertainty. These unconditional relations are consistent with our hypotheses. Among the controls, credit rating, IVOL, leverage ratio, and analyst dispersion positively relate to the credit spread. Whereas Treasury rates, individual stock return, stock market return, firm size, market-to-book ratio, ROA, and ESG rating are negatively related to the credit spread. The direction of these credit risk covariates with credit spread is consistent with the extant literature findings.

[Insert Table 3 here]

5 Empirical analysis

In this section, we empirically examine the theoretical predictions on the relation between climate risk disclosure and CDS premiums.

5.1 Climate risk disclosure and its tone

To disentangle the effect of climate risk disclosure on CDS premium, we specify the baseline regression as

$$\text{CDS premium}_{i,t+1} = \text{CR Disclosure}_{i,t} + \text{Controls}_{i,t} + D_r + D_i + D_t + \epsilon_{i,t}, \qquad (16)$$

where CDS premium$_i$ is the five-year CDS premium for firm i. This dependent variable setup is mainly designed to test Hypothesis 1. CR Disclosure$_{i,t}$ comes from the dataset by Sautner et al. (2022) and represents the climate risk disclosure proxy for a firm i at corresponding month t, and Control$_{i,t}$ is a group of credit risk control variables as described in Section 4.2. D_r, D_i, and D_t are the credit rating dummy, firm dummy, and year dummy, respectively.

The first two columns in Table 4 present the empirical results using CR Disclosure as the key independent variable. We observe that CR Disclosure is statistically significant for the CDS premium. When using the equal-weighted frequency, the CR Disclosure has a coefficient of -0.11 (with t-statistic=-6.688) in the CDS premium regression. The disclosure proxy using TFIDF frequency convinces this relation with a coefficient of -0.015 and a t-statistic of an even higher magnitude. These results provide strong evidence supporting Hypothesis 1.

[Insert Table 4 here]

The credit market reaction may be affected by the firm manager's tone associated with climate risk disclosures (Hypothesis 2). To test this conjecture, we decompose the climate risk tone into positive and negative tone around the disclosure in the earnings call. According to Columns (3) and (4) of Table 4, the positive tone related to climate risk disclosure significantly reduces the CDS premium, while the negative tone's effect on the CDS premium has much less significance. For instance, using the equal-weighted managers' sentiment proxies, the coefficient of the positive tone proxy is -0.12 (with t-statistic=-3.46), whereas the negative climate risk disclosure tone has a coefficient of -0.152, but with only slight significance (t-statistic=-1.92). We find the same pattern when using the TFIDF-based manager's tone measure. This empirical observation confirms Hypothesis 2, in that the positive tone reduces the CDS premium, whereas the negative tone shows an insignificant correlation with the CDS premium. These results provide empirical support to the intuition from the model section regarding the asymmetric effects of the positive and negative tone of climate risk disclosures on the CDS premium.

5.2 Climate change uncertainty

To further investigate the relationship between climate risk disclosures and uncertainty, we empirically construct the climate change uncertainty measure, CC Uncertainty, based on eq. (14). This uncertainty measure provides a novel dimension aggregating CR Disclosure and its tone when analyzing the role of climate risk disclosure on the CDS premium. When constructing CC Uncertainty, we use CR Disclosure as the empirical proxy for *cr*. Since both CR Positive Tone and CR Negative Tone are of small magnitude relative to that of CR Disclosure, to avoid CC Uncertainty being dominated by CR Disclosure, we construct ρ as the following:

$$\rho = -\text{sgn}(\text{CR Net Tone}) \times |\text{CR Net Tone}|^{\lambda},$$

where CR Net Tone is the sum of CR Positive Tone and CR Negative Tone,[4] $\lambda = 0.25$, and sgn is the sign function.

To test Hypothesis 3, we perform multivariate regressions and summarize the regression analysis using the uncertainty measure in Table 5. The coefficient of CC Uncertainty is 0.029 (with *t*-statistic=2.95) and 0.027 (with *t*-statistic=2.66) in the CDS premium regressions, for the equal-weighted and TFIDF measures respectively. In the CDS slope regressions, the coefficient of CC Uncertainty is -0.015 and -0.018 for equal-weighted and TFIDF measures with statistical significance levels at 5% and 1%, respectively. These empirical results are consistent with the Hypothesis 3. This uncertainty effect concentrates on the short-term credit risk compared to the long-term. The fact that CC Uncertainty is positively related to the CDS level but negatively related to the CDS slope confirms

[4] The CR Positive Tone has non-negative values, and the CR Negative Tone has non-positive values. The sum of the CR Positive Tone and CR Negative Tone represents the net sentiment measure as the CR Net Tone.

our theoretical argument that climate risk disclosures affect the CDS pricing by reducing uncertainty rather than reducing volatility risk.

[Insert Table 5 here]

Although the efforts of CC Uncertainty on CDS premium and slope shown in Table 5 are significant in the presence of ESG-related variables, e.g., E-Score and GHG Scope 1, the distinctness of the efforts will be more confirmatory if a more explicit interaction between CC Uncertainty and climate risk exposure is controlled. To this end, we add an interaction term of E-Score and CC Uncertainty to the regressions in Table 5 to further distinguish between the disclosure uncertainty effect from the underlying actual climate risk exposure effect. The results are presented in Table 6. The estimates of E-Score's coefficients in Table 6 indicate that the E-Score is a good measure of firms' climate *risk* exposure as both CDS premium and slope are higher for firms with lower E-Score (higher climate risk exposure). More importantly, we also see that CC Uncertainty's coefficients are still significant in Table 6 and consistent with those in Table 5 even after controlling the interacting term E-Score $\times$ CC Uncertainty, indicating the uncertainty effect from CC Uncertainty is distinct from and not subsumed by the climate risk exposure effect in E-Score.

[Insert Table 6 here]

5.3 Addressing endogeneity

To ensure that the results are not biased due to endogeneity, we conduct a Difference-in-Differences (DiD) regression based on the implementation of the SEC's 2010 disclosure rule related to climate change,[5] following Kim et al. (2022). More specifically, we adopt

[5] The details of the rule can be found online here: https://www.sec.gov/rules/interp/2010/33-9106.pdf.

a quasi-natural experiment using the SEC (2010) rule mandating the U.S. publicly listed firms to disclose material ESG related risk in the financial statements. In supplementary to the financial statement disclosure, the voluntary disclosure in the firms' earnings call contributes to addressing the specific questions on the political uncertainty regarding the climate change policies. We construct a treatment group where the firm managers started to disclose the climate change risk in the earnings call after the 2010 SEC rule and did not discuss the climate change risk before the rule. In the control group, we select the firms that have disclosed the climate change risk before and after the 2010 SEC rule. Compared to the control group, firms in the treatment control brought incremental information through voluntary disclosure in earnings calls after the exogenous shock on this specific information supply.

The SEC 2010 rule arose as a response to increasing calls from large institutional groups for better disclosures related to climate risk. The implementation of the rule is expected to have a notable influence on firms' decision to disclose climate risk but is not expected to have a particular impact on firms' credit risk. Therefore, from before to after the implementation of the SEC rule, if we observe CDS premiums (slopes) of firms deciding to disclose (nonzero CR Disclosure or less than one CC Uncertainty) right after the implementation differ significantly from those of other firms, we can conclude that the results in Table 5 indeed represent an unbiased causal relation between CC Uncertainty and CDS premium/slope. The significant DiD coefficients shown in Table 7 (negative for CDS premium and positive for CDS slope when disclosures reduce uncertainty) seem to support this causality. In summary, the empirical findings confirm our conjecture in Hypothesis 3.

[Insert Table 7 here]

5.4 Information environments

In this subsection, we empirically test the model predictions discussed in section 3.3.3 in relation to CC Uncertainty's impacts on CDS in different information environments. In the time-series dimension, we use before and after the Paris Agreement in December 2015 to represent two different information environments with different levels of public awareness of climate risks. In the cross-sectional dimension, we use above and below the cross-sectional median of analyst dispersion and risk disclosure specificity (Hope et al., 2016) to represent two information environments with different levels of informational friction and different disclosure practices.

5.4.1 Paris Agreement and climate change uncertainty

To test our Hypothesis 4, we follow Kölbel et al. (2022) and Delis et al. (2019), and use the Paris Agreement in December 2015 to construct a dummy variable (zero before the Agreement and one after) interacting CC Uncertainty in the regressions. To confirm Hypothesis 4, we expect the coefficients of the interacting term to be of the opposite sign to those of CC Uncertainty in Table 5, since the Paris Agreement is commonly considered to have boosted public awareness of climate risk (Clémençon, 2016), therefore the noisiness of climate change news is significantly reduced thereafter. We report the regression results in Table 8.

[Insert Table 8 here]

As in Table 5, the coefficient of CC Uncertainty is still positively significant in the CDS premium regressions and negatively significant in the CDS slope regressions. However, the coefficient of the interacting term, CC Uncertainty $\times$ Post, is negatively significant in CDS premium regressions and positively significant in CDS slope regressions. These are clear evidence supporting our Hypothesis 4.

5.4.2 Analyst dispersion and climate change uncertainty

The dispersion of analysts' forecasts can be used as a proxy for the uncertainty aspect of investors' information environment (Barron et al., 1998). To test our Hypotheses 5a and 5b, we generate a high forecast dispersion dummy based on the median of analyst dispersion as the cut-off point. The dummy variable on analyst dispersion interacted with CC Uncertainty to address the potential asymmetric effect of the information environment on the proposed uncertainty-spread relation. We run the regressions of Table 5 with CC Uncertainty and the interactive term (with forecast dispersion). The results are presented in Table 9.

[Insert Table 9 here]

Columns (1) and (2) report the results for the five-year CDS premium. The coefficients of the interactive term, CC Uncertainty $\times$ High Analyst Dispersion are positively significant. With the presence of the interactive term, the coefficients of CC Uncertainty are insignificant. The empirical evidence supports the left panel in Figure 6 and Hypothesis 5a, showing the uncertainty effect on the CDS premium level amplifies with informational frictions in the information environments. Columns (3) and (4) present the results for the slope of the CDS curve with the interactive term. The coefficients are negative for both CC Uncertainty and CC Uncertainty $\times$ High Analyst Dispersion, with the latter being more significant. In general, the effect of uncertainty on CDS is more pronounced in firms with a worse information environment (i.e., high forecast dispersion). The empirical results support the right panel in Figure 6 and Hypothesis 5b.

5.4.3 Risk disclosure specificity and climate change uncertainty

We also examine Hypotheses 5a and 5b in the dimension of the risk disclosure specificity. We follow Hope et al. (2016) and construct the specificity measure using the fraction of specific words and phrases in the Management Discussion and Analysis (MD&A)

section over the total number of words in the section of the financial statement. A higher value of the specificity corresponds to a more specific firm-level risk disclosure. From the results presented in Table 10, we find evidence supporting our hypotheses that the better practice/quality of the risk disclosure and better information environment reduce the effect of CC Uncertainty on CDS.

[Insert Table 10 here]

6 Conclusion

Risk disclosure has become a key requirement in climate finance for accurate information to be reflected in asset prices. In the foreseeable future, there will be increasing demand for firm-level climate risk disclosure by investors who factor ESG issues into their decisions. Institutional investors have started to screen their portfolio choices on environmental concerns, which already leads to certain asset pricing implications.

We examine the effect of voluntary climate risk disclosure on the U.S. CDS market, where institutional investors dominate and downside risk is reflected. Our work starts with a structural credit risk model framework where the risk disclosure and its tone reduce the uncertainty around the climate change related issues of the underlying firm, while also revealing the real impact of climate change on the underlying firm. The model implies that uncertainty relief from disclosure informativeness reduces the CDS premium and makes the term structure of CDS premiums steeper, but disclosure tone has asymmetric impacts on the CDS premiums when it comes to being positive and negative.

Consistent with the predictions of the theoretical framework, we find supportive evidence that the voluntary disclosure of the climate risks decreases the underlying firm's CDS premium, and its tone affects the CDS premiums in a pattern predicted by our model. Finally, using the proposed climate change uncertainty measure, we demonstrate that the uncertainty increases the CDS premium and makes the term structure of CDS premiums flatten, especially in information environments with high noisiness in climate change news or/and high overall informational frictions.

Generally, our study shows that climate risks materialize in the corporate credit market and are reflected in CDS premiums. The main CDS market participants are institutional investors and the CDS premium indicates the downside risk of the underlying firm. Our work connects with the extant literature on the effect of climate risks on institutional investor choice (Krueger et al., 2020) and tail risk (Ilhan et al., 2021b). Our paper also highlights the importance of voluntary disclosure, in that risk disclosure relieves the uncertainty about climate risks. The empirical evidence supports the demand for accurate information about the underlying firm's climate risks (Krueger et al., 2021).

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Figure 1: Impacts of disclosures with tone on uncertainty

This figure plots $\sqrt{\omega}$ against changing cr and ρ. The numerical values set for the parameters are as: $\sigma = 0.3$, $\theta = 0.2$, and $\phi = 1$; cr is set to [0.01, 0.2, 0.4, 0.6] for the four curves. Given each cr, ρ goes from $\underline{\rho}$ to $2\rho^*$, where $\underline{\rho} < 0$ is the root of $(1-cr)\left(1-\rho^2\right)+2\rho = 0$ and $\rho^* > 0$ is the root of $2\left(1-cr\right)\rho^3 - 3\rho^2 - 2\left(1-cr\right)\rho + 1 = 0$.

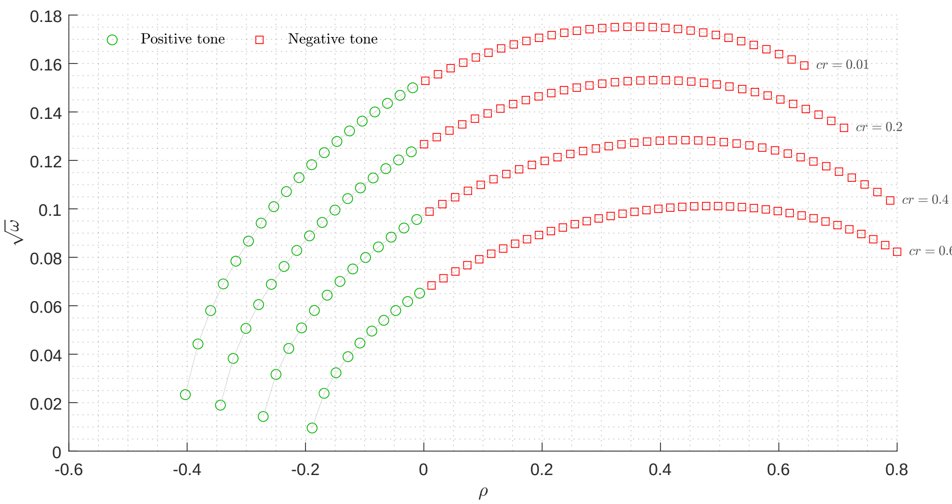


Figure 2: Impacts of disclosures with tone on CDS premiums

This figure plots $\widehat{CDS}$ against changing cr and ρ. The numerical values set for the parameters are as: $\sigma = 0.3$, $\theta = 0.2$, $\phi = 1$, cr is set to [0.01, 0.2, 0.4, 0.6] for the four curves, $r = 0.04$, $c = 2.25$, $V = 100$, and $R = 0.3$. Given each cr, ρ goes from $\underline{\rho}$ to $2\rho^*$, where $\underline{\rho} < 0$ is the root of $(1-cr)\left(1-\rho^2\right)+2\rho = 0$ and $\rho^* > 0$ is the root of $2\left(1-cr\right)\rho^3 - 3\rho^2 - 2\left(1-cr\right)\rho + 1 = 0$.

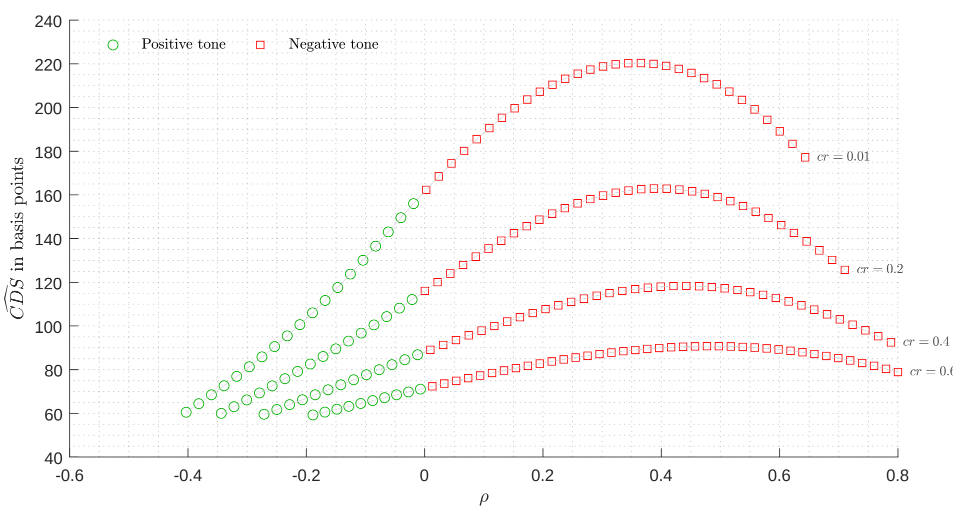
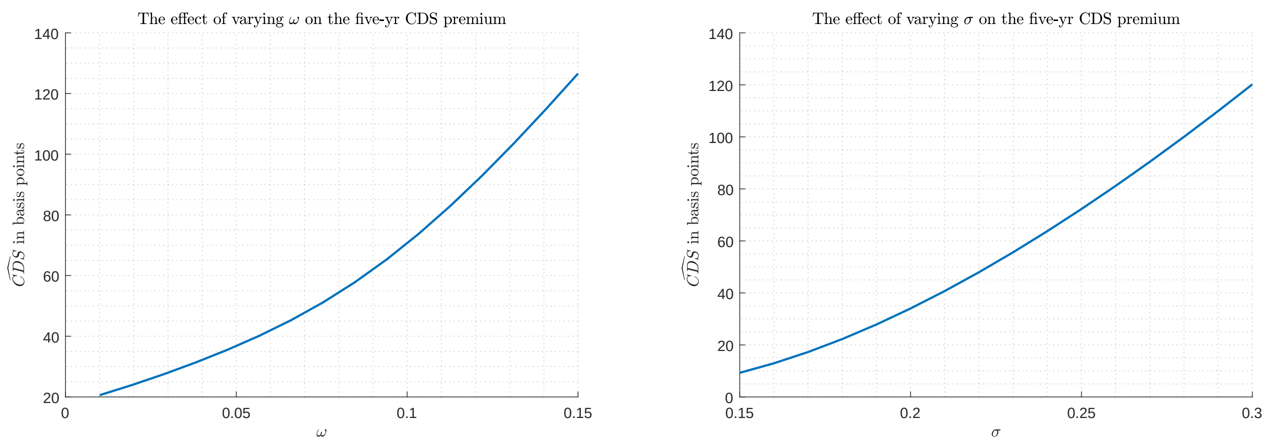


Figure 3: Informational frictions and volatility risk

Panels in this figure show the effect of ω and σ on the five-year CDS premium (Panel a) and the slope of the CDS curve (Panel b). The numerical values set for the parameters in the right panels (varying σ) are as: $\theta = 0.2$, $\phi = 1$, $cr = 0.3$, and $\rho = 0$; and in the left panels (varying ω), $\sigma = 0.2$. Other common parameters are set as: $r = 0.04$, $c = 2.25$, $V = 100$, and $R = 0.3$.

(a) CDS premium level



(b) CDS curve slope

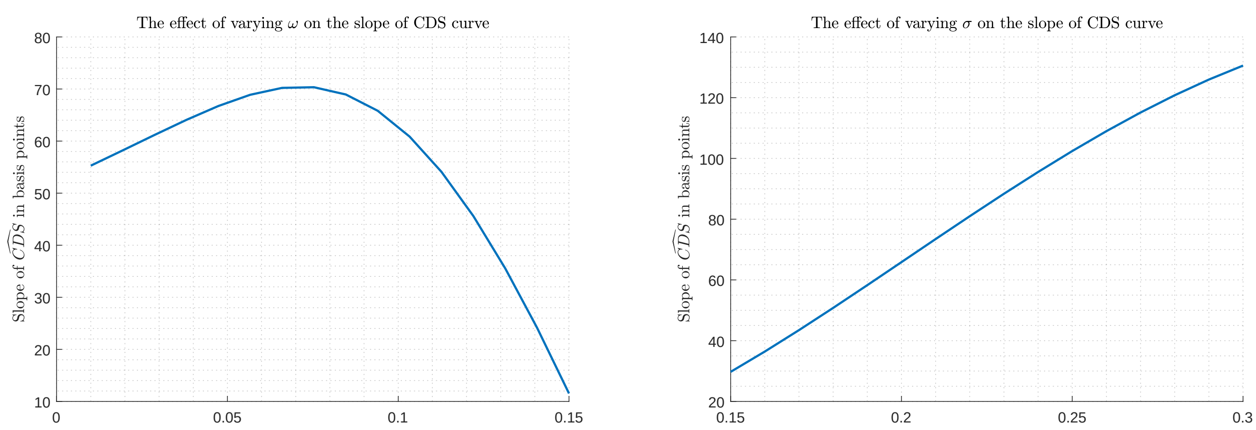


Figure 4: Term structures of credit spread with varying imprecision

This figure plots the $\widehat{CDS}$ curve against changing ω. The left panel plots the term structures of $\widehat{CDS}$ with different values (0.01, 0.04, 0.08, 0.12, and 0.15) of ω, the right panel plots the slope of the term structures on the left against ω. The numerical values for CDS parameters are set as: $\sigma = 0.2$, $r = 0.04$, $c = 2.25$, $V = 100$, and $R = 0.3$.

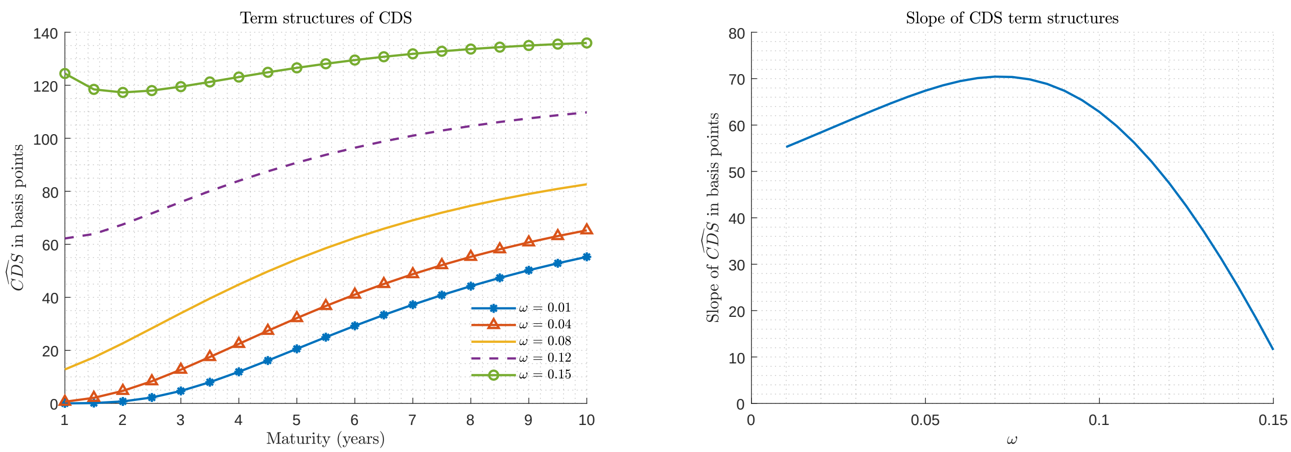


Figure 5: Impacts of disclosures with tone on the slope of the CDS curve

This figure plots the slope of $\widehat{CDS}$ curve against changing cr and ρ. The numerical values set for the parameters are as: $\sigma = 0.3$, $\theta = 0.2$, $\phi = 1$, cr is set to [0.01, 0.2, 0.4, 0.6] for the four curves, $r = 0.04$, $c = 2.25$, $V = 100$, and $R = 0.3$. Given each cr, ρ goes from $\underline{\rho}$ to $2\rho^*$, where $\underline{\rho} < 0$ is the root of $(1 - cr)\left(1 - \rho^2\right) + 2\rho = 0$ and $\rho^* > 0$ is the root of $2\left(1 - cr\right)\rho^3 - 3\rho^2 - 2\left(1 - cr\right)\rho + 1 = 0$.

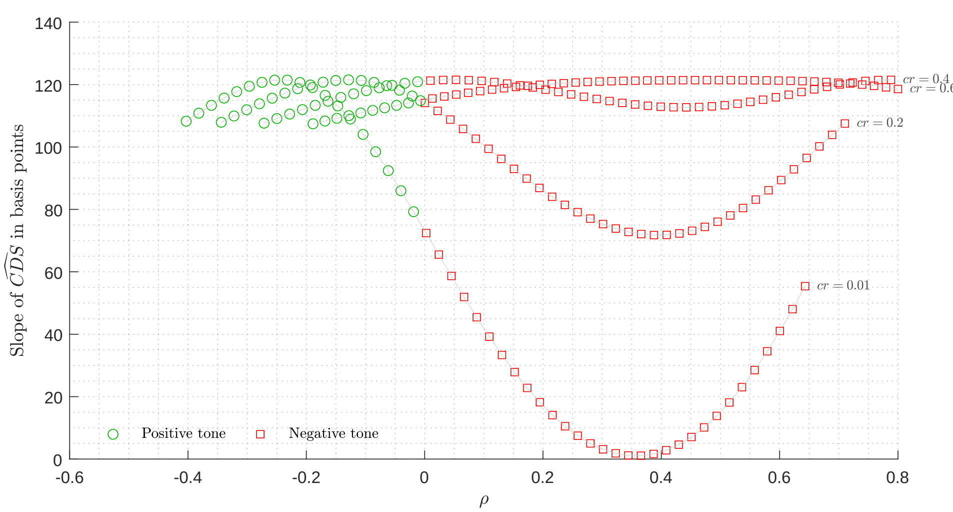


Figure 6: Climate change uncertainty in different information environments

Panels in this figure scatter-plot the five-year CDS premium (left panel) and the slope of the CDS curve against varying CC Uncertainty, which is defined as

$$(1-cr)^2\left(1-\rho^2\right)^2+2\rho\left(1-cr\right)\left(1-\rho^2\right).$$

$\phi = 0.85$ ($\phi = 1.4$) for scatters in stars (circles) labelled as Low information frictions (High information frictions). To generate variations in CC Uncertainty, cr ranges from 0 to 0.4 and for each cr, ρ goes from $\underline{\rho}$ to $2\rho^*$, where $\underline{\rho} < 0$ is the root of $(1-cr)\left(1-\rho^2\right)+2\rho = 0$ and $\rho^* > 0$ is the root of $2\left(1-cr\right)\rho^3 - 3\rho^2 - 2\left(1-cr\right)\rho + 1 = 0$. The numerical values for other parameters are kept as: $\sigma = 0.2$, $\theta = 0.4$, $r = 0.04$, $c = 2.25$, $V = 100$, and $R = 0.3$.

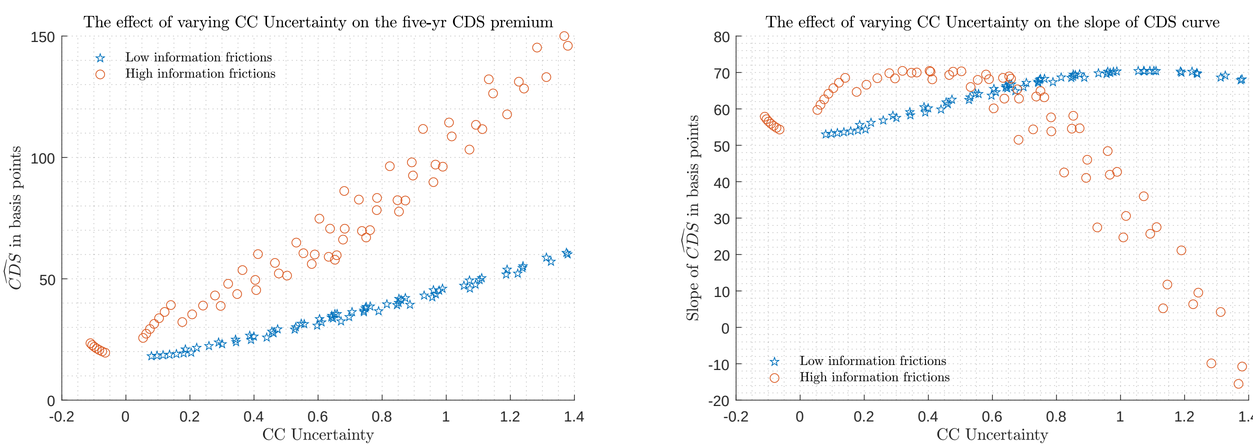


Table 1: Variable definitions.

This table presents the definitions of all variables used in the empirical tests.

Variable	Definition
CDS Premium	The monthly 5-year single-name CDS premium from Markit, if not otherwise specified.
CDS Slope	The difference between 10-year and 1-year CDS term structure.
CR Disclosure	The firm-level climate risk disclosure proxy reflects the frequency of the climate change related bigrams in the firm's earnings call.
CR Positive Tone	The positive firm-level climate risk disclosure tone associated with the climate change related bigrams in mentioned in the earnings call transcript.
CR Negative Tone	The negative firm-level climate risk disclosure tone associated with the climate change related bigrams in mentioned in the earnings call transcript.
CC Uncertainty	The firm-level climate change uncertainty measure associated with the disclosure. The formula of calculation the climate change uncertainty is: $[(1 - cr) \times (1 - \rho^2)]^2 + 2\rho \times (1 - cr) \times (1 - \rho^2)$, where cr is the CR Disclosure and $-\rho$ is the net climate change tone (CR Net Tone as the sum of CR Positive Tone and CR Negative Tone), using transformation of sgn(CR Net Tone) $\times$ $\lvert$CR Net Tone$\rvert^{\lambda}$, where $\lambda = 0.25$ and sgn is the sign function.
Treasury 3M	The 3-month constant maturity treasury rate from Federal Reserve Bank.
Treasury 10Y	The 10-year constant maturity treasury rate from Federal Reserve Bank.
Stock Return	The individual stock monthly return from CRSP.
SPX Return	The monthly S&P 500 index return.
Rating	Numerical translation of S&P's credit rating, where 1=AAA, 2=AA+, . . ., and 21=C.
IVOL	Idiosyncratic volatility estimated from the Fama-French 3-factor model, i.e. the annualized standard deviation of residual returns of the market model.
Leverage Ratio	The sum of debt in current liabilities and long-term debt as a percentage ratio of the assets' market value.
Log(Assets)	Logarithm of total assets in units of $1 million.
Market-to-Book	Market cap scaled by the book value of equity at the end of the fiscal year.
ROA	Income before extraordinary items scaled by total assets at the fiscal year end.
Analyst Coverage	The number of unique analysts who provide 1-year EPS estimations on the firm (from I/B/E/S).
Analyst Dispersion	The standard deviation of analyst forecasts on 1-year EPS on the firm (from I/B/E/S).
E-Score	The environmental rating from Thomson Refinitiv ESG rating.
GHG Scope 1	Logarithm of the absolute value of scope 1 greenhouse gas emission.

Table 2: Summary statistics for covariates

The summary statistics for the five-year single-name CDS premium of the month (CDS Premium), the CDS slope measuring as the difference between 10-year and 1-year CDS premiums (CDS Slope), the firm-level climate risk disclosure (CR Disclosure), climate change tone measures (CR Positive Tone, CR Negative Tone), the climate change uncertainty (CC Uncertainty), the three-month Treasury bill rate (Treasury Rate 3M), the ten-year Treasury note rate (Treasury Rate 10Y), the monthly stock return compounded over the month (Stock Return), the monthly S&P 500 index return compounded over the previous year (SPX Return), the numeric value of the firm's credit rating (Rating), the idiosyncratic stock volatility estimated from the Fama-French three-factor model (IVOL), the firm's book leverage ratio (Leverage Ratio), the logarithm of the firm's total assets in $ million (Size), the ratio of cash and short-term investments to total assets (Cash/TA), the market-to-book ratio (Market-to-Book), the ratio of net income to total assets (ROA), the number of unique financial analyst(s) following the firm (Analyst Coverage), the dispersion on analysts' forecast on EPS (Analyst Dispersion), the ESG score focusing on the environmental behavior (E-Score), and the logarithm of scope 1 carbon emission (GHG Scope 1). The CDS Premium and Slope summary statistics are in percentage.

	N	Mean	Std. Dev.	5%	25%	50%	75%	95%
CDS Premium	161,626	1.881	2.640	0.214	0.493	0.950	2.120	6.329
CDS Slope	161,626	1.065	1.189	0.050	0.406	0.758	1.409	3.479
CR Disclosure	120,740	0.042	0.108	0.000	0.000	0.010	0.031	0.196
CR Positive Tone	120,740	0.046	0.139	0.000	0.000	0.000	0.037	0.218
CR Negative Tone	120,740	-0.022	0.063	-0.119	-0.014	0.000	0.000	0.000
CC Uncertainty	120,740	0.373	0.502	-0.208	-0.139	0.118	1.000	1.000
Treasury Rate 3M	158,562	1.324	1.585	0.020	0.080	0.510	2.030	4.960
Treasury Rate 10Y	158,562	3.036	1.165	1.440	2.140	2.870	4.040	4.860
Stock Return	133,278	0.008	0.095	-0.148	-0.040	0.009	0.056	0.158
Index Return	161,626	0.006	0.042	-0.075	-0.016	0.012	0.031	0.070
Rating	161,626	5.046	2.231	2.000	3.000	4.000	6.000	9.000
IVOL	133,163	0.232	0.184	0.081	0.126	0.180	0.269	0.551
Leverage Ratio	129,990	0.325	0.191	0.050	0.189	0.300	0.430	0.671
log(Assets)	141,232	9.525	1.562	7.413	8.495	9.422	10.391	12.336
Market-to-Book	140,258	1.616	0.934	0.909	1.075	1.349	1.807	3.216
ROA	141,232	0.010	0.021	-0.018	0.003	0.009	0.019	0.040
Analyst Coverage	161,626	1.902	1.066	0.000	1.386	2.303	2.708	3.135
Analyst Dispersion	127,314	0.169	0.269	0.020	0.045	0.085	0.174	0.576
E-Score	100,129	-0.785	0.785	-2.292	-1.531	-0.400	-0.109	-0.055
GHG Scope 1	110,989	12.285	2.663	8.298	10.366	12.063	14.081	17.062

Table 3: Correlations for covariates

The pairwise Pearson correlations for the five-year single-name CDS premium of the month (CDS Premium), the CDS slope measuring as the difference between 10-year and 1-year CDS premiums (CDS Slope), the firm-level climate risk disclosure measures (CR Disc.), disclosure tone measures (CR Pos. Tone, CR Neg. Tone), the climate change uncertainty (CC Uncer.), the three-month Treasury bill rate (T. Rate 3M), the ten-year Treasury note rate (T. Rate 10Y), the monthly stock return compounded over the month (Stock Return), the monthly S&P 500 index return compounded over the previous year (SPX Return), the numeric value of the firm's credit rating (Rating), the idiosyncratic stock volatility estimated from the Fama-French three-factor model (IVOL), the firm's book leverage ratio (Leverage), the logarithm of the firm's total assets in $ million (Size), the ratio of cash and short-term investments to total assets (Cash/TA), the market-to-book ratio (MtB), the ratio of net income to total assets (ROA), the number of unique financial analyst(s) following the firm (Analyst Covr.) and the dispersion on analysts' forecast on EPS (Analyst Disp.), the ESG score focusing on the environmental behavior (E-Score), and the logarithm of scope 1 carbon emission (GHG Scope 1).

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)	(14)	(15)	(16)	(17)	(18)	(19)	(20)
(1) CDS Premium	1.00																			
(2) CDS Slope	0.22	1.00																		
(3) CR Disc.	-0.04	-0.02	1.00																	
(4) CR Pos. Tone	-0.03	0.00	0.78	1.00																
(5) CR Neg. Tone	0.02	0.01	-0.71	-0.54	1.00															
(6) CC Uncer.	0.04	0.02	-0.33	-0.32	0.22	1.00														
(7) T. Rate 3M	-0.12	-0.10	-0.02	-0.03	0.02	0.01	1.00													
(8) T. Rate 10Y	-0.06	-0.23	-0.04	-0.06	0.02	0.02	0.71	1.00												
(9) Stock Return	-0.03	-0.01	0.00	0.00	0.01	0.00	-0.03	-0.02	1.00											
(10) Index Return	-0.05	0.02	0.00	0.00	0.00	0.00	-0.06	-0.10	0.50	1.00										
(11) Rating	0.26	0.32	0.00	0.02	0.01	0.01	-0.05	-0.30	-0.03	-0.01	1.00									
(12) IVOL	0.43	0.06	-0.06	-0.04	0.03	0.01	-0.05	0.01	-0.09	-0.12	0.09	1.00								
(13) Leverage	0.32	0.26	0.06	0.04	-0.04	0.00	-0.05	-0.11	0.00	0.01	0.23	0.11	1.00							
(14) log(Assets)	-0.20	-0.16	0.04	0.01	-0.03	-0.02	-0.09	-0.17	-0.01	0.02	-0.07	-0.16	-0.11	1.00						
(15) MtB	-0.18	-0.10	-0.11	-0.07	0.10	0.02	0.06	0.01	0.05	0.02	-0.05	-0.11	0.01	-0.16	1.00					
(16) ROA	-0.32	-0.11	-0.05	-0.03	0.05	-0.01	0.05	0.03	0.04	0.03	-0.13	-0.20	-0.16	0.01	0.36	1.00				
(17) Analyst Covr.	-0.21	-0.11	-0.04	-0.02	0.03	-0.02	0.01	0.08	-0.01	-0.01	-0.21	-0.10	-0.20	0.27	0.15	0.18	1.00			
(18) Analyst Disp.	0.21	0.05	-0.04	-0.03	0.01	-0.02	-0.05	-0.08	-0.02	0.00	0.08	0.20	0.05	0.08	-0.09	-0.11	-0.07	1.00		
(19) E-Score	-0.16	-0.04	0.13	0.13	-0.08	-0.14	-0.13	-0.25	0.00	0.03	0.08	-0.14	-0.05	0.34	0.10	0.08	0.12	-0.05	1.00	
(20) GHG Scope 1	-0.02	-0.03	0.40	0.29	-0.32	-0.27	0.00	0.04	-0.01	-0.01	-0.04	0.01	0.11	0.13	-0.07	0.02	0.04	0.09	0.32	1.00

Table 4: Effect of climate risk disclosure and tone on CDS premium

The regressions examine the conditional effect of the firm-level climate risk disclosure on single-name CDS premium. The dependent variable is the monthly 5-year single-name CDS premium. The key independent variables are CR Disclosure in Columns (1) and (2), and CR Positive Tone and CR Negative Tone in Columns (3) and (4). Columns labeled "EW" use the equal-weighted climate change bigram frequency in the earnings call transcript. Columns labeled "TFIDF" use the term frequency-inverse document frequency for the climate change bigram frequency in the earnings call transcript. All regressions have firm and time fixed effects, with credit rating dummy and standard errors clustered at the firm level. ***, **, and * represent statistical significance at the 1%, 5%, and 10% level, respectively. *t*-statistics are in parentheses.

	(1) EW	(2) TFIDF	(3) EW	(4) TFIDF
CR Disclosure	-0.110***	-0.015***		
	[-6.688]	[-7.038]		
CR Positive Tone			-0.120***	-0.014***
			[-3.462]	[-3.215]
CR Negative Tone			-0.152*	-0.018*
			[-1.922]	[-1.841]
Treasury 3M	-0.076***	-0.076***	-0.075***	-0.075***
	[-4.455]	[-4.454]	[-4.436]	[-4.436]
Treasury 10Y	-0.121***	-0.121***	-0.121***	-0.121***
	[-7.499]	[-7.500]	[-7.495]	[-7.493]
Stock Return	-0.065	-0.065	-0.065	-0.065
	[-0.602]	[-0.601]	[-0.602]	[-0.602]
SPX Return	-1.789***	-1.790***	-1.790***	-1.790***
	[-9.682]	[-9.684]	[-9.682]	[-9.682]
IVOL	2.576***	2.576***	2.578***	2.579***
	[31.908]	[31.908]	[31.908]	[31.908]
Leverage Ratio	1.835***	1.835***	1.841***	1.842***
	[35.504]	[35.502]	[35.573]	[35.575]
log(Assets)	-0.104***	-0.105***	-0.102***	-0.102***
	[-15.790]	[-15.833]	[-15.444]	[-15.431]
Market-to-Book	-0.149***	-0.149***	-0.148***	-0.148***
	[-21.088]	[-21.097]	[-20.951]	[-20.941]
ROA	-9.990***	-9.989***	-9.994***	-9.994***
	[-20.725]	[-20.725]	[-20.733]	[-20.732]
Analyst Coverage	-0.125***	-0.125***	-0.124***	-0.124***
	[-8.954]	[-8.953]	[-8.857]	[-8.856]
Analyst Dispersion	0.460***	0.460***	0.461***	0.461***
	[10.532]	[10.535]	[10.554]	[10.557]
E-Score	-0.021**	-0.021**	-0.023**	-0.023**
	[-2.243]	[-2.234]	[-2.398]	[-2.405]
GHG Scope 1	0.038***	0.038***	0.035***	0.035***
	[9.010]	[9.069]	[8.440]	[8.427]
Intercept	0.854***	0.856***	0.835***	0.834***
	[6.890]	[6.901]	[6.732]	[6.724]
N	75,960	75,960	75,960	75,960
Adj. R^2	0.5154	0.5155	0.5153	0.5153
Rating Dummy	Yes	Yes	Yes	Yes
Industry FE	Yes	Yes	Yes	Yes
Time FE	Yes	Yes	Yes	Yes
Cluster SE	Yes	Yes	Yes	Yes

Table 5: Effect of climate change uncertainty on CDS

The regressions examine the conditional effect of the firm-level climate change uncertainty on single-name CDS premium. The dependent variable is the monthly 5-year single-name CDS premium in Columns (1) and (2), and is the monthly CDS slope in Columns (3) and (4). Key independent variables are the climate change uncertainty measure. Columns labeled "EW" use the equal-weighted climate change bigram frequency in the earnings call transcript. Columns labeled "TFIDF" use the term frequency-inverse document frequency for the climate change bigram frequency in the earnings call transcript. All regressions have firm and time fixed effects, with credit rating dummy and standard errors clustered at the firm level. ***, **, and * represent statistical significance at the 1%, 5%, and 10% level, respectively. *t*-statistics are in parentheses.

	CDS Premium		CDS Slope	
	(1) EW	(2) TFIDF	(3) EW	(4) TFIDF
CC Uncertainty	0.029***	0.027***	-0.015**	-0.018***
	[2.949]	[2.658]	[-2.496]	[-2.971]
Treasury 3M	-0.077***	-0.077***	-0.091***	-0.091***
	[-4.645]	[-4.645]	[-10.044]	[-10.041]
Treasury 10Y	-0.122***	-0.122***	-0.020**	-0.020**
	[-7.796]	[-7.795]	[-2.160]	[-2.160]
Stock Return	-0.068	-0.068	0.066	0.066
	[-0.646]	[-0.647]	[1.164]	[1.163]
SPX Return	-1.793***	-1.793***	-0.265***	-0.265***
	[-10.089]	[-10.088]	[-2.748]	[-2.746]
IVOL	2.504***	2.504***	-0.172***	-0.172***
	[31.348]	[31.346]	[-4.843]	[-4.843]
Leverage Ratio	2.054***	2.054***	-1.042***	-1.042***
	[34.679]	[34.682]	[-31.049]	[-31.044]
log(Assets)	-0.128***	-0.128***	0.154***	0.154***
	[-14.724]	[-14.730]	[30.513]	[30.515]
Market-to-Book	-0.151***	-0.151***	0.158***	0.158***
	[-19.759]	[-19.757]	[28.210]	[28.212]
ROA	-9.479***	-9.480***	2.427***	2.427***
	[-20.551]	[-20.552]	[9.320]	[9.321]
Analyst Coverage	-0.111***	-0.111***	0.005	0.005
	[-7.389]	[-7.389]	[0.597]	[0.595]
Analyst Dispersion	0.519***	0.520***	-0.029	-0.029
	[11.638]	[11.645]	[-1.194]	[-1.199]
E-Score	0.016	0.016	-0.077***	-0.077***
	[1.555]	[1.549]	[-12.508]	[-12.521]
GHG Scope 1	0.034***	0.034***	-0.040***	-0.040***
	[6.988]	[6.980]	[-13.067]	[-13.082]
Intercept	1.026***	1.027***	-1.819***	-1.818***
	[7.743]	[7.749]	[-23.114]	[-23.098]
N	75,960	75,960	75,960	75,960
Adj. R^2	0.5500	0.5500	0.4348	0.4348
Rating Dummy	Yes	Yes	Yes	Yes
Industry FE	Yes	Yes	Yes	Yes
Time FE	Yes	Yes	Yes	Yes
Cluster SE	Yes	Yes	Yes	Yes

Table 6: Effect of climate change uncertainty on CDS: conditioned on the environmental score

The regressions examine the effect of the firm-level climate change uncertainty on single-name CDS premium, conditioned on the environmental score. The dependent variable is the monthly 5-year single-name CDS premium in Columns (1) and (2), and is the monthly CDS slope in Columns (3) and (4). Key independent variables are the climate change uncertainty measure, and its cross-term with the (logarithm of) environmental rating score (E-Score). Columns labeled "EW" use the equal-weighted climate change bigram frequency in the earnings call transcript. Columns labeled "TFIDF" use the term frequency-inverse document frequency for the climate change bigram frequency in the earnings call transcript. All regressions have firm and time fixed effects, with credit rating dummy and standard errors clustered at the firm level. ***, **, and * represent statistical significance at the 1%, 5%, and 10% level, respectively. *t*-statistics are in parentheses.

	CDS Premium		CDS Slope	
	(1) EW	(2) TFIDF	(3) EW	(4) TFIDF
E-Score	-0.036***	-0.037***	-0.039***	-0.040***
	[-3.279]	[-3.334]	[-5.428]	[-5.643]
E-Score × CC Uncertainty	0.033**	0.035***	-0.025***	-0.022**
	[2.489]	[2.597]	[-2.936]	[-2.566]
CC Uncertainty	0.042***	0.042***	-0.038***	-0.039***
	[3.372]	[3.299]	[-5.112]	[-5.143]
Treasury 3M	-0.076***	-0.076***	-0.092***	-0.092***
	[-4.459]	[-4.460]	[-9.874]	[-9.873]
Treasury 10Y	-0.120***	-0.120***	-0.022**	-0.022**
	[-7.486]	[-7.485]	[-2.389]	[-2.388]
Stock Return	-0.066	-0.066	0.061	0.061
	[-0.612]	[-0.612]	[1.049]	[1.046]
SPX Return	-1.786***	-1.786***	-0.280***	-0.280***
	[-9.667]	[-9.666]	[-2.818]	[-2.813]
IVOL	2.577***	2.577***	-0.266***	-0.266***
	[31.895]	[31.895]	[-7.438]	[-7.448]
Leverage Ratio	1.843***	1.843***	-1.058***	-1.058***
	[35.670]	[35.672]	[-34.678]	[-34.679]
log(Assets)	-0.102***	-0.102***	0.118***	0.118***
	[-15.532]	[-15.530]	[30.063]	[30.065]
Market-to-Book	-0.148***	-0.148***	0.148***	0.148***
	[-21.031]	[-21.027]	[30.214]	[30.214]
ROA	-9.988***	-9.989***	2.486***	2.487***
	[-20.715]	[-20.717]	[9.365]	[9.366]
Analyst Coverage	-0.123***	-0.123***	0.023***	0.023***
	[-8.783]	[-8.785]	[2.736]	[2.748]
Analyst Dispersion	0.463***	0.463***	0.021	0.021
	[10.591]	[10.592]	[0.865]	[0.856]
GHG Scope 1	0.036***	0.036***	-0.032***	-0.032***
	[8.563]	[8.546]	[-12.240]	[-12.253]
Intercept	0.814***	0.814***	-1.500***	-1.499***
	[6.585]	[6.584]	[-19.546]	[-19.535]
N	75,960	75,960	75,960	75960
Adj. R^2	0.5153	0.5153	0.3953	0.3953
Rating Dummy	Yes	Yes	Yes	Yes
Industry FE	Yes	Yes	Yes	Yes
Time FE	Yes	Yes	Yes	Yes
Cluster SE	Yes	Yes	Yes	Yes

Table 7: Causal effect of climate risk disclosure on CDS: Difference-in-difference setting

The regressions examine the conditional effect of the firm-level climate change disclosure on single-name CDS premium. The dependent variable is the monthly 5-year single-name CDS premium in Column (1) and the monthly CDS slope in Column (2). Key independent variables are the treatment effect (Treatment) dummy with a value of one when the firm initiated the climate risk disclosure after the implementation of the SEC 2010 rule and zero otherwise, the time effect (SEC Post) dummy with a value of one after 2010 and zero otherwise, and the difference-in-difference variable (DiD) as the multiplication of treatment effect dummy and time effect dummy. All regressions have firm and time fixed effects, with credit rating dummy and standard errors clustered at the firm level. ***, **, and * represent statistical significance at the 1%, 5%, and 10% level, respectively. *t*-statistics are in parentheses.

	(1) CDS Premium	(2) CDS Slope
DiD (Treatment × Post)	-0.122**	0.201***
	[-2.059]	[5.977]
Treatment	-0.088	-0.146***
	[-1.536]	[-4.564]
Post	-0.064	-0.191***
	[-1.459]	[-5.914]
Treasury 3M	-0.077***	-0.094***
	[-4.327]	[-9.544]
Treasury 10Y	-0.127***	-0.028***
	[-7.796]	[-2.916]
Stock Return	-0.107	0.083
	[-0.970]	[1.407]
SPX Return	-1.727***	-0.341***
	[-9.210]	[-3.400]
IVOL	2.627***	-0.249***
	[32.091]	[-6.926]
Leverage Ratio	1.857***	-1.104***
	[35.366]	[-36.206]
log(Assets)	-0.098***	0.117***
	[-14.983]	[29.737]
Market-to-Book	-0.154***	0.150***
	[-21.149]	[29.750]
ROA	-9.537***	2.401***
	[-19.462]	[8.903]
Analyst Coverage	-0.147***	0.046***
	[-10.258]	[5.251]
Analyst Dispersion	0.466***	-0.021
	[11.339]	[-0.895]
E-Score	-0.045***	-0.049***
	[-4.673]	[-7.767]
GHG Scope 1	0.038***	-0.033***
	[9.036]	[-12.426]
Intercept	0.866***	-1.320***
	[6.609]	[-15.868]
N	74,728	74,728
Adj. R^2	0.5150	0.4013
Rating Dummy	Yes	Yes
Industry FE	Yes	Yes
Cluster SE	Yes	Yes

Table 8: Climate change uncertainty and the Paris Agreement (2015)

The regressions examine the conditional effect of the firm-level CC Uncertainty on single-name CDS premium, with the time effect on the Paris Agreement (2015). The dependent variable is the monthly 5-year single-name CDS premium in Columns (1) and (2), and is the monthly CDS slope in Columns (3) and (4). Key independent variables are the climate change uncertainty measure. Post is the time dummy with value one after December 2015 and zero otherwise. The interacting term is the multiplication of the climate change measure and the time dummy value. Columns labeled "EW" use the equal-weighted climate change bigram frequency in the earnings call transcript. Columns labeled "TFIDF" use the term frequency-inverse document frequency for the climate change bigram frequency in the earnings call transcript. All regressions have firm and time fixed effects, with credit rating dummy and standard errors clustered at the firm level. ***, **, and * represent statistical significance at the 1%, 5%, and 10% level, respectively. *t*-statistics are in parentheses.

	CDS Premium		CDS Slope	
	(1) EW	(2) TFIDF	(3) EW	(4) TFIDF
CC Uncertainty	0.099***	0.094***	-0.038***	-0.036***
	[4.251]	[4.213]	[-3.508]	[-3.507]
CC Uncertainty × Post	-0.047**	-0.045**	0.012*	0.012*
	[-2.307]	[-2.279]	[1.916]	[1.942]
Post	-0.045	-0.041	-0.118***	-0.118***
	[-0.710]	[-0.640]	[-3.158]	[-3.155]
Treasury 3M	-0.076***	-0.076***	-0.091***	-0.091***
	[-4.448]	[-4.448]	[-9.651]	[-9.651]
Treasury 10Y	-0.121***	-0.121***	-0.027***	-0.027***
	[-7.371]	[-7.371]	[-2.814]	[-2.814]
Stock Return	-0.070	-0.070	0.058	0.058
	[-0.648]	[-0.648]	[0.995]	[0.995]
SPX Return	-1.781***	-1.782***	-0.276***	-0.276***
	[-9.642]	[-9.642]	[-2.774]	[-2.773]
IVOL	2.580***	2.580***	-0.268***	-0.268***
	[31.928]	[31.929]	[-7.495]	[-7.496]
Leverage Ratio	1.840***	1.840***	-1.058***	-1.058***
	[35.619]	[35.621]	[-34.716]	[-34.717]
log(Assets)	-0.102***	-0.102***	0.118***	0.118***
	[-15.418]	[-15.420]	[29.960]	[29.958]
Market-to-Book	-0.148***	-0.148***	0.148***	0.148***
	[-20.953]	[-20.954]	[30.206]	[30.205]
ROA	-9.994***	-9.994***	2.493***	2.493***
	[-20.716]	[-20.716]	[9.387]	[9.387]
Analyst Coverage	-0.122***	-0.122***	0.024***	0.024***
	[-8.738]	[-8.739]	[2.865]	[2.864]
Analyst Dispersion	0.463***	0.463***	0.02	0.02
	[10.605]	[10.605]	[0.812]	[0.812]
E-Score	-0.024**	-0.024**	-0.050***	-0.050***
	[-2.540]	[-2.537]	[-8.165]	[-8.164]
GHG Scope 1	0.036***	0.036***	-0.032***	-0.032***
	[8.464]	[8.464]	[-12.186]	[-12.180]
Intercept	0.849***	0.847***	-1.378***	-1.380***
	[6.099]	[6.083]	[-16.078]	[-16.099]
N	75,960	75,960	75,960	75,960
Adj. R^2	0.5154	0.5154	0.3954	0.3954
Rating Dummy	Yes	Yes	Yes	Yes
Industry FE	Yes	Yes	Yes	Yes
Time FE	No	No	No	No
Cluster SE	Yes	Yes	Yes	Yes

Table 9: Climate change uncertainty and CDS premium conditional on the analyst dispersion

The regressions examine the effect of the firm-level CC Uncertainty on single-name CDS premium, with the interactive term of high forecast dispersion depending on the median of analyst forecast dispersion. The dependent variable is the monthly 5-year single-name CDS premium in Columns (1) and (2) and is the monthly slope of CDS curve in Columns (3) and (4). Columns labeled "EW" use the equal-weighted climate change bigram frequency in the earnings call transcript. Columns labeled "TFIDF" use the term frequency-inverse document frequency for the climate change bigram frequency in the earnings call transcript. All regressions have firm and time fixed effects, with credit rating dummy and standard errors clustered at the firm level. ***, **, and * represent statistical significance at the 1%, 5%, and 10% level, respectively. *t*-statistics are in parentheses.

	CDS Premium		CDS Slope	
	(1) EW	(2) TFIDF	(3) EW	(4) TFIDF
CC Uncertainty	0.004	0.003	0.002	0.002
	[0.357]	[0.242]	[0.299]	[0.307]
CC Uncertainty × High Analyst Dispersion	0.039**	0.040**	-0.054***	-0.062***
	[2.192]	[2.185]	[-4.985]	[-5.624]
Treasury 3M	-0.190***	-0.190***	-0.044***	-0.044***
	[-41.397]	[-41.419]	[-16.340]	[-16.327]
Treasury 10Y	0.070***	0.070***	0.209***	0.209***
	[8.404]	[8.415]	[43.281]	[43.291]
Stock Return	0.036	0.036	0.189***	0.189***
	[0.323]	[0.323]	[3.120]	[3.120]
SPX Return	-2.244***	-2.244***	-0.387***	-0.386***
	[-12.240]	[-12.240]	[-3.874]	[-3.868]
IVOL	2.764***	2.763***	0.098***	0.098***
	[34.254]	[34.250]	[2.703]	[2.716]
Leverage Ratio	1.757***	1.757***	-1.055***	-1.054***
	[33.951]	[33.953]	[-33.867]	[-33.853]
log(Assets)	-0.143***	-0.143***	0.121***	0.121***
	[-22.181]	[-22.171]	[30.538]	[30.585]
Market-to-Book	-0.195***	-0.195***	0.156***	0.156***
	[-26.874]	[-26.876]	[32.374]	[32.359]
ROA	-9.496***	-9.497***	1.922***	1.921***
	[-19.543]	[-19.544]	[6.965]	[6.962]
Analyst Coverage	0.015	0.015	-0.002	-0.002
	[1.124]	[1.127]	[-0.214]	[-0.220]
Analyst Dispersion	0.499***	0.499***	0.056**	0.059**
	[10.950]	[10.947]	[2.137]	[2.216]
E-Score	-0.019**	-0.019**	-0.075***	-0.075***
	[-2.039]	[-2.048]	[-12.317]	[-12.336]
GHG Scope 1	0.040***	0.040***	-0.025***	-0.025***
	[9.638]	[9.620]	[-9.284]	[-9.315]
Intercept	0.993***	0.994***	-2.178***	-2.178***
	[12.284]	[12.292]	[-44.187]	[-44.185]
N	75,960	75,960	75,960	75,960
Adj. R^2	0.4989	0.4989	0.3486	0.3488
Rating Dummy	Yes	Yes	Yes	Yes
Industry FE	Yes	Yes	Yes	Yes
Time FE	Yes	Yes	Yes	Yes
Cluster SE	Yes	Yes	Yes	Yes

Table 10: Climate change uncertainty and CDS premium conditional on risk disclosure specificity

The regressions examine the effect of the firm-level CC Uncertainty on single-name CDS premium, with the interactive term of high disclosure specificity depending on the median of the ratio between specific words/phrases and a total number of words in the MD&A section. The dependent variable is the monthly 5-year single-name CDS premium in Columns (1) and (2) and is the monthly slope of the CDS curve in Columns (3) and (4). Columns labeled "EW" use the equal-weighted climate change bigram frequency in the earnings call transcript. Columns labeled "TFIDF" use the term frequency-inverse document frequency for the climate change bigram frequency in the earnings call transcript. All regressions have firm and time fixed effects, with credit rating dummy and standard errors clustered at the firm level. ***, **, and * represent statistical significance at the 1%, 5%, and 10% level, respectively. *t*-statistics are in parentheses.

	CDS Premium		CDS Slope	
	(1) EW	(2) TFIDF	(3) EW	(4) TFIDF
CC Uncertainty	0.062***	0.057***	-0.108***	-0.102***
	[3.722]	[3.488]	[-10.788]	[-10.456]
CC Uncertainty × High Specificity	-0.067***	-0.060***	0.120***	0.113***
	[-3.803]	[-3.383]	[11.042]	[10.421]
Treasury 3M	-0.190***	-0.190***	-0.044***	-0.044***
	[-41.356]	[-41.361]	[-16.404]	[-16.391]
Treasury 10Y	0.070***	0.070***	0.211***	0.210***
	[8.326]	[8.344]	[43.590]	[43.548]
Stock Return	0.034	0.034	0.191***	0.191***
	[0.310]	[0.313]	[3.164]	[3.157]
SPX Return	-2.243***	-2.243***	-0.387***	-0.387***
	[-12.234]	[-12.234]	[-3.880]	[-3.880]
IVOL	2.762***	2.763***	0.101***	0.101***
	[34.249]	[34.256]	[2.802]	[2.782]
Leverage Ratio	1.760***	1.760***	-1.058***	-1.058***
	[33.986]	[33.981]	[-34.057]	[-34.050]
log(Assets)	-0.145***	-0.145***	0.124***	0.124***
	[-22.364]	[-22.317]	[31.365]	[31.259]
Market-to-Book	-0.194***	-0.194***	0.155***	0.155***
	[-26.790]	[-26.806]	[32.238]	[32.259]
ROA	-9.478***	-9.483***	1.883***	1.889***
	[-19.501]	[-19.510]	[6.828]	[6.847]
Analyst Coverage	0.015	0.015	-0.003	-0.002
	[1.164]	[1.154]	[-0.323]	[-0.301]
Analyst Dispersion	0.512***	0.512***	0.038	0.038
	[11.622]	[11.623]	[1.477]	[1.477]
E-Score	-0.020**	-0.020**	-0.073***	-0.073***
	[-2.179]	[-2.167]	[-12.068]	[-12.088]
GHG Scope 1	0.041***	0.040***	-0.026***	-0.026***
	[9.657]	[9.656]	[-9.544]	[-9.539]
Intercept	1.004***	1.001***	-2.194***	-2.191***
	[12.421]	[12.395]	[-44.528]	[-44.479]
N	75,960	75,960	75,960	75,960
Adj. R^2	0.4989	0.4989	0.3496	0.3495
Rating Dummy	Yes	Yes	Yes	Yes
Industry FE	Yes	Yes	Yes	Yes
Time FE	Yes	Yes	Yes	Yes
Cluster SE	Yes	Yes	Yes	Yes

Appendices

A Proofs

Proof of Proposition 1: For notational convenience, we drop subscript i here. There is one observable GBM:

$$\frac{d\widetilde{V}(t)}{\widetilde{V}(t)} = \left(\gamma + \frac{\widetilde{\sigma}^2}{2} - \theta\eta(t)\right) dt + \widetilde{\sigma} d\widetilde{Z}(t).$$

The unobservable GBM is

$$\frac{dV(t)}{V(t)} = (r - \delta)dt + \sigma dZ(t).$$

Given $\widetilde{v}(t) \equiv \log \widetilde{V}(t)$ and $v(t) \equiv \log V(t)$, the partially observable system can be rewritten in log terms as

$$d\widetilde{v}(t) = (\gamma - \theta\widetilde{v}(t) + \theta v(t))dt + \widetilde{\sigma} d\widetilde{Z}(t), \tag{A1}$$

$$dv(t) = \gamma dt + \frac{\sigma^2}{\widetilde{\sigma}} d\widetilde{Z}(t) + \sigma\sqrt{1 - \frac{\sigma^2}{\widetilde{\sigma}^2}} d\overline{Z}(t). \tag{A2}$$

where $\widetilde{Z}(t)$ and $\overline{Z}(t)$ are independent standard Brownian Motions. By Liptser and Shiryaev (2013, Theorem 12.1), we have

$$d\hat{v}(t) = \gamma dt + \left(b_2 + \omega(t)\frac{A_1}{B}\right) dZ^I(t) \tag{A3}$$

where $b_2 = \sigma^2/\widetilde{\sigma}$, $B = \widetilde{\sigma}$, $A_1 = \theta$, and

$$\frac{d\omega(t)}{dt} = \sigma^2 - \left(\frac{\sigma^2}{\widetilde{\sigma}} + \omega(t)\frac{\theta}{\widetilde{\sigma}}\right)^2. \tag{A4}$$

In the steady-state, $\frac{d\omega(t)}{dt} = 0$, that is $\omega(t) = \omega$ is no longer a function of t and

$$\sigma = \frac{\sigma^2}{\widetilde{\sigma}} + \omega\frac{\theta}{\widetilde{\sigma}}. \tag{A5}$$

Therefore, we have proven eq. (10) in Proposition 1. Solving eq. (A5) for ω gives

$$\omega = \frac{\widetilde{\sigma}\sigma - \sigma^2}{\theta}.$$

Since $\widetilde{\sigma} > \sigma$ (see eq. (7)), $\omega > 0$ is a well-defined variance. Substituting $\widetilde{\sigma}$ with

$$\sigma\sqrt{1 + \phi^2 (1 - cr)^2 (1 - \rho^2)^2 + 2\phi\rho (1 - cr) (1 - \rho^2)}$$

gives eq. (11).

Proof of Proposition 2: For notational convenience, we drop subscript i here. From eq. (11), we have

$$\omega = \frac{\sigma^2}{\theta}\left(\sqrt{1 + \Omega} - 1\right),$$

where $\Omega = \phi^2 (1 - cr)^2 \left(1 - \rho^2\right)^2 + 2\phi\rho (1 - cr) \left(1 - \rho^2\right)$. Showing ω is a decreasing function of cr is equivalent to showing Ω is a decreasing function of cr. Taking the first order derivative of Ω with respect to cr gives:

$$\frac{\partial\Omega}{\partial cr} = -2\phi\left(1 - \rho^2\right)\left[\phi (1 - cr)\left(1 - \rho^2\right) + \rho\right].$$

When $\rho > 0$, it is trivial that $\partial\Omega/\partial cr < 0$. When $\rho < 0$, by eq. (9), we have:

$$\phi (1 - cr)\left(1 - \rho^2\right) + 2\rho > 0 \Rightarrow \phi (1 - cr)\left(1 - \rho^2\right) + \rho > 0 \Rightarrow \frac{\partial\Omega}{\partial cr} < 0.$$

Proof of Proposition 3: For notational convenience, we drop subscript i here. $\partial\omega/\partial\rho$ and $\partial\Omega/\partial\rho$ are of the same sign. So it is sufficient to focus on $\partial\Omega/\partial\rho$:

$$\frac{\partial\Omega}{\partial\rho} = 2\phi^2 (1-cr) \left[-2\rho \left(1-\rho^2\right)(1-cr)\phi - 3\rho^2 + 1\right].$$

When $\rho \leq 0$, by eq. (9), we have:

$$\begin{aligned} &\phi \left(1-\rho^2\right)(1-cr) + 2\rho > 0 \\ \overset{\rho<0}{\Longrightarrow}\ &-2\rho\phi\left(1-\rho^2\right)(1-cr) - 4\rho^2 > 0 \\ \Rightarrow\ &-2\rho\phi\left(1-\rho^2\right)(1-cr) - 3\rho^2 + 1 > \rho^2 + 1 > 0. \end{aligned}$$

Therefore, when $\rho \leq 0$, $\partial\Omega/\partial\rho > 0$. This means the more positive tone (the more negative ρ), the more precision of the investors' inference (the smaller Ω and ω).

When $\rho > 0$, $\partial\Omega/\partial\rho = 0$ has one root in $[0,1]$ given by:

$$\rho^* = b - \frac{\left(\frac{b^2+\frac{1}{3}}{U} + U\right) - \sqrt{3}\left(\frac{b^2+\frac{1}{3}}{U} - U\right)i}{2}, \tag{A6}$$

where $b = 1/[2\phi(1-cr)]$ and $U = \left(i\sqrt{b^4 + b^2/3 + 1/27} + b^3\right)^{1/3}$. Therefore when $\rho < \rho^*$ ($\rho \geq \rho^*$), $\partial\Omega/\partial\rho > 0$ ($\partial\Omega/\partial\rho \leq 0$). This means when the disclosure tone is negative, the relation between the tone and precision of the investors' inference is non-monotonic.