

# Can Municipal Bonds Hedge US State-Level Climate Risks?

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## Highlights

- Negative correlation between municipal bonds and equity returns, barring extreme crises.
- Climate risks generally strengthen the negative stock-bond correlation.
- Extreme climate disasters can make the stock-bond correlation positive.
- Municipal bonds act as a hedge against climate risks.

## Abstract

Using daily data on municipal bonds and equity returns of the 50 US states over the period of 2<sup>nd</sup> May 2006 to 9<sup>th</sup> February 2024, we find, barring extreme periods of financial, macroeconomic and health crises, the underlying conditional correlation between these two assets, as derived from the Asymmetric Dynamic Conditional Correlations (ADCC)-Generalized Autoregressive Conditional Heteroskedasticity (GARCH) model is negative. Then, when we utilize the Quantile-on-Quantile (QQ) regression model to capture the effect of the quantiles of climate risks on the entire conditional distribution of the underlying time-varying stock-bond correlation, we observe a negative impact in general for alternative levels of climate risks, though the sign could possibly turn positive in event of extreme climate disasters. In sum, the role of municipal bonds as a hedge against climate risks cannot be denied, thus 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

## 1. Introduction

Theoretically speaking, climate change-related extreme weather conditions, serving as a large aggregate risk, leads to reduction in productivity and/or the increase in the stochastic depreciation rate of capital to produce adverse impact 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 tends 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, b), among others.<sup>1</sup>

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 government 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). And second, we utilize the Quantile-on-Quantile (QQ) regression approach of Sim and Zhou (2015) to analyse the (possible negative) effect of various levels (quantiles) of climate risks on the entire conditional distribution, i.e., 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 stocks and bonds returns, as well as climate risks data involving the 50 states of the United States (US), rather than looking at these two asset markets from an aggregate perspective. The rationale for doing this is because: (a) primary business activities of companies tend to be concentrated around their headquarters, which consequently, results in stock prices to reflect notable regional influences (Korniotis and Kumar, 2013). At the same time, with us considering municipal bonds, which can be thought of as investor loans made to local governments to fund public works (such as, parks, libraries, bridges and roads, and other infrastructure), the importance of a regional factor cannot be underestimated again (Painter, 2020), and; (b) 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 two points, and the fact that climate risks carry leading information for the economic conditions at the US state-level (Cepni et al., 2024), our analysis should be of immense value to investors from the perspective of portfolio diversification and risk management. Note that, the debt involving the municipal bonds are generally paid back by the municipality using tax revenue (i.e., general obligation bonds), though other sources of revenue that come from the project (i.e., revenue bonds), can also be used. For instance, in terms of the latter, a bond issued to fund the building of a parking garage could

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<sup>1</sup> 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).

then be paid back using the revenue from selling parking passes to the garage. General obligation bonds are seen as less risky because municipalities are able to raise taxes in the event that there is not enough funds to pay all debtholders, thus making municipal bond as a possible safe haven option, relative to stocks, for investors at the state-level.

To the best of our knowledge, this is the first paper to delve into the hedging capabilities of bonds in terms of climate risks for the 50 US states over the daily period of 2<sup>nd</sup> May, 2006 to 9<sup>th</sup> February, 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:  $CR_t = [std(temp_t^A) + std(prec_t^A) + std(C_t^A) - std(H_t^A) + std(wind_t^A)]/5$ .<sup>2</sup>

Based on data availability at the time of writing this paper, our analysis covers the daily period of 2<sup>nd</sup> May, 2006 to 9<sup>th</sup> 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  $I_{t-1}$ :

$$r_t = \mu + \varphi r_{t-1} + \varepsilon_t \quad (1)$$

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  $D_t = \text{diag}(h_{1,t}, \dots, h_{n,t})$  represents the diagonal conditional variances, the conditional correlation matrix  $R_t$  is given as:

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

where  $\Theta_t$  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  $\theta_1$  and  $\theta_2$  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:

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

where the indicator function  $I_{t-1} = 1$  if  $\varepsilon_{i,t-1} < 0$  otherwise function  $I_{t-1} = 0$ . In this context, the ‘‘asymmetric’’ effect is represented by a positive value for  $\gamma_i$ , indicating that positive

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<sup>2</sup> 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,  $\Theta_t$  is formulated by

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

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

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

$$y_t = \beta^\theta x_t + \varepsilon_t^\theta, \quad (5)$$

where  $\varepsilon_t^\theta$  is an error term that has a zero  $\theta$ -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  $\theta$ -quantile of  $y$  and  $\tau$ -quantile of  $x$ , denoted by  $x^\tau$ , we linearize the function  $\beta^\theta(x_t)$  by taking a first-order Taylor expansion of  $\beta^\theta(\cdot)$  around  $x^\tau$ , which yields the following:

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

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

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

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

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

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

To estimate (8), we solve for:

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

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

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

from  $\tau$ , where  $\tau$  is the value of the distribution function that related to  $x^\tau$ .

## 5. Empirical Results

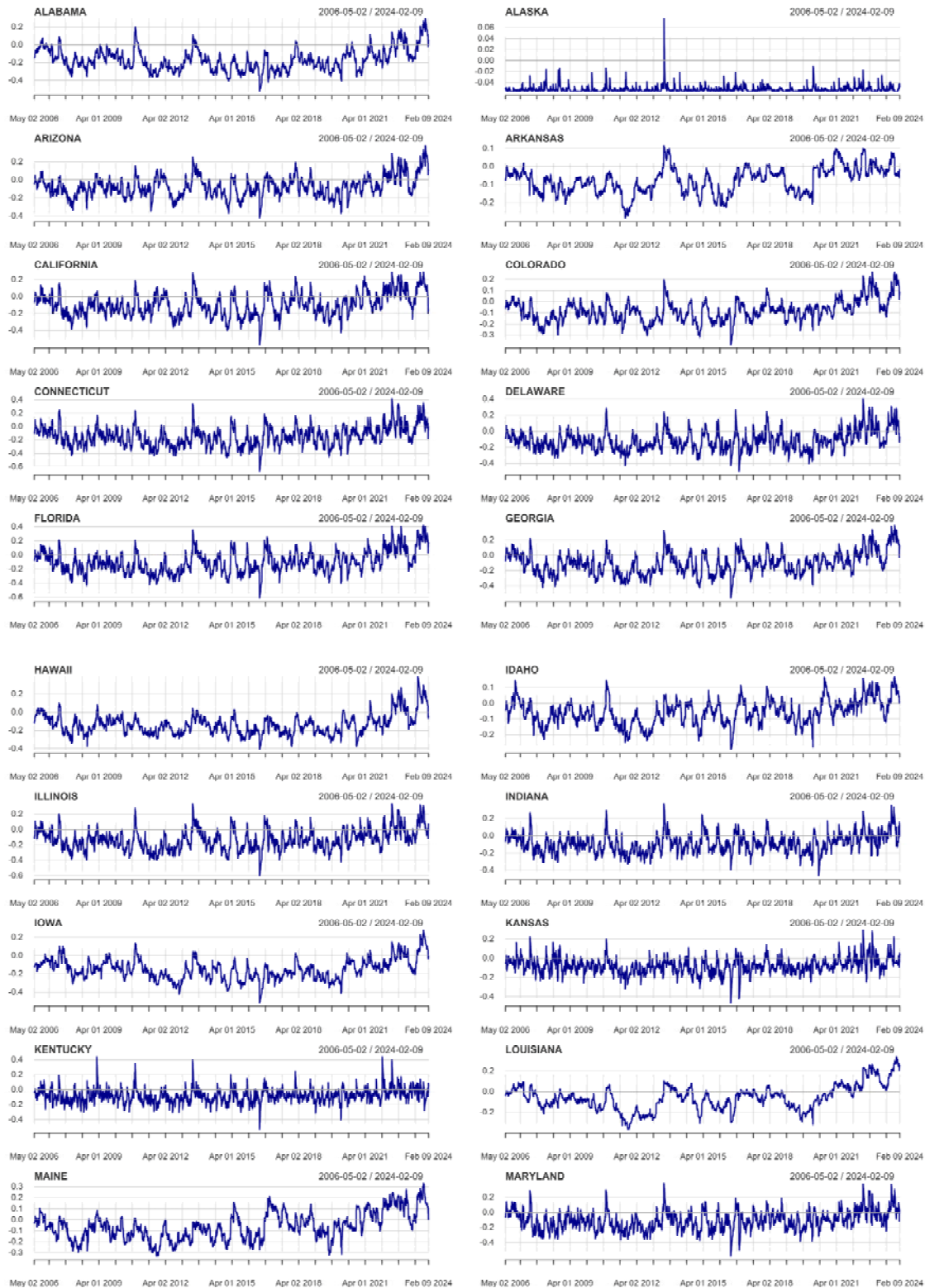
The analysis illustrated in Figure 1, derived from the ADCC model,<sup>3</sup> reveals predominantly negative trends in time-varying correlations between stock and bond log-returns, except for short-lived episodes associated with Global Financial Crisis (GFC) of 2008 and very high-levels of US debt registered in 2012, and then for relatively prolonged periods towards the end of the sample period associated with the outbreak of COVID-19, and the Federal Reserve's monetary policy tightening thereof, hence higher bond yields and lower prices, in the wake of high inflation rates following the pandemic. Interestingly, the correlation fluctuated between positive and negative territories quite a bit during 2016-2019, coinciding with the administration of President Donald J. Trump, whereby the stock markets performed quite well, albeit skittishly, due to frequent uncertainty shocks associated with unpredictable policy changes.<sup>4</sup> In general, barring periods of extreme financial, macroeconomic and health-related situations, the negative stock-bond correlation, and the fact that climate risks-related events have become a regular phenomenon in the US (Liao et al., forthcoming), one can hypothesize that municipal bonds can possibly serve as a hedge against weather-related disasters across the US states that tends to negatively impact the equity market.

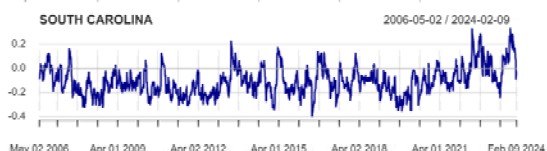
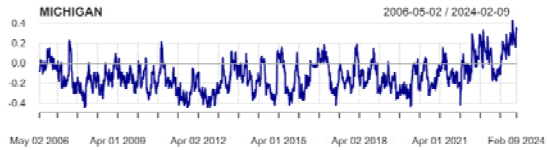
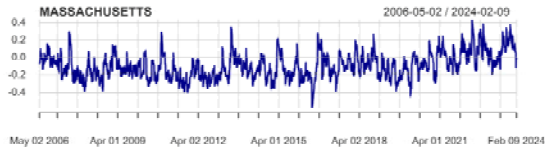
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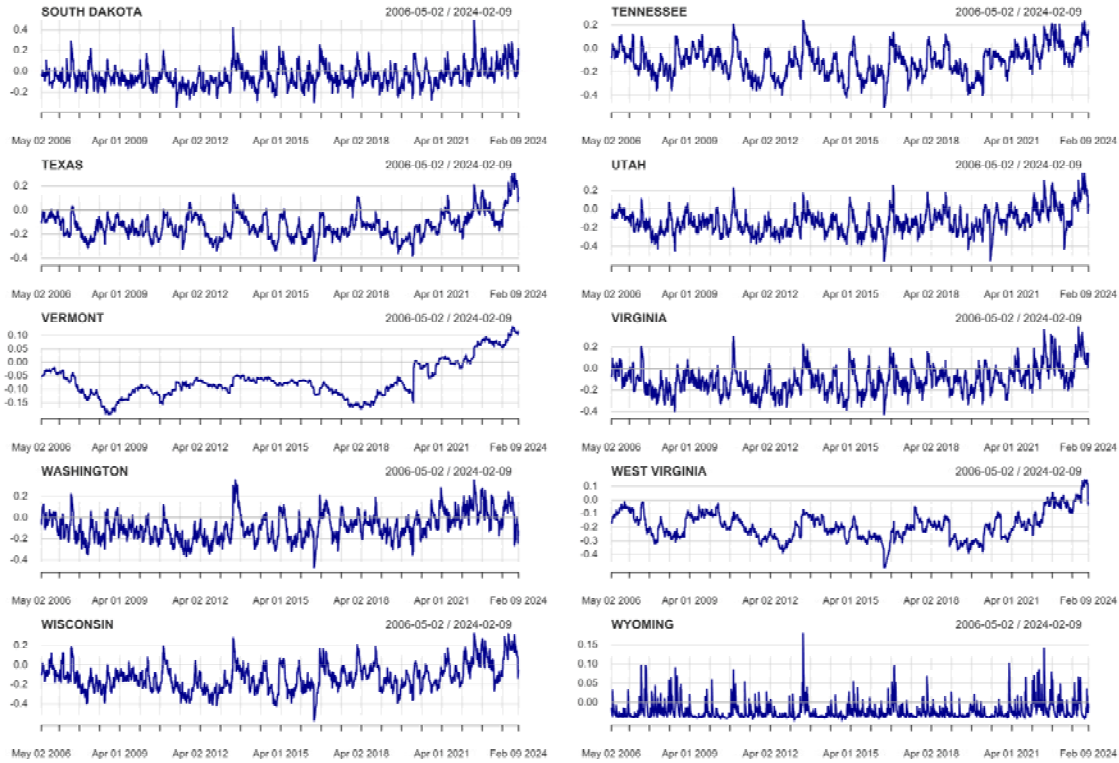
<sup>3</sup> Complete details of the parameter estimates ADCC models for the 50 US states involving stock and bond returns are available upon request from the authors.

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

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

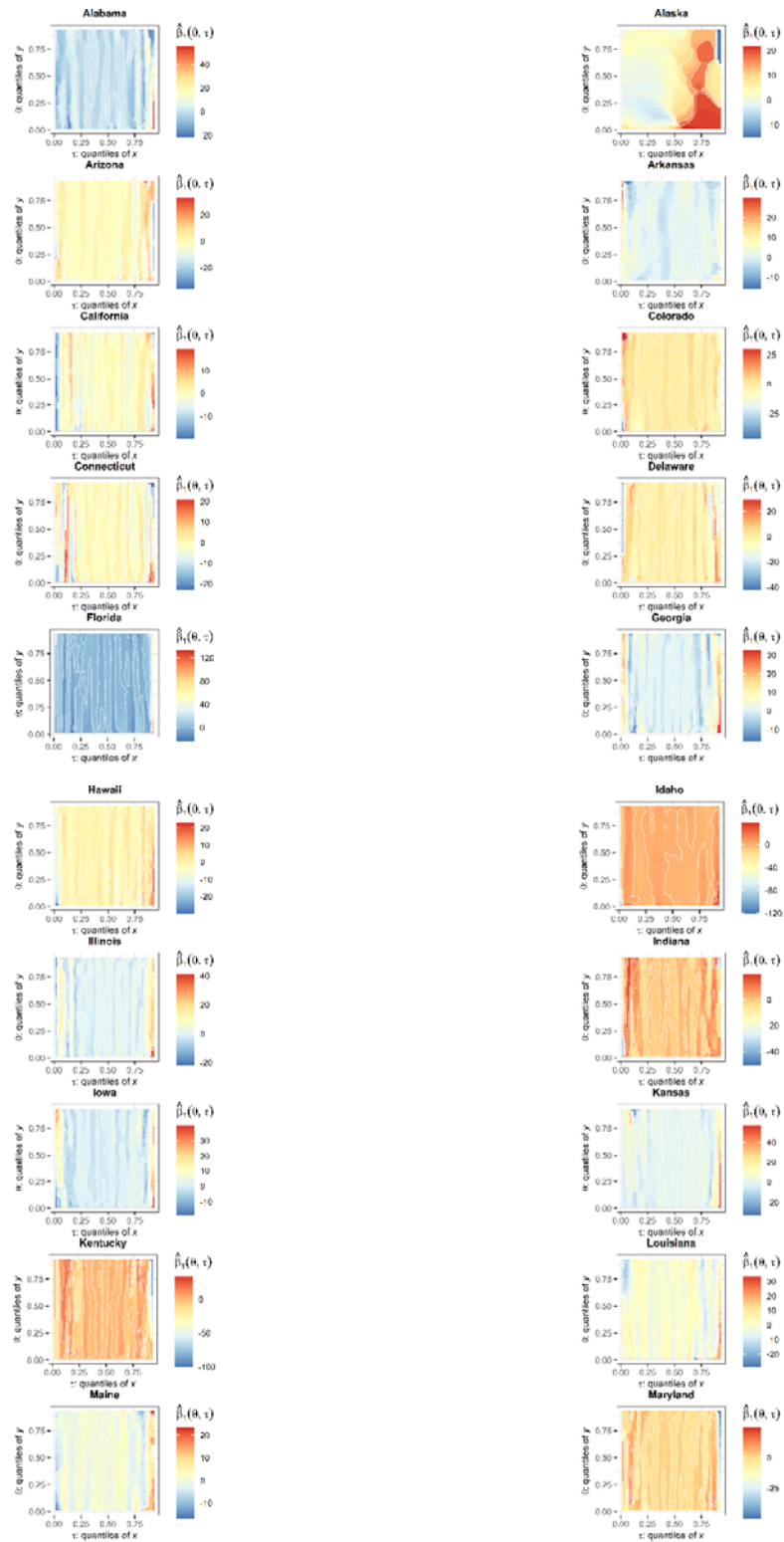


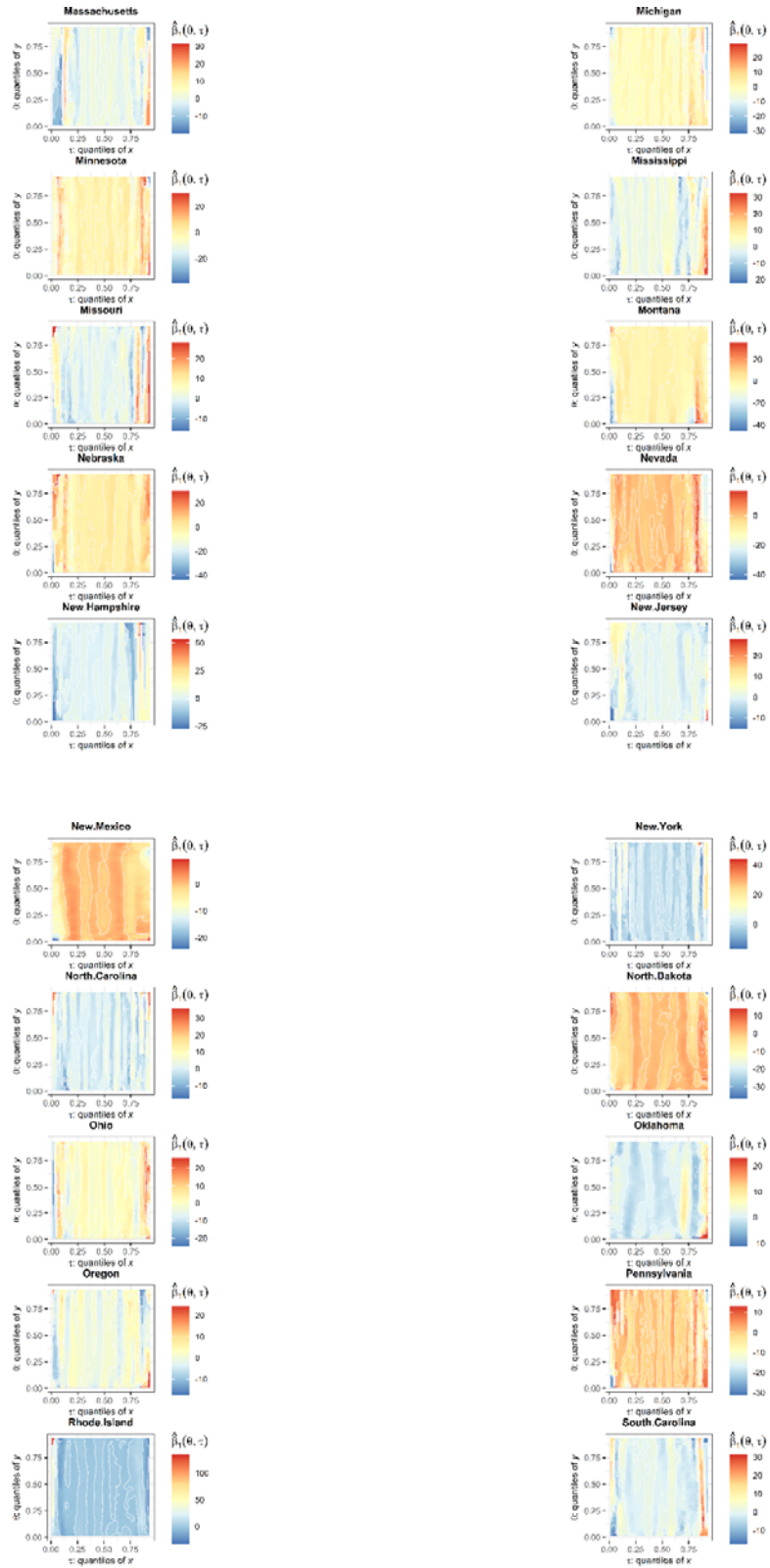


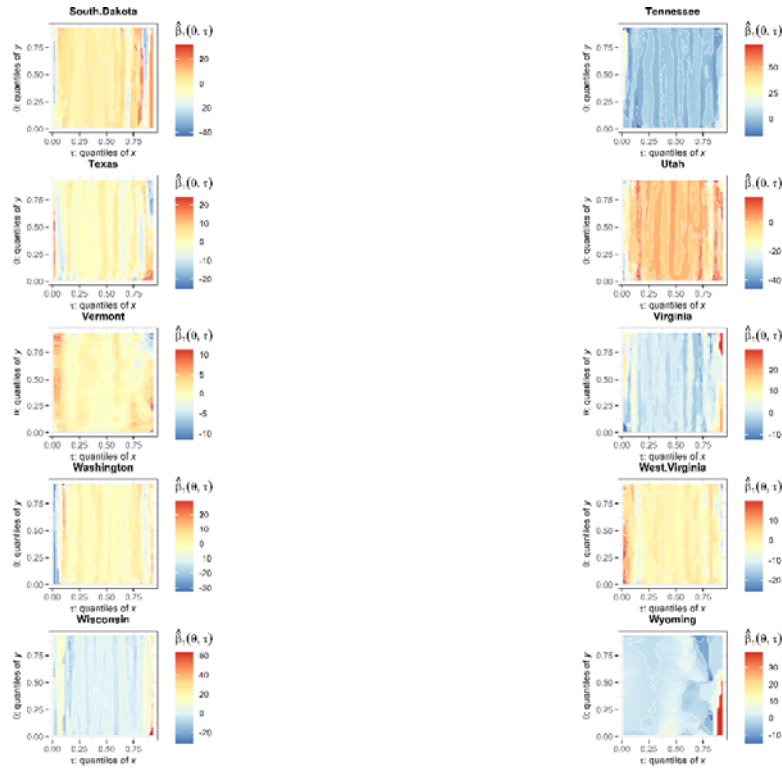


To provide convincing statistical evidence in this regard, we next turn to the QQ regression results between the conditional quantiles of the time-varying correlations of stocks and bonds returns regressed on the quantiles of climate risks. Upon reviewing the results depicted in Figure 2, we observe 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. Having said this, there are also instances when high quantiles of the climate risks are observed to be associated positively with the conditional quantiles of stock-bond correlation. This should not be surprising, since extreme climate risks are likely to impact infrastructure, and with municipal bonds funding public works, bond returns are also likely to be negatively impacted along with stock returns. In sum, we can conclude, except for large weather-related disasters, municipal bonds can indeed hedge financial risks associated with climate risks in a consistent manner.

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







## 6. Conclusion

In this paper, we analyse whether municipal bonds across the 50 US states can hedge climate risks, which are known to negatively impact corresponding regional stock market returns. In this regard, we use the ADCC-GARCH model to first recover time-varying correlations between stocks and bonds for each of the states, and then utilize QQ regressions to capture the impact of climate risks on the stock-bond nexus. We find that, barring extreme periods of financial, macroeconomic and health crises, the underlying conditional correlation between the stocks and bond returns of each of the states are negative, suggesting a general hedging role for municipal bonds. Then the QQ results confirm that varied levels of climate risks negatively impact the entire conditional distributions of the time-varying correlation, though the sign could turn positive in event of extreme climate disasters. All in all though, the role of municipal bonds as a hedge against climate risks cannot be denied. With both stocks and bonds known to be driven by regional factors which are strongly impacted by climate risks, our results have significant implications for portfolio diversification in the wake of increasing-frequency of adverse climate events.

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