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Book

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Can Municipal Bonds Hedge US State-Level Climate Risks?

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Abstract

Using daily data on municipal bonds and equity returns from the 50 US states over the period from May 2, 2006, to February 9, 2024, we find that barring extreme periods of financial, macroeconomic, and health crises, the underlying conditional correlation between these two assets is negative, as derived from the Asymmetric Dynamic Conditional Correlations (ADCC)-Generalized Autoregressive Conditional Heteroskedasticity (GARCH) model. When we utilize the Quantile-on-Quantile (QQ) regression model to capture the effect of climate risk quantiles on the entire conditional distribution of the underlying time-varying stock-bond correlation, we generally observe a negative impact at different levels of climate risks, although this could turn positive in the event of extreme climate disasters. In summary, the role of municipal bonds as a hedge against climate risks cannot be denied, carrying important portfolio allocation implications for investors.

Keywords: Stocks and bonds returns, Time-varying conditional correlation, ADCC-GARCH, Climate risks, QQ regressions, US states

JEL Classification: C22, C32, G10, G12, Q54

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1. Introduction

Theoretically speaking, climate change-related extreme weather conditions, serving as a large aggregate risk, lead to reductions in productivity and/or an increase in the stochastic depreciation rate of capital, producing adverse impacts on equity valuations due to far out-in-the-left-tail realizations of the underlying states of the economy (Donadelli, 2017, 2021, 2022; Giglio et al., 2021). In other words, climate risks tend to negatively impact stock returns, as empirically shown by Choi et al. (2020), Bolton and Kacperczyk (2021), Balcilar et al. (2023), Faccini et al. (2023), Salisu et al. (2023a, 2023b), among others.[1]

Against this backdrop, and the well-established characteristic of flight-to-quality or flight-to-safety of government bonds during stock market turbulence (Demirer and Gupta, 2018; Gupta et al., 2018; Twala et al., 2018; Selmi et al., 2021), the objective of this paper is to empirically analyze whether municipal bonds can serve as a hedge against climate risks. To achieve our objective econometrically, we first compute the time-varying correlations between stocks and bond returns using the Asymmetric Dynamic Conditional Correlations (ADCC) - Generalized Autoregressive Conditional Heteroskedasticity (GARCH) model of Cappiello et al. (2006). Second, we utilize the Quantile-on-Quantile (QQ) regression approach of Sim and Zhou (2015) to analyze the (possible negative) effect of various levels (quantiles) of climate risks on the entire conditional distribution, i.e., the conditional quantiles of the underlying time-varying stock-bond correlation to provide us a complete picture of the hedging capabilities of bonds when stock returns are adversely impacted by climate risks.

For our analysis, we rely on stock and bond returns as well as climate risk data involving the 50 states of the United States (US), rather than examining these two asset markets from an aggregate perspective. The rationale for this approach is twofold: (a) The primary business activities of companies tend to be concentrated around their headquarters, which, consequently, causes stock prices to reflect notable regional influences (Korniotis and Kumar, 2013). Simultaneously, by considering municipal bonds—which can be thought of as investor loans made to local governments to fund public works such as parks, libraries, bridges, roads, and other infrastructure—the importance of a regional factor cannot be underestimated (Painter, 2020); (b) The time series properties of climate risks across the states tend to be heterogeneous and also differ from those of the overall US (Gil-Alana et al., 2022). In light of these points, and the fact that climate risks carry leading information for economic conditions at the US state level (Cepni et al., 2024), our analysis should be of immense value to investors in terms of portfolio diversification and risk management. Note that the debt involving the municipal bonds is generally paid back by the municipality using tax revenue (i.e., general obligation bonds), although other sources of revenue from the project (i.e., revenue bonds) can also be used. For instance, a bond issued to fund the

[1] In this regard, a related strand of literature has highlighted comparatively better portfolio performance of green stocks rather than brown stocks in hedging climate risks (see, Cepni et al. (2022, 2023) for detailed discussions in this regard).

building of a parking garage could then be paid back using the revenue from selling parking passes to the garage. General obligation bonds are seen as less risky because municipalities can raise taxes if there are insufficient funds to pay all debtholders, thus making municipal bonds a potentially safe haven option, relative to stocks, for investors at the state level.

To the best of our knowledge, this is the first paper to explore the hedging capabilities of bonds in terms of climate risks for the 50 US states over the daily period from May 2, 2006, to February 9, 2024. The rest of the paper is structured as follows: Section 2 provides an overview of the data, while Section 3 outlines the basics of the methodology. Section 4 presents the results, and Section 5 concludes the paper.

3. Data

The state-level stock market indices, for which we compute the log returns, are derived from the Bloomberg terminal, which, in turn, creates these indexes by taking the capitalization-weighted index of equities domiciled in a given state. As far as the corresponding municipal bond indexes are concerned, which are also converted to log returns and sourced from the Bloomberg terminal, basically measures the market-value-weighted performance of bonds issued by state and local municipalities in the US.

To produce the metric of climate risks, we collect daily weather data from the Bloomberg terminal too, as compiled by the National Climatic Data Center (NCDC), for the 50 US states. The weather data captures meteorological phenomena along several dimensions, including temperature, precipitation, number of heating degree days (HDD), number of cooling degree days (CDD), and wind speed as described below:

• Temperature ($temp_t$): The average temperature (usually of the high and low) that was observed between 7 am and 7 pm local time, expressed in Fahrenheit.

• HDD (H_t): The number of degrees that the average temperature of a day is below 65 degrees Fahrenheit. It is used to calculate the heating requirements of a building.

• CDD (C_t): The number of degrees the average temperature of a day is above 65 degrees Fahrenheit, aiding in estimating the cooling needs of a building.

• Precipitation ($prec_t$): The amount of rain, snow, sleet, or hail that falls in a specific location.

• Wind speed ($wind_t$): The average speed of the wind, not accounting for gusts, represented in knots.

As in Choi et al., (2020), we decompose the weather-related variables into three components that account for seasonal, predictable, and abnormal patterns. In particular, for each day, t, we compute the daily weather measure (W_t) for each of the states as a time-series, based on: $W_t = W_t^M + W_t^D + W_t^A$, where $W_t = \{temp_t, H_t, C_t, prec_t, wind_t\}$, and the term W_t^M denotes the mean of W_t for a specific-state spanning the 120 months prior to t. Moreover, the variable W_t^D denotes the difference of the mean of the deviation of the W_t from the daily average temperature for the particular state in the same calendar day over the last ten years and W_t^M. Finally, the variable W_t^A is the remainder (i.e., the abnormal deviation of weather conditions) and, hence, captures extreme departures from normal weather conditions. For this reason, we focus on this variable in our analysis. We standardize the abnormal deviations, commonly known as the standardized anomaly, to obtain the comprehensive measure of climate risks (*CR*), as given by:$CR_t = [std(temp_t^A) + std(prec_t^A) + std(C_t^A) - std(H_t^A) + std(wind_t^A)]/5$.[2]

Based on data availability at the time of writing this paper, our analysis covers the daily period of 2nd May, 2006 to 9th February, 2024.

4. Methodology

In this section we lay out the basics of the ADCC and QQ models utilized in deriving our empirical results.

4.1. Estimating US States Time-Varying Stocks-Bonds Conditional Correlations

We utilize the ADCC model of Cappiello et al. (2006) to estimate the time-varying correlations between stocks and municipal bonds across the US states.

Considering $n \times 1$ vector of returns, r_t, the mean equation is specified based on the information set available at time $t-1$, denoted by I_{t-1}:

$$r_t = \mu + \varphi r_{t-1} + \varepsilon_t \tag{1}$$

with the residuals denoted by $\varepsilon_t = H_t^{1/2} z_t$where H_t is the conditional covariance matrix of r_t, and z_t is a $n \times 1$ *i.i.d*. errors. Expressing H_t as $H_t = D_t^{1/2} R_t D_t^{-1/2}$ where $D_t = diag(h_{1,t}, \dots, h_{n,t})$ represents the diagonal conditional variances, the conditional correlation matrix R_t is given as:

$$R_t = diag\left(q_{1,t}^{-1/2}, \dots, q_{n,t}^{-1/2}\right) \Theta_t diag\left(q_{1,t}^{-1/2}, \dots, q_{n,t}^{-1/2}\right) \tag{2}$$

where Θ_t is symmetric positive definite matrix with $\Theta_t = (1 - \theta_1 - \theta_2)\bar{\Theta} + \theta_1 z_{t-1} z'_{t-1} + \theta_2 \Theta_{t-1}$. $\bar{\Theta}$ represents the $n \times n$ unconditional matrix of standardized residuals $z_{i,t}$ where θ_1 and θ_2 are non-negative satisfying the condition $\theta_1 + \theta_2 < 1$.

Cappiello et al. (2006) introduce an asymmetric adaptation of Engle's (2002) DCC model, to accommodate for the well-known "leverage effect" (Black, 1976) in asset markets, wherein the conditional volatility of the GARCH(1,1) model is delineated as:

$$h_{i,t} = w_i + a_i \varepsilon_{i,t-1}^2 + \tau_i h_{i,t-1} + \gamma_i \varepsilon_{i,t-1}^2 I(\varepsilon_{i,t-1}) \tag{3}$$

where the indicator function $I_{t-1} = 1$ if $\varepsilon_{i,t-1} < 0$ otherwisefunction $I_{t-1} = 0$. In this context, the "asymmetric" effect is represented by a positive value for γ_i d, indicating that positive

[2] Note that in CR_t, the standardized HDD_t^A enters with negative sign. HDD is a measure used to estimate the demand for energy needed to heat a building. Hence, high HDD indicates that more energy is needed to heat buildings due to lower temperatures, which implies less risk of global warming.

residuals have a lesser impact on increasing variance compared to negative residuals. Therefore, Θ_t is formulated by

$$\Theta_t = (\overline{\Theta} - A'\overline{\Theta}A - B'\overline{\Theta}B - G'\overline{\Theta} - G) + A'z_{t-1}z_t'A + B'\Theta_{t-1}B + G'z_t^- z_t'^- G \qquad (4)$$

where A, B and G are $n \times n$ parameter matrices and z_t^- are zero-threshold standardized errors with an unconditional matrix $\overline{\Theta}^-$.

4.2. Quantile-on-Quantile Regression

Sim and Zhou (2015) pioneered the QQ regression approach, extending the capabilities of traditional quantile regression model (Koenker and Bassett, 1978). This model examines how different quantiles of a single independent variable influence the various conditional quantiles of the dependent variable. This approach primarily relies on a combination of nonparametric estimation and quantile regression. We utilize the QQ regression approach to examine the impact of climate risks (x) on time-varying conditional correlations (y) for each state.

Let θ superscript represents the quantile of the y and x under consideration. We assume a model for the θ-quantile of y as a function of the x, so we have:

$$y_t = \beta^{\theta} x_t + \varepsilon_t^{\theta} \ , \qquad (5)$$

where ε_t^{θ} is an error term that has a zero θ -quantile.

Since we lack prior knowledge about the interconnection between the changes in y and x, we allow the relationship function $\beta^{\theta}(x_t)$ to be unknown. To analyse this relationship between the θ-quantile of y and τ-quantile of x, denoted by x^{τ}, we linearize the function $\beta^{\theta}(x_t)$ by taking a first-order Taylor expansion of β^{θ} (.) around x^{τ}, which yields the following:

$$\beta^{\theta}(x_t) \approx \beta^{\theta}(x^{\tau}) + \beta^{\theta\prime}(x^{\tau})(x_t - x^{\tau}) \qquad (6)$$

Following Sim and Zhou (2015), we redefine $\beta^{\theta}(x^{\tau})$ and $\beta^{\theta\prime}(x^{\tau})$, respectively, as $\beta_0(\theta,\tau)$ and $\beta_1(\theta,\tau)$. Then, equation (6) can be re-structured as follows:

$$\beta^{\theta}(x_t) \approx \beta_0(\theta,\tau) + \beta_1(\theta,\tau)(x_t - x^{\tau}) \qquad (7)$$

Ultimately, we substitute equation (7) into equation (5) to obtain the following:

$$y_t = \beta_0(\theta,\tau) + \beta_1(\theta,\tau)(x_t - x^{\tau}) + \varepsilon_t^{\theta} \qquad (8)$$

The expression: $\beta_0(\theta,\tau) + \beta_1(\theta,\tau)(x_t - x^{\tau})$ captures the relationship between the θ-quantile of the y and τ-quantile of x, given that $\beta_0$and β_1 are doubly indexed in θ and τ.

To estimate (8), we solve for:

$$\min_{\beta_0\beta_1} \sum_{i=1}^{n} \rho_{\theta} \left[y_t - \beta_0 - \beta_1(x_t - x\hat{}\tau)\right] K\left(\frac{F_n(x_t) - \tau}{h}\right) \qquad (9)$$

and obtain the estimates $\hat{\beta}_0(\theta,\tau)$ and $\hat{\beta}_1(\theta,\tau)$, where the function ρ_{θ} is the tilted absolute value function that provides the θ-conditional quantile of y_t as the solution. To examine the effect exerted locally by the τ-quantile of x, we utilize a Gaussian kernel $K(.)$ to weight the observations in the neighbourhood of x^τ, based on bandwidth h (=0.02). The weights are inversely related to the distance of x_t from x^τ, i.e., the distance of the empirical distribution function as:

$$F_n(x_t) = \frac{1}{n}\sum_{k=1}^{n} I(x_k < x_t) \tag{10}$$

from τ, where τ is the value of the distribution function that related to x^τ.

5. Empirical Results

The analysis illustrated in Figure 1, derived from the ADCC model,[3] reveals predominantly negative trends in time-varying correlations between stock and bond log-returns. These trends generally hold, except during short-lived episodes associated with the Global Financial Crisis (GFC) of 2008, the spike in uncertainty due to US debt ceiling crisis in 2011-2012 (causing both equity and bond returns to decline (Aye et al., 2016)), and more prolonged periods at the end of the sample linked to the outbreak of COVID-19 and subsequent monetary policy tightening by the Federal Reserve, which led to higher bond yields and lower prices amid high inflation rates post-pandemic. Interestingly, the correlation displayed significant fluctuations between positive and negative territories during 2016-2019, a period that coincides with the administration of President Donald J. Trump, during which stock markets performed robustly but unpredictably, reacting to frequent uncertainty shocks due to unpredictable policy changes.[4] Expanding on these observations, it is evident that these fluctuations in correlations are not merely statistical anomalies but reflect deeper economic and policy-driven dynamics. The positive correlations in times of crisis suggest a breakdown of the typical inverse relationship between stocks and bonds, which could undermine the hedging capability of bonds during such extreme events. This pattern warrants a closer look at the structural vulnerabilities and systemic risks embedded within the financial markets during periods of significant economic and political turmoil.

Furthermore, the general trend of negative correlation outside these extreme periods underscores the potential of municipal bonds as stable investment vehicles capable of countering the volatility seen in equity markets, particularly in response to regular occurrences of climate risk-related events in the US, as suggested by Liao et al. (forthcoming). The persistence of negative correlations in less turbulent times supports the hypothesis that municipal bonds could indeed serve as effective hedges against weather-related disasters that negatively impact equity markets across the US states.

<Insert Figure 1 here>

To provide convincing statistical evidence in this regard, we next turn to the QQ regression results between the conditional quantiles of the time-varying correlations of stocks and bonds returns regressed

[3] Complete details of the parameter estimates ADCC models for the 50 US states involving stock and bond returns are available upon request from the authors.

[4] See: https://www.gsb.stanford.edu/insights/why-uncertainty-shocks-are-part-trump-era-economy, and also Cervantes and Rambaud (2020).

on the quantiles of climate risks. Upon reviewing the results depicted in Figure 2, we observe that the impact of various levels of climate risks is predominantly negatively related across the conditional quantiles of the correlations involving the log returns of stocks and bonds. In other words, in the wake of heightened climate risks, with stock markets known to be negatively impacted, the reduced stock-bond correlation provides evidence in favour of the flight-to-quality phenomenon, i.e., the municipal bonds can indeed serve as a hedge against climate risks.

However, it is also crucial to note instances where high quantiles of climate risks correlate positively with the conditional quantiles of stock-bond correlations. This positive correlation in extreme scenarios is logical, as severe climate events can damage infrastructure significantly, affecting public works financed by municipal bonds and consequently, the returns on these bonds along with stocks. This nuanced view highlights the complex interactions between market dynamics and external risks, emphasizing the need for targeted strategies to manage these risks effectively.

In conclusion, except in cases of large weather-related disasters, municipal bonds consistently hedge financial risks associated with climate changes. This finding offers significant policy implications, suggesting that enhancing the resilience of financial markets to climate-related risks not only requires diversification in investment strategies but also a more robust policy framework that continuously assesses and adapts to the evolving nature of these risks.

<Insert Figure 2 here>

6. Conclusion

In conclusion, our analysis reveals that municipal bonds across the 50 US states serve as effective hedges against climate risks, which adversely affect regional stock market returns. Utilizing the ADCC-GARCH model and QQ regressions, we demonstrate that despite the inherent variability in correlations between stocks and bonds, a consistent negative correlation prevails under normal conditions. This suggests that municipal bonds generally provide a safeguard against climate-related market fluctuations. However, it is crucial to note that in extreme climate events, this correlation may shift to positive, indicating a potential vulnerability in times of severe climate crises.

Given these findings, policymakers and municipal bond issuers should consider the integration of climate risk assessments in their financial strategies to strengthen the resilience of bond markets. Enhancing transparency about the exposure of municipal bonds to climate risks and adopting climate-adaptive investment strategies could mitigate the impact of extreme events on bond valuations. Additionally, these insights should guide legislative frameworks aimed at supporting sustainable investment practices, thus reinforcing the role of municipal bonds in stabilizing regional economies in the face of escalating climate challenges. This strategic approach will not only safeguard investments but also encourage a broader commitment to addressing the financial implications of climate risks.

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Figure 1. Time-varying correlations between log-returns of US state-level stocks and municipal bonds using the ADCC-GARCH model

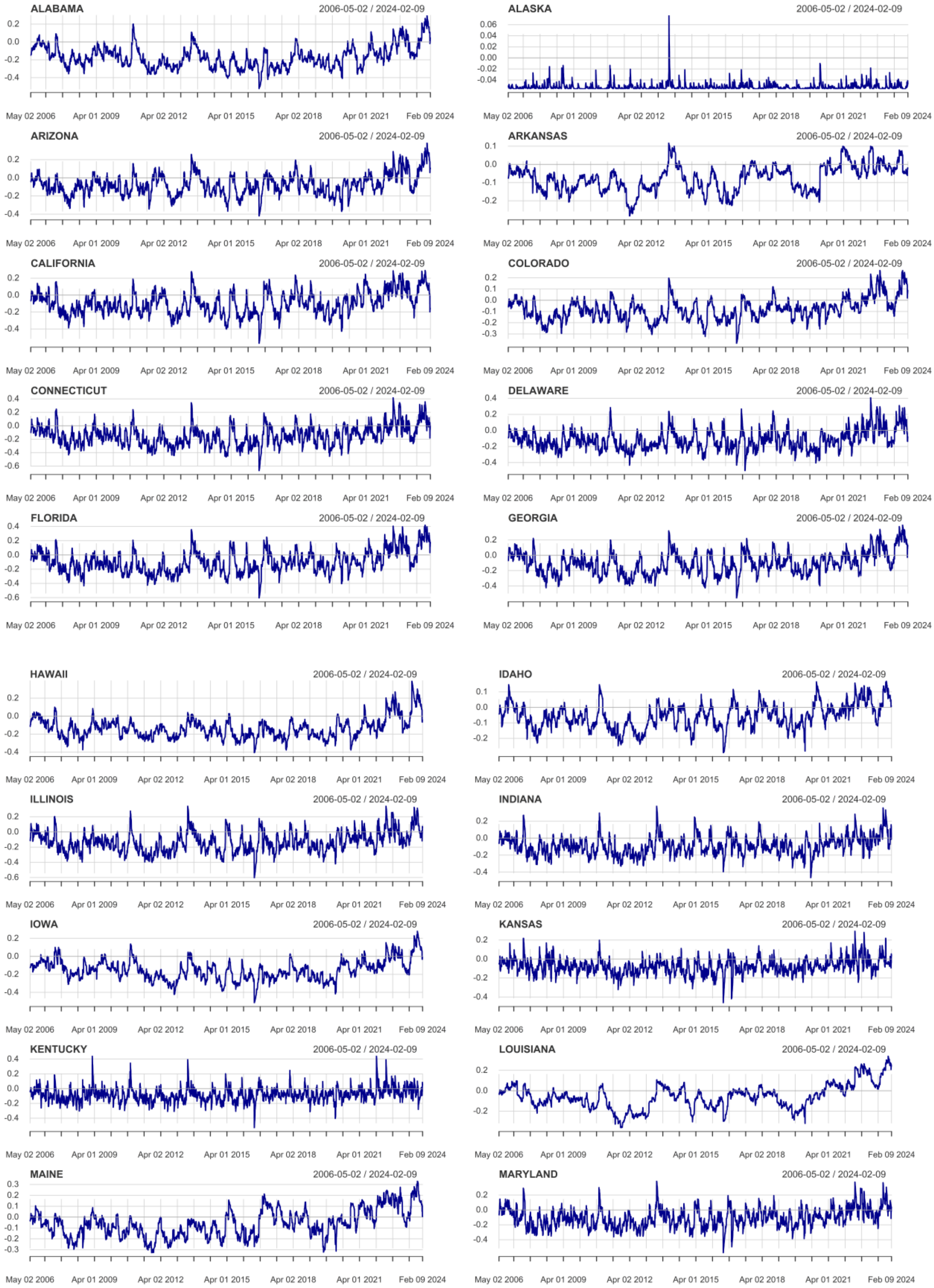

Figure 1-continued. Time-varying correlations between log-returns of US state-level stocks and municipal bonds using the ADCC-GARCH model

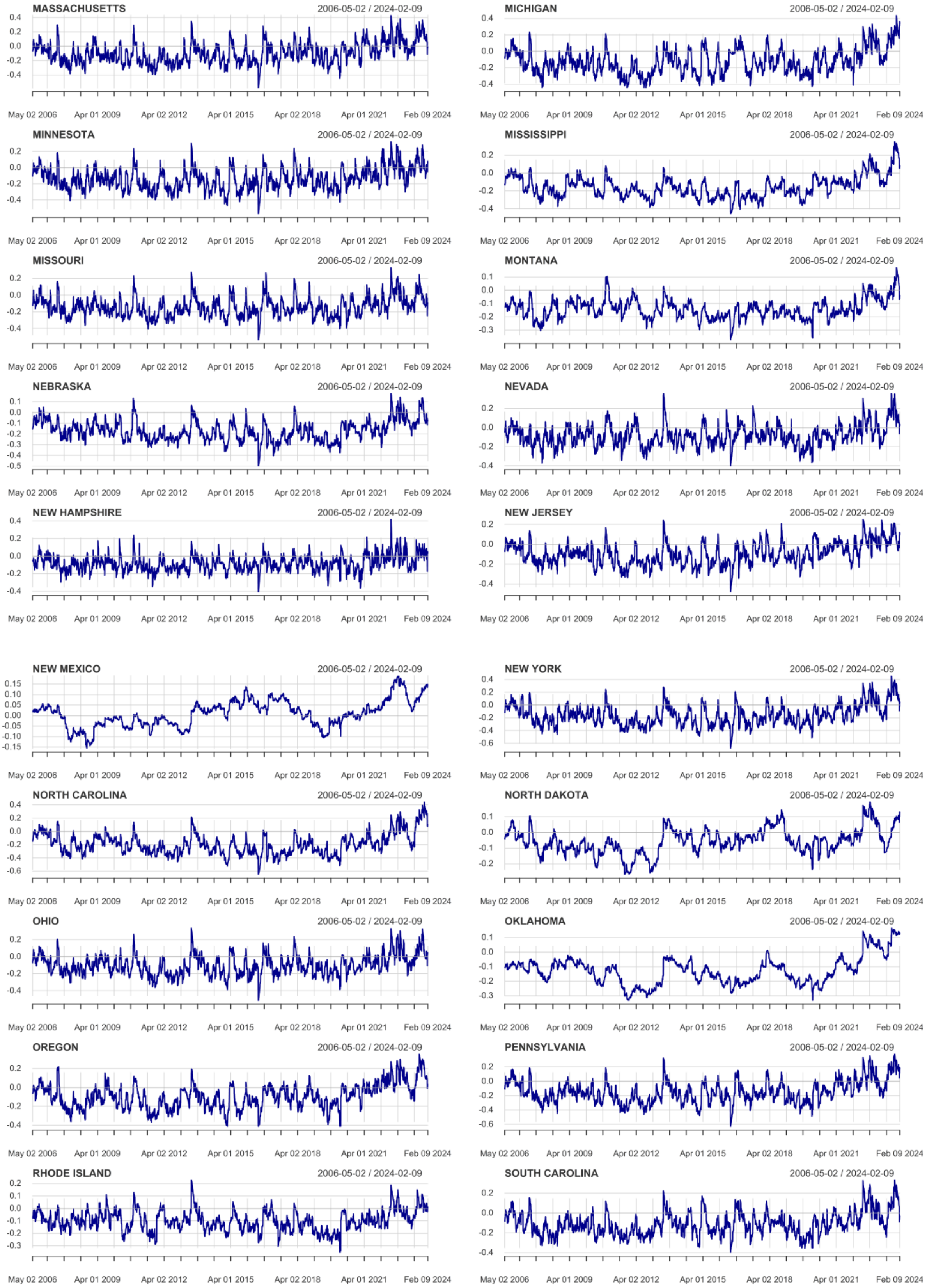

Figure 1-continued. Time-varying correlations between log-returns of US state-level stocks and municipal bonds using the ADCC-GARCH model

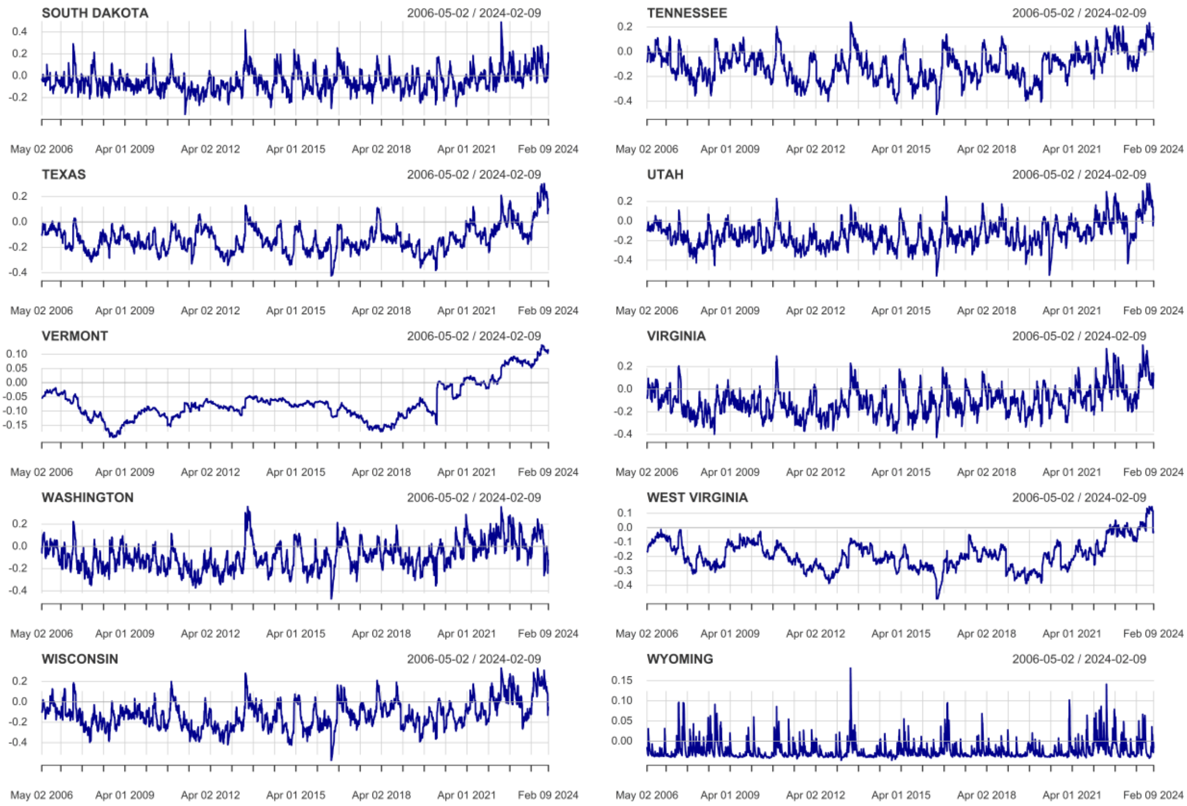

Figure 2. Quantile-on-Quantile (QQ) regressions-based estimated impact of climate risks on stock-bond correlations

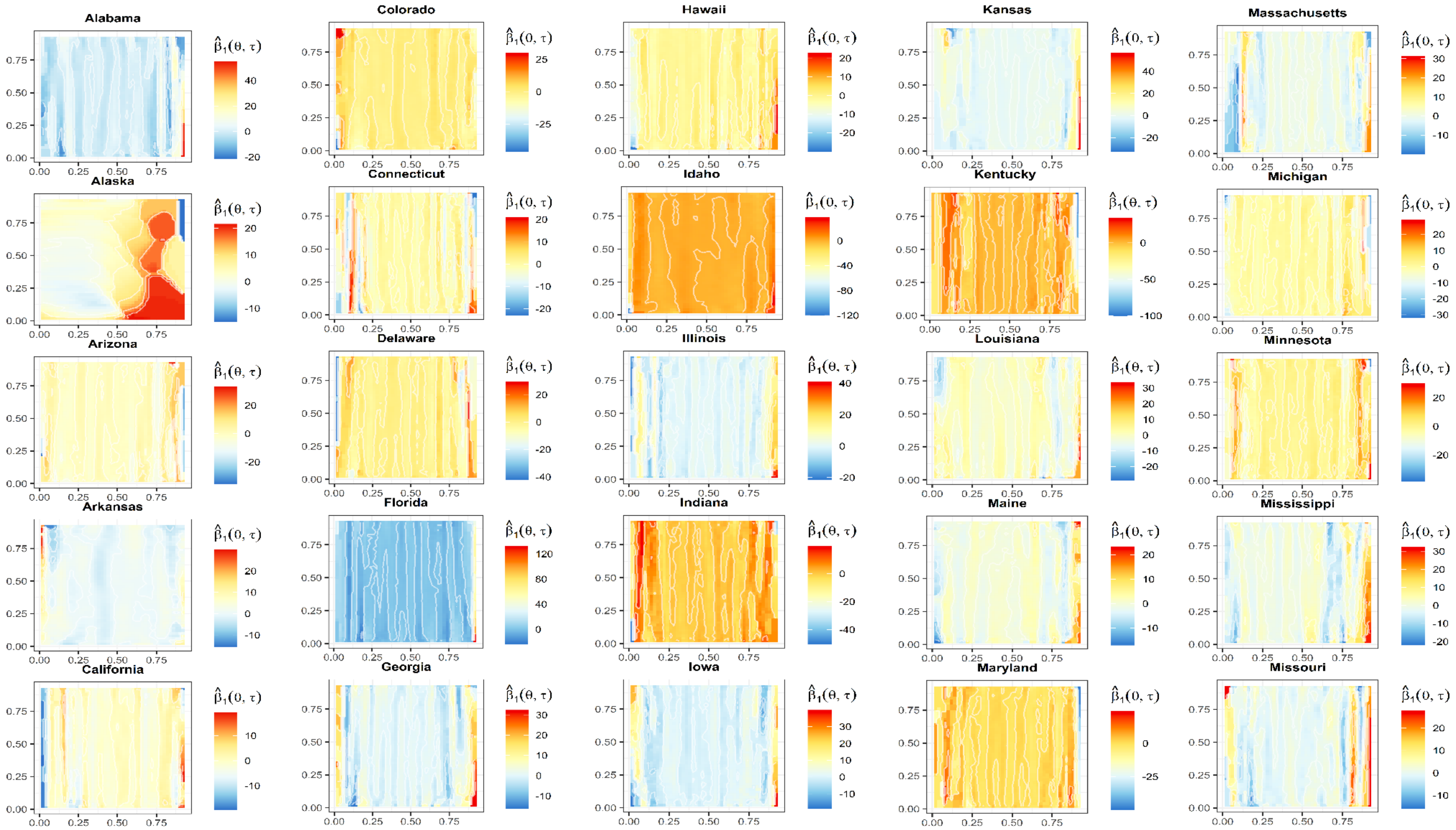

Figure 2-continued. Quantile-on-Quantile (QQ) regressions-based estimated impact of climate risks on stock-bond correlations