Endogenous Preferences and Green Bond Pricing*

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Keywords: Green Bonds, Municipal Bonds, Climate Risk, News Media, Endogenous Preferences.

JEL Codes: H74, Q50

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Abstract

Using a macro model based on endogenous preferences theory, our paper explores the influence of climate change concerns, as reflected in news media, on green bond premiums. Empirical analysis of U.S. municipal bonds shows that green bonds are traded at an average of seven basis points lower than brown bonds during the periods of heightened climate change concerns. Our study also reveals that investors' non-pecuniary motives, rather than the desire to hedge against climate risk, is the primary mechanism driving our results. While both physical and transitional aspects of climate risk are relevant, we observe that the physical risk has a more pronounced impact. Our study provides a nuanced understanding of the time-varying nature of green bond premiums shaped by evolving investor preferences and climate change discourse.

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1 Introduction

Classical choice theory assumes that individuals have fixed preferences. However, evidence from behavioral economics and finance demonstrates that external factors, such as environmental, social, and cultural influences, can shape preferences and decision-making (Hirshleifer and Shumway, 2003; DellaVigna, 2009; Hoff and Stiglitz, 2016; among others). Therefore, critics of classical choice theory argue that these external factors can endogenously shape preferences. Using the US municipal bonds as the setting, this paper examines whether accounting for investors' time-varying preferences for green bonds can explain the changing dynamics of green premiums over time.

There are numerous instances in financial markets where investor characteristics, often assumed to be fixed, change in response to the market and environment. Campbell and Cochrane (1999) demonstrate that investors' risk aversion fluctuates with the economic cycle. Similarly, Acharya and Pedersen (2005) show how liquidity risk and market dynamics shape investor preferences and influence asset prices. In the context of sustainable investing, the long-term nature of climate change and evolving market dynamics can influence investors' perceptions of risks and their taste for green products. Pastor et al. (2021) recently developed an equilibrium model that allows for shifts in investors' preferences for green assets when there are shocks to ESG factors. In their model, firms and investors are allowed to exhibit different characteristics. For instance, at the aggregate level, investors may have different tastes for ESG products, and the dispersion in their preferences can alter market dynamics and impact returns on green assets.

Building on the implications of the Pastor et al. (2021) model, we develop a simple macro model in which investors' preferences are endogenously determined and, hence, time-varying. Both the Pastor et al. (2021) model and our model assumes variation in investors' preferences. However, the key difference lies in the source of this variation. While the Pastor et al. (2021) model attributes changes to market dynamics and assumes ESG preferences are exogenous, we endogenize investors' ESG preferences, making them dependent on external factors. The proposed model allows us to examine how and to what extent external factors influence investors' preferences and decisions in ESG investing over time. Additionally, endogenizing investor preferences is crucial for understanding the mechanisms behind green bond premiums. Our model suggests that green bonds will have a stronger correlation with marginal utility if investors' preferences are primarily motivated by hedging rather than non-pecuniary considerations.

There are papers studying whether investors' perceptions and concerns on climate change matter enough to affect the pricing of assets independently of the underlying risk (Choi et al., 2020; El Ouadghiri et al., 2021; Ardia et al., 2022; among others). While several factors can influence investors' perceptions of climate risk and their demand for green assets, we focus on media as a key driver of investors' perceptions. This selection is based on substantial evidence of the media's broad reach and its significant role in directing public focus on a wide range of topics (Lippmann, 1922; McCombs and Shaw, 1972; Ball-Rokeach and Defleur; 1976; Scheufele, 1999; Tetlock, 2007; Happer and Philo, 2013; Kirilenko et al., 2015; Valkenburg et al., 2016; Engle et al., 2020, among others). We hypothesize that when concerns about climate change are pronounced, investors prefer green bonds over brown bonds, resulting in lower yields and higher prices for green bonds. To clarify, we do not argue that the green premium is driven by media coverage of climate change. Instead, the central argument in our paper is that investors' time-varying preferences influence green premiums, and the media serves as one of the potential channels through which their preferences can be affected.

We use the unexpected media climate change concerns (UMC) developed by Ardia et al. (2022) as our primary proxy for unexpected change in climate concerns. Our baseline results suggest that green bonds are traded at lower yields (more specifically, seven basis points lower) and thus higher prices during periods of greater climate concerns, reflecting a shift in investors' preference towards green products when climate change sentiments are high. These empirical findings align with the predictions of our theoretical model.

We further investigate the mechanisms behind investors' decisions, examining whether the shift towards green investments is driven by a desire to hedge against climate risk or by non-pecuniary motivations such as social and environmental preferences. Our heterogeneity tests suggest that green premiums are more likely influenced by investors' non-pecuniary motives rather than their desire to hedge climate risk. More specifically, we split all bonds into two groups – less than 10 years of maturity and more than 10 years of maturity – and find that green bonds from both groups show significantly lower yields than brown bonds when climate concerns are high, while the magnitude of impact is stronger for the former group. When we further break all bonds into groups by their time to maturity in 5-year increments, we find that the impact is more pronounced in less-than-five-year maturity group, while the other groups show similar magnitude. Our explanation is that green bonds with shorter maturities have pricing and yield changes that can more accurately reflect the short-term shifts in investor preferences driven by current events or changes in climate-related policies. This result also supports our argument that investors' preference for green bonds is more likely driven by alignment with environmental values (i.e., non-pecuniary motives) than by purely risk-hedging motives. If investors' preferences for green bonds stem from the risk-hedging purpose, the time to maturity may become significantly relevant, especially for long-term bonds. Additionally, we find that types of bonds and prior beliefs on climate change play an important role in influencing green premiums. More specifically, we document a stronger impact among revenue bonds as opposed to general obligation bonds, and when investors have stronger prior beliefs and concerns about climate change. These results further support the non-pecuniary motives rather than the hedging channel.

Our study also explores how different sources of climate risks influence green bond premiums differently. Our results show that while both physical and transition risks are relevant, the impact of physical risk concerns is more pronounced. These findings provide new evidence to the recent literature that different aspects of climate risk are reflected in asset prices (Hong et al, 2019; Krueger et al., 2020; Ardia et al., 2022; Bolton and Kacperczyk, 2023; Faccini et al., 2023; Zhou et al., 2023; Guo et al., 2023; Butler and Uzmanoglu, 2024; Pham and Kamal, 2024).

We conduct three groups of robustness tests. First, we add three additional macro factors (treasury yield, term spread, and credit spread) as the control variables to address the endogeneity concerns that our results are driven by broader economic factors. Second, we use a propensity-score-matched sample to make sure that the results are not driven by certain bond characteristics. Third, we adopt the alternative climate concern measure created by Engle et al. (2020) which is constructed using the Wall Street Journal as the primary news sources to capture the broad climate change sentiments among the investment community.

We contribute to the literature in three ways. First, our treatment of investors' preferences as endogenous is related to the broader literature in finance where investor preferences are time-varying, changing with new information and evolving risks (Campbell and Cochrane, 1999; Bansal and Yaron, 2004; Vayanos and Wang, 2012; Pastor and Stambaugh, 2012; among others). While these papers focus on macroeconomic cycles and long-term consumption risks, our paper shifts the focus to climate-related concerns and their impact on green bond premiums.[1] By demonstrating that climate concerns can drive green bond premiums, our paper extends the literature on investors' time-varying preferences by adding new evidence from the municipal bond market.

Second, previous studies provide mixed evidence on whether green bond premiums ("greenium") exist and whether investors preference for green bonds varies over time (Karpf and Mandel, 2017; Baker et al., 2018; Zerbib, 2019; Deng et al., 2020; Larcker and Watts, 2020; MacAskill et al., 2021, among others). Our theory and empirical results provide new evidence to support the existence of green bond premiums. Since we find that investors' demand for green bonds varies based on their climate concerns, it partly explains why there are mixed results of green premiums.

Moreover, our paper is related to the growing literature suggesting the motivation of investors to approach Social Responsibility Investing (SRI) (Heinkel et al., 2001; Martin and Moser, 2016; Hart and Zingales, 2017; Reboredo, 2018; Albuquerque et al., 2019; Broadstock and Cheng, 2019; Starks et al. 2023; among others). While our findings do not entirely dismiss the hedging motive, we emphasize the importance of recognizing the role of non-pecuniary motives in influencing investor behavior.

The remainder of the paper is organized as follows. Section 2 develops the macro model, Section 3 discusses the data and summary statistics, Section 4 introduces empirical design and presents empirical findings, Section 5 presents the robustness tests, and Section 6 concludes.

2 Macro Model

In a standard macro model, the utility function representing investors' preferences depends on their consumption over time.

$$U = E \sum_t e^{-\rho t} (log\ c_t) \tag{1}$$

Here ρ is the discount factor, and c_t is the real consumption per capita. Building on the framework of the endogenous preferences theory, we add a time-varying preference for green bonds (g_t), and

[1] Cho (2020) also explores time-varying investor preferences within the context of ESG investing. However, the study focuses on the performance of ESG stocks amid shifting economic conditions in an emerging market.

the utility function U becomes

$$U = E\sum_t e^{-\rho t}(log\, c_t + \lambda_t\, g_t) \tag{2}$$

The parameter λ_t reflects investors' preference for green bonds, which can be influenced by external factors (e.g. personal experiences, weather-related events, media, policy change, etc.). In the empirical section, we use media as the external factor of our interest, so we use the notation N_t to capture the change in news discussion on the topic of climate change over time. Implicitly, we assume that news media can influence investors' concerns about climate change and affect their preference for green bonds.

$$\lambda_t = \gamma_0 + \gamma_1 N_t \tag{3}$$

Hypothesis 1: Investors exhibit time-varying, non-pecuniary preferences for green bonds, driven by their concern about climate change.

Besides, investors' consumption (c_t), and investment decisions (brown bonds (b_t), green bonds (g_t), and Treasury bonds (τ_t)) at any given time are limited by their income in the same period (y_t) and the returns on their investments from the previous period: $R_t^g g_{t-1}$ is the yield on a green bond; $R_t^b b_{t-1}$ is the yield on brown bond; $R_t^\tau \tau_{t-1}$ is the yield on Treasury bonds.

$$c_t + b_t + g_t + \tau_t = y_t + R_t^g g_{t-1} + R_t^b b_{t-1} + R_t^\tau \tau_{t-1} \tag{4}$$

Then, we rewrite the budget constraints in terms of yield spread:

$$c_t + b_t + g_t + \tau_t = y_t + \widetilde{R}_t^g g_{t-1} + \widetilde{R}_t^b b_{t-1} + R_t^\tau (g_{t-1} + b_{t-1} + \tau_{t-1}) \tag{5}$$

$\widetilde{R}_t^g$ is the yield spread for green bonds, i.e. the yield on a green bond minus the yield on a Treasury bond. Similarly, $\widetilde{R}_t^b$ is the yield spread for brown bonds.

To derive the first order conditions, we use the budget constraint (5) to substitute out consumption in the utility function (3).

$$U = E\sum_t e^{-\rho t}(log(y_t + \widetilde{R}_t^g g_{t-1} + \widetilde{R}_t^b b_{t-1} + R_t^\tau(g_{t-1} + b_{t-1} + \tau_{t-1}) - b_t - g_t - \tau_t) + \lambda_t\, g_t) \tag{6}$$

$$\frac{\partial U}{\partial \tau_t} = -e^{-\rho t} c_t^{-1} + e^{-\rho(t+1)} E_t(R_{t+1}^\tau c_{t+1}^{-1}) = 0 \tag{7}$$

$$\frac{\partial U}{\partial b_t} = -e^{-\rho t} c_t^{-1} + e^{-\rho(t+1)} E_t((\widetilde{R}_{t+1}^b + R_{t+1}^\tau) c_{t+1}^{-1}) = 0 \tag{8}$$

$$\frac{\partial U}{\partial g_t} = -e^{-\rho t}(c_t^{-1} - \lambda_t) + e^{-\rho(t+1)} E_t((\widetilde{R}_{t+1}^g + R_{t+1}^\tau) c_{t+1}^{-1}) = 0 \tag{9}$$

Next, we use the equation (7) to eliminate $E_t(R_{t+1}^\tau c_{t+1}^{-1})$ and simplify (8) and (9).

$$E_t(\widetilde{R}_{t+1}^b c_{t+1}^{-1}) = 0 \tag{10}$$

$$E_t(\widetilde{R}_{t+1}^g c_{t+1}^{-1}) = -e^\rho \lambda_t \tag{11}$$

Assume that $\widetilde{R}_{t+1}^b c_{t+1}^{-1}$ and $\widetilde{R}_{t+1}^g c_{t+1}^{-1}$ are independently and identically distributed. Then,

$$\mu_b = -\mu_{mu}^{-1} \sigma_b \sigma_{mu} corr(\widetilde{R}_{t+1}^b, c_{t+1}^{-1}) \tag{12}$$

$$\mu_g = -\mu_{mu}^{-1} \sigma_g \sigma_{mu} corr(\widetilde{R}_{t+1}^g, c_{t+1}^{-1}) - \mu_{mu}^{-1} e^\rho(\gamma_0 + \gamma_1 N_t) \tag{13}$$

where μ_b is the expected rate of return on brown bonds, and μ_g is the expected rate of return on green bonds. μ_{mu} is the expected value of marginal utility (c_{t+1}^{-1}), which will be a positive constant. The standard deviations of $\widetilde{R}_{t+1}^b$, $\widetilde{R}_{t+1}^g$, and c_{t+1}^{-1} are σ_b, σ_g, and σ_{mu}, respectively. We then fit the regression

$$\begin{aligned} YieldSpread_{i,j,t} &= \delta_0 + \delta_1(1 - GreenBondDummy_i)\, corr(\widetilde{R}_{t+1}^b c_{t+1}^{-1}) \\ &+ \delta_2\, GreenBondDummy_i\, corr(\widetilde{R}_{t+1}^g c_{t+1}^{-1}) \\ &+ \delta_3\, GreenBondDummy_i\, N_t \\ &+ \delta_4\, GreenBondDummy_i + \omega X + \epsilon \end{aligned} \tag{14}$$

where $YieldSpread_{i,j,t}$ is the yield spread of bond i issued by issuer j at time t; $GreenBondDummy_i$ is the dummy variable that identifies green bonds, N_t is the exogenous shock to climate change concerns, and X is a set of controls.

Hypothesis 2: Investors time-varying preferences for green bonds explain the variation in green bond premiums over time.

Since there is only one observation of consumption for each point in time, $corr(\widetilde{R}^g_{t+1}, c^{-1}_{t+1})$ and $corr(\widetilde{R}^b_{t+1}, c^{-1}_{t+1})$ will be constants. We can shorten (14) as follow:

$$YieldSpread_{i,j,t} = \alpha + \beta_1\, GreenBondDummy_i N_t + \beta_2\, GreenBondDummy_i + \omega X + \epsilon \qquad (15)$$

where δ_0, δ_1, and δ_2 will be a part of α; β_1 and β_2 correspond to δ_3 and δ_4, respectively. $Corr(\widetilde{R}^g_{t+1}, c^{-1}_{t+1})$ could reflect a hedging motive for holding green bonds.

Generally, there is a negative correlation between uncertainty and consumption (Sandmo, 1970; Dreze and Modigliani, 1972). In our context, the periods of increased concerns about climate change can also represent the times of higher perceived climate risks, which may stem from unexpected weather-related events or uncertainties surrounding new policies and regulations. Green bonds, which are linked to sustainable projects, will have a higher correlation with marginal utility during the periods of heightened concerns on climate change, allowing investors to smooth out their consumption. As a result, investors may prefer green bonds for hedging purposes. If the hedging effect is substantial, we would observe $corr(\widetilde{R}^g_{t+1}, c^{-1}_{t+1}) > corr(\widetilde{R}^b_{t+1}, c^{-1}_{t+1})$. The regression analysis helps differentiate between a hedging motive and a non-pecuniary preference for green bonds: the intercepts (which capture the correlations) indicate hedging, while the coefficient on the news reflects investor preferences.

Hypothesis 3: If the hedging motive is significant, green bonds will exhibit a higher correlation with marginal utility.

3 Data and Summary Statistics

We obtained the list of all municipal green bonds using the Bloomberg "green bond" tag, a replicable identification method meeting institutional standards. The first official municipal green bond is issued in June 2013 by Massachusetts.[2] We follow Baker et al. (2018) to construct our sample which includes green bonds issued between June 2013 and June 2017. The initial sample during our analysis period includes 3,067 green bonds and 13,722 brown bonds matched by the issuer. We obtain the secondary market transaction data for green and brown bonds from the Municipal Securities Rulemaking Board (MSRB) database of Wharton Research Data Services (WRDS). We further drop the transactions with yields outside the 1st and 99th percentiles to weed out outliers.

Appendix B provides the initial sample distribution of green bonds by quarter. Both the number of issued and the number of traded green bonds have tripled from 2014 to 2017, and the number of green bond transactions occurring quarterly in the secondary market has reached almost 26,000 by mid-2017. Appendix C provides the distribution of green bonds by state. Over our sample period, California is the leading state issuing green bonds, followed by New York and Texas.

To compute the yield spread on these bonds, we match their yields with Treasury bond yields of similar maturities obtained from the U.S. Department of the Treasury's website, adjusting Treasury bond yields via linear interpolation.[3] Next, we calculate the monthly yield spread as the weighted average of yield spreads within a month, with the weights based on trade amounts. We keep bonds with maturities between 1 and 30 years and those without any missing information on transactions (e.g., yield, trade amount) and bond characteristics (e.g., maturity, seniority). After these cleaning steps, we have 2,737 green bonds and 10,009 brown bonds remaining in our sample. For each green bond, we match it to brown bonds that are from the same issuer and traded in the same month. The assumption behind this approach is that as long as the riskiness of the issuer does not change, controlling for bond characteristics should be sufficient to account for the difference in their yield caused by non-climate related factors and will allow us to examine whether climate change concerns influence green bond premiums. After this last matching step, our final sample includes 984 green bonds and 6,042 brown bonds from 72 unique issuers. Appendix D details the number of green and brown bonds in our sample after each data cleaning step.

[2] According to Bloomberg, municipal bonds issued as early as 2010 under the Federal Clean Renewable Energy Bond (CREB) and Qualified Energy Conservation Bond (QECB) programs are also tagged as green bonds. Following the approach of Baker et al. (2018), we eliminate the bonds issued under CREB and QECB from our sample.

[3] See https://www.treasury.gov/resource-center/data-chart-center/interest-rates for details on daily Treasury yield curve rates.

Table 1 reports that the average yield spread for green and brown bonds is 0.23% and 0.19%, respectively. Green bonds, on average, have high yields, longer times to maturity, and lower offering amounts than brown bonds. They are also more likely to be subordinated, insured, or have a call option attached, and less likely to be general obligation bonds.

[Insert Table 1 here]

We obtain the climate change news index constructed by Ardia et al. (2022) to proxy for the climate change concerns captured by news media. Ardia et al. (2022) develop the Media Climate Change Concerns (MCCC) index by measuring concerns, sentiment (positive or negative), and the levels of uncertainty about climate change, and analyzing climate-related articles from ten leading newspapers and two newswires. Their index also measures the degree of media attention on various climate issues. Pastor et al. (2021, 2022) argue that, despite having lower expected returns, green assets tend to outperform brown assets and generate higher realized returns when there is an unexpected shift in investors' ESG preference. Therefore, it is crucial to segregate the unexpected part of the concerns from what has been expected based on prior information. We use the unexpected media climate change concerns (UMC) developed by Ardia et al. (2022)[4] as our primary proxy for unexpected change in climate concerns.

Panels A and B of Figure 1 is the time series of the aggregate MCCC and the UMC, respectively. During our sample period, the MCCC Index has a mean of 1.26 and a median of 1.25, while the UMC Index has a mean of 0.16 and a median of 0.13. Overall, there are rich variations in both climate risk news indices over time. The higher the indices, the more extensive the media coverage and public concerns about climate change. The periods of heightened concerns also coincide with several salient events related to climate change (e.g., the Paris Agreement, National Climate Assessment, the United States Environmental Protection Agency (EPA) Initiatives, and Trump's withdrawal from the Paris Agreement), especially so for the UMC index.

[Insert Figure 1 here]

The UMC index also has different components to reflect multiple sources of climate risk. Physical risks arise from weather-related events and direct destruction of the environment such as

[4] Ardia et al. (2022) use the prediction error of an explanatory-variables-augmented autoregressive time series regression model calibrated on the MCCC index to construct the UMC index.

wildfire, floods, and hurricane. Transition risks are associated with the process of adjustment toward a lower-carbon economy, changing in regulations, technologies, or market sentiment. Liability risk is the potential climate change-linked legal liability, which can arise from either physical or transition risks. It is well-established in the literature that the physical risk of climate change impacts asset prices (Bernstein et al., 2019, Giglio et al., 2021, Murfin and Spiegel, 2020, Painter, 2020, Goldsmith-Pinkham et al., 2023, Kahn et al., 2024, and Le et al., 2023). Other channels of climate change such as transition risk can also affect asset prices (Giglio et al., 2021, Bolton and Kacperczyk, 2023, among others). In the context of municipalities, besides the physical aspect of climate change, the transition risk arising from municipalities transitioning to a more sustainable economy is particularly important and relevant (Butler and Uzmanoglu, 2024). Therefore, we use the topical UMC indices to examine whether there are variations in green bond premiums when concerns arise from different sources of climate risks. We discuss these results in section 4.3.

4 Empirical Test

4.1 Baseline Results

In this section, we use our model to empirically test the yields of green and brown bonds issued by municipalities in the U.S. The baseline regression model is constructed as

$$\begin{aligned} YieldSpread_{i,j,t} = \alpha + \beta_1 GreenBondDummy_i \times AboveP_xUMC_t + \\ \beta_2 GreenBondDummy_i + \omega X + \epsilon_{i,j,t} \end{aligned} \tag{16}$$

where t is the month subscript, $YieldSpread_{i,j,t}$ is the yield spread of municipal bond i issued by issuer j in month t, α is the intercept, $GreenBondDummy_i$ indicates whether the bond is a green bond, $AboveP_xUMC_t$ indicates the months in which the climate change concerns are above a certain threshold x (50%, 75%), and $\epsilon_{i,j,t}$ is the error term. We cluster standard errors at the bond level to account for within-bond correlation in error terms.

The financial characteristics we control for in our regressions include *Log(Year to Maturity)*, *Log(Offering Amount)*, *Subordinated Bond Dummy*, *Put Dummy*, *Call Dummy*, *Insured Dummy*, and *General Obligation Dummy*, which proxy for bonds' characteristics that can ultimately affect bond pricing. While these variables control for the cross-sectional variation in bonds' riskiness, the issuer- and year-fixed effects control for the issuer-varying and time-varying trends in risk factors that affect bond pricing. Controlling for bonds' characteristics, our variable of interest is the interaction terms of the green bond dummy and climate concern news index. We do not control for issuer characteristics because green bonds and brown bonds are matched by issuer.

Column (1) in Table 2 reports the result without conditioning on climate concern news proxy. The coefficient estimate on $GreenBondDummy$ is statistically insignificant, indicating that on average green bonds do not trade at a premium compared with matched brown bonds. Investors, on average, do not show a preference for green or brown bonds over the full sample period. The coefficient estimates on *Log(Year to Maturity)*, *Log(Offering Amount)*, *Subordinated Bond Dummy*, *Put Dummy*, *Call Dummy*, *Insured Dummy*, and *General Obligation Dummy* suggest that, as credit risk models predict, bonds with insurance, call option attached, longer time to maturity, and lower priority in receiving money, have higher yield and lower price. On the other hand, general obligation bonds and bonds with higher offering amounts have lower yields and higher prices.

[Insert Table 2 here]

In columns (2) – (4), we interact the green bond dummy with the climate concern proxy. In column (2) where we interact the continuous UMC measure with the green bond dummy, the coefficient estimate on $LnUMC \times GreenBondDummy$ is -0.04, statistically significant at the 1% level. It indicates that as the UMC increases by 1%, the yield spread of green bonds decreases by 4 basic points compared to brown bonds. In columns (3) and (4), we interact the green bond dummy with the indicator of above 50% and 75% UMC threshold, respectively. The interaction term in column (3) indicates that during the time when the climate concern is above the median, green bonds are traded at 2 basis points lower than brown bonds. When we increase the threshold to 75% in column (4), we find a stronger result that green bonds are traded at 7 basis points lower than brown bonds, representing 30% of green bond yield average in our sample. The magnitude of our finding is consistent with the prior studies which document an average of green bond premium ranging between 1 and 9 basic points on the secondary market (MacAskill, 2021). These baseline findings suggest that green bonds are traded at lower yields and thus higher prices during periods of greater climate concerns, reflecting a shift in investors' preference towards green products when climate change sentiments are high. We acknowledge that the coefficient of $GreenBondDummy$ is positive and significant in columns (2)-(4), indicating that investors show a preference for brown bonds when the climate concerns are low.

Pastor et al. (2021, 2022) show that green assets have lower expected returns but higher realized returns when there are unexpected shifts in investor preferences. Using the unexpected climate news index to capture the unexpected change in investors' sentiment, we provide evidence that green bonds tend to have higher price levels and lower yields compared with the matched brown bonds only when unexpected climate concerns are high, consistent with the theoretical model and empirical findings documented in Pastor et al. (2021, 2022).

Two distinctive mechanisms can potentially offer explanations for our baseline results. The first one arises from investors' need to hedge climate risk. As concerns about climate change increase, investors' sense of urgency to hedge climate risk increases, resulting in a stronger demand for green products. Yousef et al. (2022) investigate the diversification and hedging benefits of green investments, concluding that these investments have evolved from being perceived as luxury goods to essential components for enhancing portfolio stability and performance. Arfaoui et al. (2024) further demonstrate that green investment funds provide significant diversification benefits, particularly in mitigating climate risk. Similarly, Cepni et al. (2022) confirm that green bonds present a more resilient option for investors concerned about climate risk exposures, as evidenced by their consistently positive, time-varying correlations with both physical and transition climate risks.

On the other hand, a shift in investor demand towards green products might come from their non-pecuniary preference, particularly during times of heightened concerns about climate change. Several theoretical studies have demonstrated that investors may be willing to forgo financial returns to invest in environmentally friendly or socially responsible assets (e.g., Friedman and Heinle, 2016; Geczy et al., 2021; Heinkel et al., 2001). Similarly, the broader asset pricing literature, which examines how investors' preferences for assets with specific characteristics can influence asset prices, supports these findings (e.g., Fama and French, 2007; Hong and Kacperczyk, 2009).

Based on our theoretical model, $corr(\widetilde{R}^g_{t+1}, c^{-1}_{t+1})$ and $corr(\widetilde{R}^b_{t+1}, c^{-1}_{t+1})$ are the intercepts in our baseline regressions for green and brown bonds, respectively, and $corr(\widetilde{R}^g_{t+1}, c^{-1}_{t+1})$ reflects a hedging motive for holding green bonds. If there is a hedging motive, we would expect $corr(\widetilde{R}^g_{t+1}, c^{-1}_{t+1})$

to be greater than $corr(\widetilde{R}^b_{t+1}, c^{-1}_{t+1})$. Appendix E shows the point estimate of $corr(\widetilde{R}^g_{t+1}, c^{-1}_{t+1})$ to be greater than the point estimate of $corr(\widetilde{R}^b_{t+1}, c^{-1}_{t+1})$. However, we find that there is no significant difference between the two correlations based on their overlapping confidence interval. As a result, the findings in our baseline study are more likely influenced by investors' non-pecuniary motives, rather than their desire to hedge against climate risk.

4.2 The Heterogeneity of Green Bond Premiums and Climate Change Concerns

In this section, we test for heterogeneity in the earlier findings. More specifically, Section 4.2.1 examines whether the impact of climate change concerns on green bond premium varies by bonds' characteristics such as its year to maturity or type of bond; Section 4.2.2 investigates whether the earlier findings vary depending on the climate risk belief or concern.

4.2.1 Is the Effect of Climate Change Concerns More Pronounced for Longer Maturity Bonds and Revenue Bonds?

We first examine whether the impact of climate change concerns on the green bond premiums is more pronounced for green bonds with longer maturities. Since climate risk is inherently a long-term risk, any realization of this risk is likely to occur over a longer time horizon. Consequently, investors may prefer to invest in green bonds with longer maturities to better hedge against these potential long-term risks. To do so, we run our baseline regressions (column (2) of Table 2) for different subsamples. When we construct the subsamples, we make sure that each issuer contributes at least one green bond and one brown bond to the sample in each month. Columns (1) and (2) of Table 3 report the regression results for bonds with less than 10 years to maturity and more than 10 years to maturity, respectively. We find that the coefficient estimate on the interaction term $LnUMC \times GreenBondDummy$ for shorter-maturity and longer-maturity bonds are -0.07 and -0.04, respectively, and they are both significant at the 1% level. To our surprise, the result is more pronounced for shorter-term bonds. Therefore, we repeat the regressions from Column (2) of Table 2 for different bond groups, categorizing them by their time to maturity in 5-year increments. Then, we plot the coefficient estimates on the interaction term $LnUMC \times GreenBondDummy$ and their confidence intervals by groups in Figure 2.

[Insert Table 3 here]

[Insert Figure 2 here]

Figure 2 reveals two interesting observations. First, the green premium is most significant for green bonds with maturities of less than five years. Our conjecture is that this trend may arise from investors' preference for green bonds with shorter maturities, as they can more easily verify how the proceeds are used and avoid investments in greenwashing projects. Baker et al. (2018) find that green bonds have higher ownership concentration and are more likely to be held by concerned investors who value the certification of these bonds. In a corporate context, Flammer (2020) also find that investors respond positively to announcements of green bond issuances, particularly when these bonds are certified by third parties. For shorter-term bonds, the verification and reporting process is less complex and more transparent, which reduces the risk of controversies or failures to adhere to green principles over time. This increased transparency can boost investor confidence, increasing demand for short-term bonds where the green use of proceeds is immediately verifiable. Additionally, the sustainable investment industry has expanded significantly over the past decade, as evidenced by the emergence of numerous new funds incorporating ESG criteria into their investment decisions (Hartzmark et al., 2019; Starks et al., 2023). As demand for green investments grows, these investors may prioritize short-term green bonds, thus increasing the green premiums.

Second, Figure 2 also shows that green premiums do not become more statistically significant as the time to maturity extends beyond five years. This result also aligns with the previous finding that investors' preference for green bonds is more likely driven by alignment with environmental values (i.e., non-pecuniary motives) than by purely risk-hedging motives. If risk hedging is the primary purpose of investors buying green bonds, one would expect long-term bonds to be affected more due to the long-term nature of climate risk. However, this does not appear to be consistent with our results.

We acknowledge the findings from the prior literature (Painter, 2020, Pastor et al., 2021, Goldsmith-Pinkham et al., 2023) that bonds with longer maturities tend to be more sensitive to climate risk and investors' climate concerns. Our findings do not necessarily contradict the prior literature. Painter (2020) examines the primary market of municipal bonds in a general setting and does not focus on green bonds in particular. Goldsmith-Pinkham et al. (2023) also use the general municipal bond sample and find that sea-level rise has a larger impact on long-maturity bonds. Distinct from their framework, our sample has green bonds matched to brown bonds by their maturities and by issuer. Our finding that investors prefer green bonds over maturity-matched brown bonds only during high climate concern periods indicates that investors' preference is indeed time-varying. Green bonds with shorter maturities have pricing and yield changes that can more accurately reflect the short-term shifts in investor preferences driven by current events or changes in climate-related policies.

To explore whether the type of bond affect our baseline results, in columns (3) and (4) of Table 3, we estimate column (2) of Table 2 for general obligation and revenue bonds, respectively. While the general obligation bond is backed by the municipality's broad tax base, the revenue bond is backed by the revenue generated by a specific project. For that reason, general obligation bonds, on average, offer lower yields than similar revenue bonds. In our analysis, we find that interaction terms $LnUMC \times GreenBondDummy$ is significant at the 1% level for revenue bonds but not for general obligation bonds. This is consistent with the fact that green bonds are more likely to be revenue bonds in our sample. As discussed earlier, green bonds are held in high concentration by an investor who advocates for environmental projects and contributes to sustainable development. Therefore, revenue bond's direct connection to specific projects and transparency in the use of proceed make green revenue bonds more attractive to investors who are focused on green credentials.

4.2.2 Does Prior Belief or Concern about Climate Risk Influence the Impact of Climate Change Concerns on Green Bond Premiums?

Evidence of confirmation bias has been well documented in the literature on economics and finance (Nickerson, 1998; Pouget et al., 2017; Hirshleifer et al., 2021, among others). As investors exhibit biases, they have the tendency to select and interpret the news in a way that aligns with their prior beliefs on climate change. This can lead them to accept information confirming their beliefs and reject or ignore information contradicting their prior belief (Baldauf et al., 2020).

In this section, we test whether prior belief or concern about climate change can influence the impact of climate concerns on green bond premiums. To do so, we first obtain the data on climate belief and concern at the state level from the Yale Climate Opinion Survey. The survey has been conducted biannually since 2014. A model then downscales the results at the national level to reflect cross-sectional variations in climate change beliefs and risk perceptions at the state level.[5] On average, in a given state, more than 54% and 65% of the population believe in or are concerned about climate change, respectively. We match this measure to our sample by year and by issuer state, and then create above- and below-median groups by state-year cohort. Columns (2) and (4) of Table 4 report coefficient estimates for bonds with above median belief and concern in climate change, respectively. The interaction terms $LnUMC \times GreenBondDummy$ are -0.05 and -0.04, both significant at the 1% level. Whereas in columns (1) and (3), we do not find a significant preference for green bonds that are below cohort median climate change beliefs/concerns. These results indicate that investors' time-varying preference for green bonds is stronger if they have stronger prior beliefs and concerns about climate change.

[Insert Table 4 here]

Overall, the results from our heterogeneity tests further support the argument that green premiums observed during periods of heightened climate concerns are more likely driven by investors' non-pecuniary preferences rather than by a hedging motive. If a hedging purpose is the primary motivation, one would expect green bond premiums to vary with the bond's maturity regardless of bond type or investors' prior beliefs.

4.3 How Do Different Sources of Climate Risks Influence Green Bond Premiums?

Climate risk involves various physical, economic, social, and environmental factors. According to Carney (2015), climate risk comes from three sources, (i) physical risk, (ii) transition risk, and (iii) liability risk. Prior studies document that different sources of climate risk can potentially impact different asset classes in diverse ways.[6] We build on the findings of previous studies by examining how climate concerns, specifically those arising from sub-categories of transition and physical risk, influence the pricing of green bonds relative to brown bonds.

[5]Please see https://climatecommunication.yale.edu/visualizations-data/ycom-us/ for details on the methodology of the survey.

[6]See Krueger et al. (2020), Ardia et al. (2022), Bolton and Kacperczyk (2023), and Faccini et al. (2023) for equity market evidence, and see Zhou et al. (2023), Pham and Kamal (2024), and Guo et al. (2023) for the commodity market evidence.

Following Ardia et al. (2022), we consider four climate change concerns themes: Business Impact, Environmental Impact, Societal Debate, and Research. The correlation matrix in Appendix C shows strong positive correlations among the four themes. Notably, while the Business Impact and Research themes exhibit the lowest correlation among the pairs, the Business Impact and Societal Debate themes have the highest correlation of 0.71. This strong correlation is attributed to the interconnected nature of business practices and societal concerns. Within each theme, there are also associated sub-topics. Most sub-topics under Business Impact and Societal Debate capture various dimensions of transition risks, except the Legal Actions topic that is related to liability risk. The theme of Environmental Impact captures the physical risks of climate change. The last theme, Research, includes sub-topics related to physical and transition risks.

Table 5 investigates how the relationship between climate change concerns and green bond premium varies across the sources of climate change concerns. Column (1) reports the coefficient estimates for the interaction term $LnUMC \times GreenBondDummy$. The coefficient estimates for Business Impact, Environmental Impact, and Research are mostly negative and significant. The effect magnitude of the Research theme on the green bond premiums is the largest, followed by Business Impact and Environmental Impact. However, the effect of the Societal Debate theme on green bond premiums is mostly insignificant. Among the topics, Climate Legislation/Regulations, Extreme Temperature, UN/IPCC[7] reports, and Marine Wildfire exhibit the most significant effects on green bond premiums. Columns (2) and (3) of Table 5 report the results for the interaction terms $AboveP_{50}UMC \times GreenBondDummy$ and $AboveP_{75}UMC \times GreenBondDummy$, respectively. The coefficient estimates on these interaction terms remain the most significant for Research and Environmental Impact. Our results indicate that among all three risks, both the physical and transitional aspects of climate risk are reflected in asset prices, consistent with Butler and Uzmanoglu (2024). Moreover, the physical risk of climate concerns appears to have the strongest impact on green premiums. One explanation is that physical risk represents a more tangible threat for municipalities than transition risk and therefore investors are more sensitive to the news related to physical risk.

[Insert Table 5 here]

[7] United Nations and Intergovernmental Panel on Climate Change.

5 Robustness Tests

5.1 Endogeneity Concern Driven by Macro Factors

There are worries that the periods of elevated climate change concerns may coincide with other broader periods of economic uncertainty, potentially causing confounding effects in our regressions. To address this problem, we add $TreasuryYield$, $TermSpread$, and $CreditSpread$ as additional independent variables in our baseline regression. While treasury yield and term spread are often used as indicators of monetary policy influence and future policy intentions, credit yield is a proxy for broader economic conditions. Table 6 reports the results from these specifications.

[Insert Table 6 here]

Columns (1), (2), and (3) of Table 6 each includes *Treasury Yield*, *Term Spread*, and *Credit Spread* as the additional control variable, respectively. The interaction terms $LnUMC \times GreenBondDummy$ vary from -0.04 to -0.06 and remain significant at the 1% level. Column (4) includes all three variables in the regression, and the interaction term remains significant at the 5% level. These consistent results suggest that our findings are unlikely driven be the broad economic environment.

5.2 Propensity Score Matching Approach to Estimate Green Premium

In this section, we implement a propensity score matching (PSM) approach to find a control sample for 984 green bonds from the pool of 6,042 brown bonds. The PSM approach allows us to assess the robustness of our baseline results by controlling for a variety of bond and issuer characteristics. To calculate the propensity scores, we run the following probit regression using the combined sample of both green and brown bonds:

$$GreenBondDummy_i = \alpha + X_i'\beta + \epsilon_i \tag{17}$$

where i denotes bond, and X is a vector of bond characteristics that include *Log(Year to Maturity)*, *Log(Offering Amount)*, *Subordinated Dummy*, *Call Dummy*, *Insured Dummy*, and *General Obligation Dummy*. Using the coefficient estimates from this regression, we calculate the probability of being treated (i.e., the propensity score) for all brown bonds. Then, we match each green bond with a brown bond that has the closest propensity score.[8] The final sample in our robustness test would include transactions of only green bonds and their matching brown bonds. Panel A of Table 7 reports the summary statistics for the characteristics of green bonds and the control brown bonds. In this panel, the Differences column reports the statistics from the tests of differences in mean (t-value from a two-tailed Student's t-test) and median (z-value from a two-tailed Wilcoxon rank-sum test) of green and brown bonds. Overall, the treatment and control groups have similar propensity scores and appear to be comparable in terms of their characteristics.

[Insert Table 7 here]

Panel B of Table 7 reports the regression results for green bonds and their one-to-one matched brown bonds. Columns (1) reports the results using the continuous climate concern measure and columns (2) and (3) use the 50% and 75% cut-offs indicators, respectively. The interaction terms are significant at the 1% level in all columns, suggesting that our baseline results hold after controlling for the differences in the green and brown bond characteristics.

5.3 Alternative Proxy for Climate Concerns

To make sure that our baseline results are robust to alternative climate concern measures, we obtain the climate change news index constructed by Engle et al. (2020). The index measures the extent to which climate change is discussed in Wall Street Journal (WSJ). Specifically, it represents the correlation between all text content of WSJ each month and a list of climate change vocabulary, which is a collection of words that frequently appear on reports published by governmental and research organizations. Distinct from our primary measure which captures the unexpected component of climate concerns of investors, this measure reflects the broad climate change sentiments among the investment community.

[Insert Table 8 here]

We adopt the regression framework similar to equation (16) and replace the UMC measure with the WSJ measure. In Table 8, we report the baseline regression results using this alternative

[8] Using the sampling with replacement approach, a brown bond can be repeatedly selected as the control for different green bonds.

climate concern news index. We observe consistent results that green bonds are traded at significantly lower yields than brown bonds when the climate concerns are high. The magnitude of the coefficient of the interaction terms is larger compared with the results in Table 2. For example, in column (4), the yields of green bonds are on average 14 basic points lower than the yields of brown bonds when climate concerns are above the 75% threshold.

Overall, the findings in this section suggest that our baseline results do not appear to be driven by macro factors correlated with the periods of high climate change concerns, the differences in bond characteristics, or the climate concern proxies.

6 Conclusion

In this paper, we develop a macro model that accounts for non-pecuniary aspects, such as climate change concerns captured by news media, to influence investors' preference for green and brown assets over time. We then use the model to explore the dynamics of municipal green bond pricing in response to climate change concerns. We find that, during the time of increased climate concerns, green bonds are traded at lower yields and higher prices than brown bonds. Our analysis and heterogeneity tests also reveal that green bond premiums are more likely driven by investors' non-pecuniary motives rather than their desire to hedge against climate risk.

Our study also explores how physical and transition risks affect the pricing of green bonds. We observe that the highly abnormal increase in concerns due to the physical risk of climate change can significantly influence green bond premiums.

Overall, our paper contributes to the literature on how non-pecuniary motives and climate risks influence asset pricing. By recognizing investors' variation in preferences for green assets over time, we offer a new perspective on previous studies' mixed results regarding the green bond premiums. Additionally, our study connects environmental economics with finance, highlighting the role of investor preferences shaped by climate concerns.

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Table 1: Summary Statistics

This table provides summary statistics for the variables used in the paper's baseline study. The sample includes 984 green bonds, and 6,042 matched brown bonds, which are from the same issuers and were traded in the same month as the green bonds. Refer to Appendix A for the definition of the variables and Appendix D for detailed information on the sample selection process. *, **, *** denotes significance at the 10, 5, and 1 percent levels, respectively.

Sample:	**Green Bonds**			**Brown Bonds**			**Test of Differences**
Variables:	**N**	**Mean**	**Std.**	**N**	**Mean**	**Std.**	**t-stat**
Year to Maturity	984	12.31	6.41	6,042	10.87	6.38	-6.54***
Offering Amount (in millions)	984	8.59	15.39	6,042	14.28	24.02	7.20***
Subordinated Dummy	984	0.03	0.19	6,042	0.01	0.19	-6.18***
Call Dummy	984	0.57	0.50	6,042	0.45	0.50	-7.09***
Insured Dummy	984	0.04	0.20	6,042	0.02	0.20	-3.96***
General Obligation Dummy	984	0.32	0.50	6,042	0.61	0.50	17.46***
Yield Spread	5,911	0.23	0.43	36,722	0.19	0.37	-7.36***

Table 2: The Influence of Climate Change Concerns on Green Bond Premiums

This table presents the regression results investigating the relations between green bond premiums and climate change concerns. The regression equation is as follows:

$$YieldSpread_{ijt} = \alpha + \beta_1 GreenBondDummy_i \times AboveP_xUMC_t + \beta_2 GreenBondDummy_i + \omega X + \epsilon_{i,j,t}$$

where i, j, t denote bond, issuer, and month, respectively, and X is a vector of controls for bonds' characteristics.The sample includes 42,633 observations of transactions contributed by 984 green bonds and 6,042 brown bonds between June 2013 and June 2017. Refer to Appendix A for the definition of the variables and Appendix D for detailed information on the sample selection process. Reported in parentheses are t-statistics calculated using robust standard errors clustered at the bond level. *, **, *** denotes significance at the 10, 5, and 1 percent levels, respectively.

Dependent Variables:	**Yield Spread**			
Model:	**No cut-off**	**Continuous**	**P50 cut-off**	**P75 cut-off**
Independent Variables:	**(1)**	**(2)**	**(3)**	**(4)**
Green Bond Dummy	0.02	0.03**	0.03**	0.04***
	(1.59)	(2.01)	(2.17)	(3.05)
LnUMC × Green Bond Dummy		-0.04***		
		(-3.23)		
Above P50 UMC × Green Bond Dummy			-0.02**	
			(-2.27)	
Above P75 UMC × Green Bond Dummy				-0.07***
				(-8.44)
Log(Year to Maturity)	0.16***	0.16***	0.16***	0.16***
	(16.04)	(16.04)	(16.04)	(16.05)
Log(Offering Amount)	-0.05***	-0.05***	-0.05***	-0.05***
	(-11.05)	(-11.06)	(-11.05)	(-11.09)
Subordinated Bond Dummy	0.01	0.01	0.01	0.02
	(0.20)	(0.30)	(0.25)	(0.49)
Call Dummy	0.17***	0.17***	0.17***	0.17***
	(13.78)	(13.78)	(13.78)	(13.80)
Insured Bond Dummy	0.05	0.05	0.05	0.05
	(0.72)	(0.72)	(0.72)	(0.73)
General Obligation Dummy	-0.13***	-0.13***	-0.13***	-0.13***
	(-4.66)	(-4.65)	(-4.65)	(-4.66)
Intercept	1.18***	1.18***	1.18***	1.18***
	(11.23)	(11.21)	(11.24)	(11.16)
Issuer Fixed Effect	Yes	Yes	Yes	Yes
Year Fixed Effect	Yes	Yes	Yes	Yes
Number of Observations	42,633	42,633	42,633	42,633
Adjusted R^2	38.83%	38.84%	38.83%	38.91%

Table 3: Green Bond Premium by Bond Characteristics

This table presents the regression results that examine how climate change concerns' impact on green bond premiums varies with bond characteristics. Each column displays results from the regression model in Column (2) of Table 2, using different subsamples. Columns (1) and (2) focus on bonds with maturities of ten years or less and those with maturities exceeding ten years, respectively. Columns (3) and (4) cover general obligation bonds and revenue bonds, respectively. Refer to Appendix A for the definition of the variables and Appendix D for detailed information on the sample selection process. Reported in parentheses are t-statistics calculated using robust standard errors clustered at the bond level. *, **, *** denotes significance at the 10, 5, and 1 percent levels, respectively.

Dependent Variables:	**Yield Spread**			
Sample:	**Maturity<=10**	**Maturity>10**	**General Obligation**	**Revenue**
Independent Variables:	**(1)**	**(2)**	**(3)**	**(4)**
Green Bond Dummy	0.02	0.03*	0.01	0.06***
	(1.52)	(1.65)	(0.35)	(4.91)
LnUMC × Green Bond Dummy	-0.07***	-0.04***	-0.00	-0.06***
	(-3.99)	(-2.63)	(-0.18)	(-4.29)
Intercept	1.20***	0.99***	1.07***	0.58***
	(9.99)	(5.87)	(9.36)	(6.75)
Bond Control Variables	Yes	Yes	Yes	Yes
Issuer Fixed Effect	Yes	Yes	Yes	Yes
Year Fixed Effect	Yes	Yes	Yes	Yes
Number of Observations	22,173	20,460	26,889	15,744
Adjusted R^2	35.30%	35.28%	38.84%	42.31%

Table 4: Green Bond Premiums by Prior Climate Beliefs and Concerns

This table presents the regression results that examine how climate change concerns' impact on green bond premiums varies by prior climate belief and concern. Each column displays results from the regression model in Column (2) of Table 2, using different subsamples. Columns (1) and (2) report the results from regressions of yield spread for the below and above median belief in climate change, respectively. Columns (3) and (4) report the results from regressions of yield spread for the below and above median concern about climate change, respectively. Refer to Appendix A for the definition of the variables and Appendix D for detailed information on the sample selection process. Reported in parentheses are t-statistics calculated using robust standard errors clustered at the bond level. *, **, *** denotes significance at the 10. 5, and 1 percent levels, respectively.

Dependent Variables:	**Yield Spread**			
Sample:	**Belief in Climate Change**		**Concern about Climate Change**	
	<= Median	**>Median**	**<= Median**	**>Median**
Independent Variables:	**(1)**	**(2)**	**(3)**	**(4)**
Green Bond Dummy	0.04**	0.03*	0.03*	0.03**
	(1.98)	(1.94)	(1.68)	(2.04)
LnUMC × Green Bond Dummy	-0.03	-0.05***	-0.04	-0.04***
	(-1.27)	(-3.26)	(-1.51)	(-3.08)
Intercept	1.19***	0.40***	0.80***	1.04***
	(8.83)	(3.56)	(5.74)	(12.25)
Bond Control Variables	Yes	Yes	Yes	Yes
Issuer Fixed Effect	Yes	Yes	Yes	Yes
Year Fixed Effect	Yes	Yes	Yes	Yes
Number of Observations	4,997	37,636	4,192	38,441
Adjusted R^2	47.41%	37.68%	47.04%	37.90%

Table 5: Sources of Climate Risk

This table presents the regression coefficients of the interaction terms using thematic and topical UMC indices. Columns (1)-(3) run the regression models in Columns (2)-(4) of Table 2, respectively. Refer to Appendix A for the definition of the variables and Appendix D for detailed information on the sample selection process. Reported in parentheses are t-statistics calculated using robust standard errors clustered at the bond level.

Interaction Terms		**LnUMC * GreenDummy**	**AboveP50UMC * GreenDummy**	**AboveP75UMC * GreenDummy**
Thematic and Topical UMC Indices	Risk Category	(1)	(2)	(3)
Aggregate UMC		-0.04***	-0.02***	-0.07***
Theme 1: Business impact	Transition	-0.07***	-0.00	-0.05***
Climate summits	Transition	-0.06***	0.00	0.00
Agreements/actions	Transition	-0.05***	-0.00	-0.06***
Climate legislation/regulations	Transition	-0.19***	-0.10***	-0.04***
Legal actions	Liability	0.04***	0.05***	.0.02***
Renewable energy	Transition	-0.06***	-0.02***	-0.05***
Carbon reduction technologies	Transition	-0.13***	-0.09***	-0.05***
Carbon credits market	Transition	-0.03**	-0.02***	-0.04***
Carbon tax	Transition	-0.06***	-0.02***	-0.04***
Government programs	Transition	-0.08***	0.02***	-0.06***
Corporations/investments	Transition	-0.02**	-0.01	-0.02***
Car industry	Transition	-0.04***	-0.09***	-0.07***
Airline industry	Transition	-0.05***	-0.03***	-0.02***
Theme 2: Environmental impact	Physical	-0.05***	-0.02***	-0.06***
Extreme temperatures	Physical	-0.15***	-0.08***	-0.08***
Food shortage/poverty	Physical	0.02***	-0.03***	-0.06***
Hurricanes/floods	Physical	-0.05***	-0.06***	-0.02***
Glaciers/ice sheets	Physical	-0.02***	-0.05***	-0.05***
Ecosystems	Physical	0.03***	0.05***	0.04***
Forests	Physical	0.06***	-0.02***	0.03***
Water/drought	Physical	-0.03***	-0.04***	-0.00
Tourism	Physical	-0.05***	0.03***	-0.05***
Arctic wildlife	Physical	0.00	-0.00	0.00
Marine wildlife	Physical	-0.09***	-0.01	-0.03***
Agriculture shifts	Physical	0.03**	0.06***	0.01
Theme 3: Societal debate	Transition	-0.01	-0.01	0.01
Political campaign	Transition	0.01	-0.01*	-0.03***
Social events	Transition	-0.05***	0.02*	-0.03***
Controversies	Transition	0.01	-0.00	-0.00
Cities	Transition	-0.05***	-0.04***	-0.01*
Theme 4: Research	Physical/Transition	-0.10***	-0.06***	-0.08***
Global warming	Physical/Transition	-0.07***	-0.03***	-0.08***
UN/IPCC reports	Physical/Transition	-0.10***	-0.04***	-0.10***
Scientific studies	Physical/Transition	-0.06***	-0.02***	-0.07***

Table 6: Robustness Tests for the Influence of Climate Change Concerns on Green Bond Premiums

This table examines the robustness of the baseline findings by adding additional macro control variables to the baseline regression model (Column (2) of Table 2). Columns (1), (2), and (3) include *Treasury Yield*, *Term Spread*, and *Credit Spread* as additional control variables, respectively. Column (4) includes all three as additional control variables. Refer to Appendix A for the definition of the variables and Appendix D for detailed information on the sample selection process. Reported in parentheses are t-statistics calculated using robust standard errors clustered at the bond level. *, **, *** denotes significance at the 10, 5, and 1 percent levels, respectively.

Dependent Variables:	**Yield Spread**			
Independent Variables:	**(1)**	**(2)**	**(3)**	**(4)**
Green Bond Dummy	0.04***	0.04**	0.04***	0.03**
	(3.08)	(2.57)	(2.68)	(2.13)
LnUMC × Green Bond Dummy	-0.06***	-0.04***	-0.04***	-0.02**
	(-8.14)	(-5.47)	(-5.57)	(-2.28)
Treasury Yield	0.06***			0.01
	(15.08)			(1.45)
Term Spread		0.20***		0.20***
		(31.56)		(27.28)
Credit Spread			-0.00***	-0.00***
			(-29.27)	(-30.10)
Intercept	1.06***	0.53***	1.65***	0.98***
	(10.08)	(5.03)	(15.72)	(9.40)
Bond Control Variables	Yes	Yes	Yes	Yes
Issuer Fixed Effect	Yes	Yes	Yes	Yes
Year Fixed Effect	Yes	Yes	Yes	Yes
Number of Observations	42,633	42,633	42,633	42,633
Adjusted R^2	39.35%	40.05%	40.24%	41.52%

Table 7: Propensity Matching Approach

This table presents the baseline results using a propensity score-matched sample. Control bonds are selected from a sample of 6,042 brown bonds. Panel A presents the summary statistics for the characteristics of green and brown bonds. The Differences column reports the statistics from the tests of differences in mean (t-value from a two-tailed Student's t-test) and median (z-value from a two-tailed Wilcoxon rank-sum test) characteristics of green bonds and brown bonds. Panel B reports the results from the baseline regressions of Table 2 using the matched sample. Refer to Appendix A for the definition of the variables and Section 5.2 for the details of our matching procedure. Reported in parentheses are t-statistics calculated using robust standard errors clustered at the bond level. *, **, *** denotes significance at the 10, 5, and 1 percent levels, respectively.

Panel A: Characteristics of Green and Brown Bonds

Sample:	**Green Bonds**			**Brown Bonds**			**Differences**	
Variables:	**N**	**Mean**	**Median**	**N**	**Mean**	**Median**	**t-stat**	**z-stat**
Propensity Score	984	0.20	0.20	606	0.18	0.19	-0.02	-0.00
Year to Maturity	984	11.81	10.92	606	10.89	9.72	-1.02	-1.23
Offering Amount (millions)	984	8.59	3.23	606	9.59	3.42	1.08	0.24
Subordinated Dummy	984	0.04	0.00	606	0.02	0.00	-1.20	-1.20
Call Dummy	984	0.58	1.00	606	0.52	1.00	-2.29**	-2.28**
Insured Dummy	984	0.04	0.00	606	0.04	0.00	0.32	0.32
General Obligation Bond	984	0.32	0.00	606	0.35	0.00	1.59	1.60
Yield Spread	5,911	0.23	0.17	3,125	0.21	0.16	-1.95*	-1.41

Panel B: Regression Results Using the Matched Sample

Dependent Variables:	**Yield Spread**		
Models:	**Continuous**	**P50 cut-off**	**P75 cut-off**
Independent Variables:	(1)	(2)	(3)
Green Bond Dummy	0.03*	0.04**	0.05***
	(1.87)	(2.12)	(2.87)
LnUMC × Green Bond Dummy	-0.07***		
	(-5.61)		
Above P50 UMC × Green Bond Dummy		-0.02***	
		(-3.90)	
Above P75 UMC × Green Bond Dummy			-0.09***
			(-12.30)
Intercept	0.70	0.70	0.69
	(1.54)	(1.57)	(1.55)
Bond Control Variables	Yes	Yes	Yes
Issuer Fixed Effect	Yes	Yes	Yes
Year Fixed Effect	Yes	Yes	Yes
Number of Observations	9,036	9,036	9,036
Adjusted R^2	55.97%	55.90%	56.37%

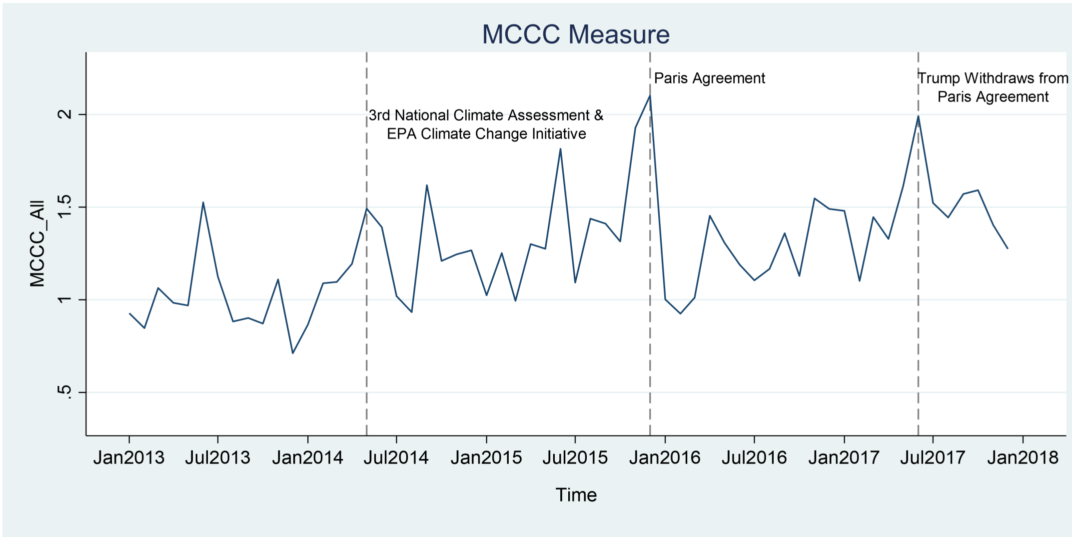
Table 8: Alternative Proxy for Climate Concerns

This table presents the regression results investigating the relations between green bond premiums and climate change concerns using the alternative climate concern proxy (WSJ news index following Engle et al., 2020). The regression equation is as follows:

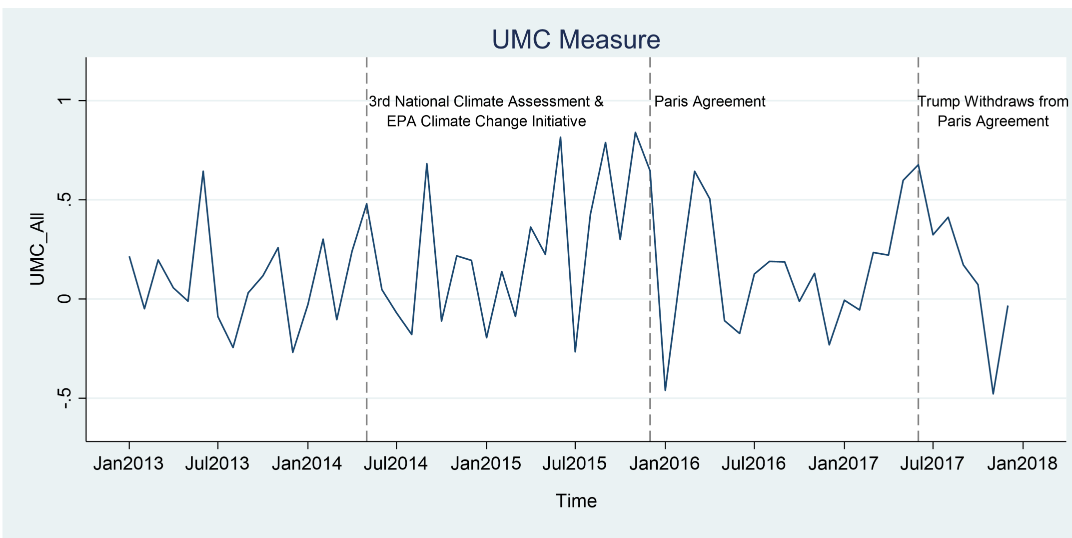
$$YieldSpread_{ijt} = \alpha + \beta_1 GreenBondDummy_i \times AboveP_x WSJ_t + \beta_2 GreenBondDummy_i + \omega X + \epsilon_{i,j,t}$$

where i, j, t denote bond, issuer, and month, respectively, and X is a vector of controls for bonds' characteristics.The sample includes 42,633 observations of transactions contributed by 984 green bonds and 6,042 brown bonds between June 2013 and June 2017. Refer to Appendix A for the definition of the variables and Appendix D for detailed information on the sample selection process. Reported in parentheses are t-statistics calculated using robust standard errors clustered at the bond level. *, **, *** denotes significance at the 10, 5, and 1 percent levels, respectively.

Dependent Variables:	**Yield Spread**			
Model:	**No cut-off**	**Continuous**	**P50 cut-off**	**P75 cut-off**
Independent Variables:	**(1)**	**(2)**	**(3)**	**(4)**
Green Bond Dummy	0.02	-0.99***	0.04**	0.04***
	(1.59)	(-8.50)	(2.74)	(2.89)
LnWSJ × Green Bond Dummy		-0.20***		
		(-8.98)		
Above P50 WSJ × Green Bond Dummy			-0.07***	
			(-5.89)	
Above P75 WSJ × Green Bond Dummy				-0.15***
				(-12.61)
Intercept	1.18***	1.19***	1.19***	1.18***
	(11.23)	(11.35)	(11.26)	(11.38)
Bond Control Variables	Yes	Yes	Yes	Yes
Issuer Fixed Effect	Yes	Yes	Yes	Yes
Year Fixed Effect	Yes	Yes	Yes	Yes
Number of Observations	42,633	42,633	42,633	42,633
Adjusted R^2	38.83%	38.99%	38.90%	39.05%



Panel A: MCCC Measure from January 2013 to December 2017



Panel B: UMC Measure from January 2013 to December 2017

Figure 1: Climate Change Concerns over Time

Panel A shows the time series of the aggregate Climate Change Concern Index (MCCC) from January 2013 to December 2017. Panel B displays the Unexpected Media Climate Change Concern (UMC) Index for the same period. Based on Ardia et al. (2022), the UMC Index is derived from the prediction error of an autoregressive time series regression model augmented with explanatory variables, based on the MCCC Index. During this period, the MCCC Index has a mean of 1.26 and a median of 1.25, while the UMC Index has a mean of 0.16 and a median of 0.13.

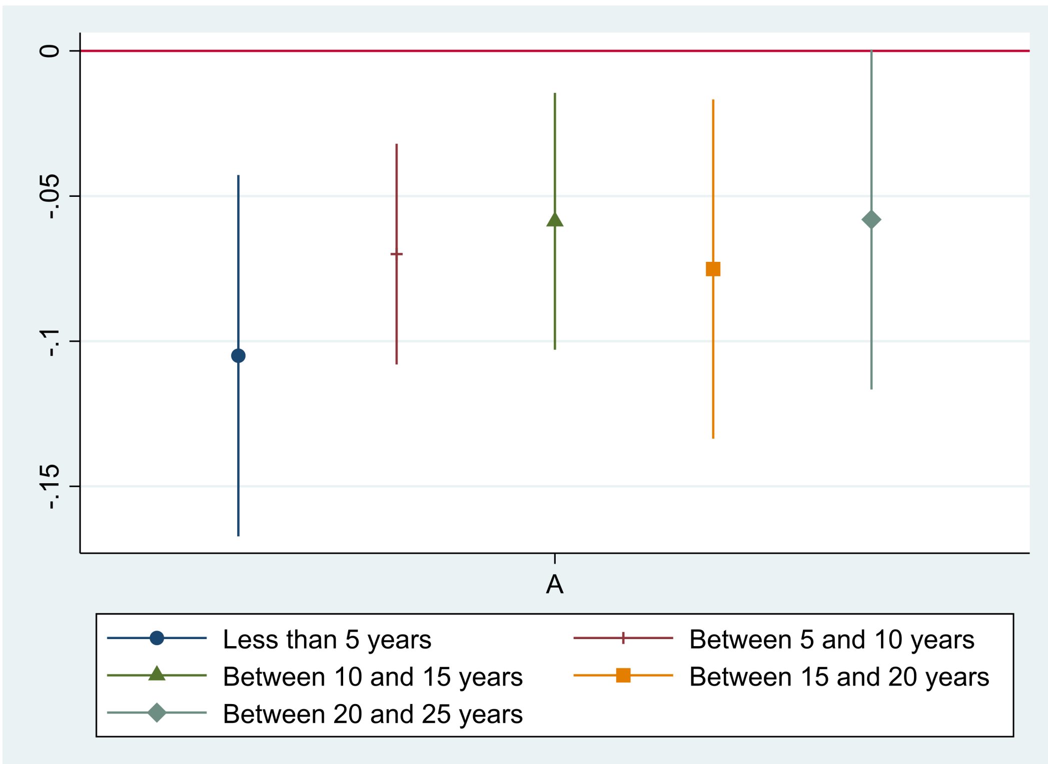


Figure 2: The Influence of Climate Change Concerns on Green Bond Premiums by Maturities

This figure shows the regression coefficient estimates for the interaction term from the regression model in Column (2) of Table 2, using bonds with the following maturities: (1) less than five years, (2) between five and ten years, (3) between ten and fifteen years, (4) between fifteen and twenty years, and (5) between twenty and twenty-five years. Dots represent coefficient estimates, and vertical lines represent the 95% confidence intervals.

Appendix A. Variable Definitions

This appendix provides information about the variables' definitions and their data sources.

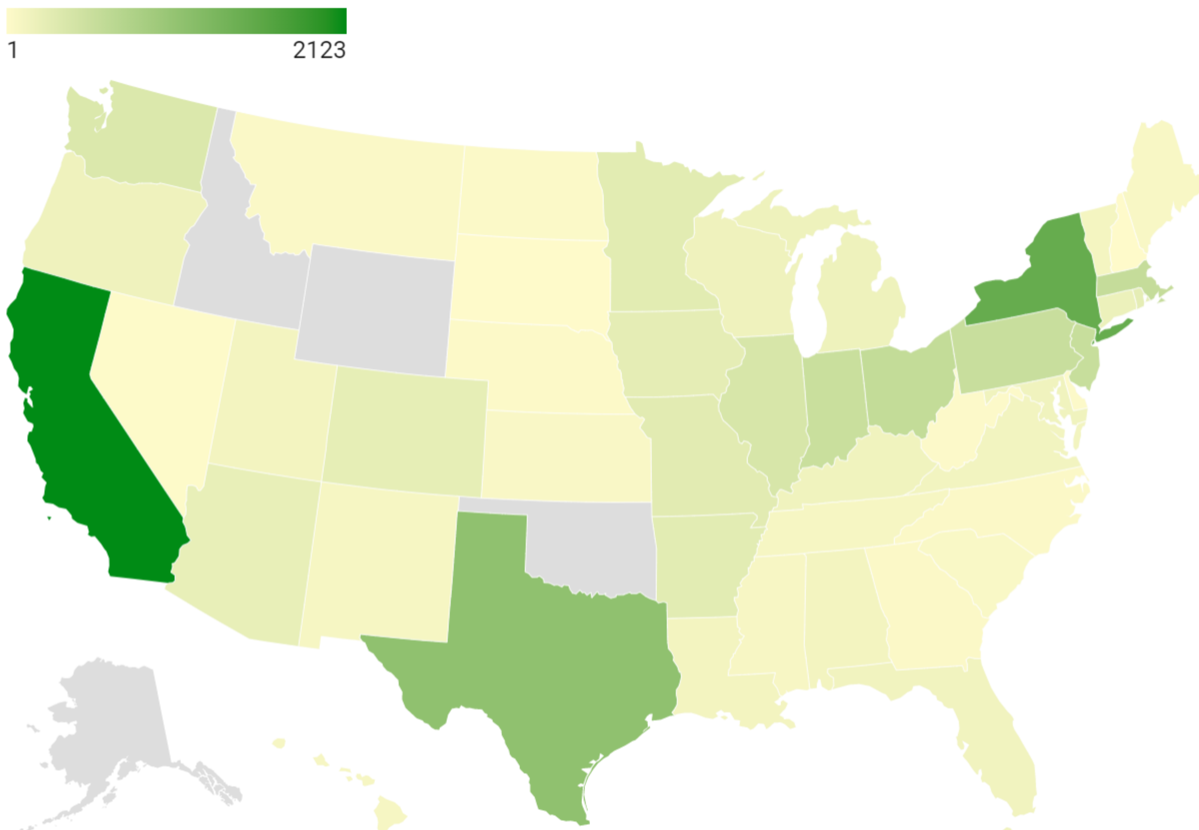
Variables	Descriptions	Data Sources
Year to Maturity	The difference between the maturity date and the trading date.	Bloomberg
Log (Year to Maturity)	Log of the Year to Maturity	Constructed by Authors
Offering Amount (in millions)	The total face value of bonds offered to the public.	Bloomberg
Log (Offering Amount)	Log of the Offering Amount	Constructed by Authors
Subordinated Dummy	Dummy variable taking the value of one for bonds that are not senior, and zero otherwise.	Bloomberg
Call Dummy	Dummy variable taking the value of one for bonds with call options, and zero otherwise.	Bloomberg
Insured Dummy	Dummy variable taking the value of one for bonds with put options, and zero otherwise.	Bloomberg
General Obligation Dummy	Dummy variable taking the value of one for non-revenue bonds, and zero otherwise.	Bloomberg
Yield Spread	The difference between the yield to maturities of municipal bonds and maturity-matched Treasury bonds.	Bloomberg
Green Bond Dummy	Dummy variable taking the value of one if a bond is a green bond defined by Bloomberg, and zero otherwise.	Bloomberg
MCCC	The aggregate media climate change concern index.	Ardia et al. (2022), Sentometrics Research
UMC	The unexpected media climate change concern index constructed by the prediction error of an explanatory-variables-augmented autoregressive time series regression model calibrated on the MCCC index.	Ardia et al. (2022), Sentometrics Research
LnUMC	Log of one plus UMC	Constructed by Authors
Above P50 UMC	Dummy variable taking the value of one for a period in which the climate change concern proxy is above the median.	Constructed by Authors
Above P75 UMC	Dummy variable taking the value of one for a period in which the climate change concern proxy is above the 75th percentile	Constructed by Authors
Belief in Climate Change	Percentage of population in a state that have belief in climate change.	Yale Climate Opinion Survey
Concern about Climate Change	Percentage of population in a state that have concerns about climate change.	Yale Climate Opinion Survey
Treasury Yield	Yield of maturity-matched Treasury bonds.	U.S. Department of the Treasury
Term Spread	The difference between the yield to maturity (YTM) of a 30-year Treasury bond and that of a 1-year Treasury bond	Constructed by Authors
Credit Spread	The difference in yield between two bonds of similar maturity but different credit quality	Bloomberg

Appendix B. Distribution of Green Bonds by Quarter

This table reports the distribution of our sample by quarters. We obtain the list of green bonds and their trading data from Bloomberg, and Wharton Research Data Services (WRDS), respectively. The first official labeled municipal green bond was not issued until May 2013, so our sample starts in the third quarter of 2013. "Number of Issued Green Bonds" column reports the number of green bonds that were issued during each period. "Number of Traded Green Bonds" column shows the number of green bonds traded in the secondary market, and "Number of Transactions" column indicates the number of trades from the traded green bonds.

Year	**Quarter**	**Number of Issued Green Bonds**	**Number of Traded Green Bonds**	**Number of Transactions**
2013	3	69	227	2,005
2013	4	41	209	2,130
2014	1	2	177	1,842
2014	2	62	280	2,626
2014	3	67	227	4,558
2014	4	154	444	4,965
2015	1	196	469	4,523
2015	2	218	523	8,055
2015	3	226	589	9,587
2015	4	230	710	10,255
2016	1	131	704	13,087
2016	2	263	826	9,946
2016	3	300	993	11,142
2016	4	378	1,249	16,972
2017	1	251	1,311	21,042
2017	2	479	1,510	25,714

Appendix C. Distribution of Green Bonds by States



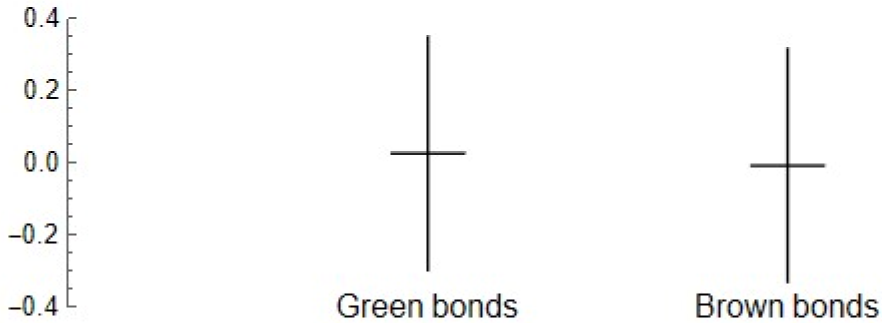
This figure in this appendix illustrates the color coding for each state based on the number of green bonds issued between June 2013 and June 2017. States shaded in darker colors are more active in issuing green bonds, while lighter shades indicate lower activity. California leads with the highest number of green bonds issued. Together, California, Texas, and New York account for approximately one-third of all municipal green bonds issued.

Appendix D. Data Cleaning Steps

This appendix presents the number of green bonds and brown bonds remaining after each data cleaning step.

Data Steps	**Number of Green Bonds**	**Number of Brown Bonds**
Full sample (excluding bonds issued under CREB and QECB)	3,067	13,722
Drop bonds with time to maturity outside of 1 and 30 years	2,828	10,133
Drop transactions of bonds with yields outside the 1st and 99th percentiles	2,737	10,009
Drop bonds with no matching brown bonds traded in the same month	984	6,042

Appendix E: Hedging versus Non-pecuniary Motives



The figure in this appendix plots the correlation coefficients $corr(\widetilde{R}^g_{t+1}, c^{-1}_{t+1})$ and $corr(\widetilde{R}^b_{t+1}, c^{-1}_{t+1})$ which are the intercepts for green and brown bonds, respectively. $corr(\widetilde{R}^g_{t+1}, c^{-1}_{t+1})$ could reflect a hedging motive for holding green bonds. If there is a hedging motive, we would expect $corr(\widetilde{R}^g_{t+1}, c^{-1}_{t+1}) > corr(\widetilde{R}^b_{t+1}, c^{-1}_{t+1})$.

Appendix F: Correlation Table

This appendix presents the correlation coefficients among the four themes of the UMC indices. The sample consists of 60 months of time series data from January 2013 to December 2017.

Thematic UMC Indices	**(1)**	**(2)**	**(3)**	**(4)**
(1) Theme 1: Business Impact	1.00			
(2) Theme 2: Environmental Impact	0.54	1.00		
(3) Theme 3: Societal Debate	0.71	0.55	1.00	
(4) Theme 4: Research	0.52	0.55	0.55	1.00