Sea Level Rise and Municipal Bond Yields*

Paul Goldsmith-Pinkham† Matthew T. Gustafson‡ Ryan C. Lewis §
Michael Schwert¶

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Abstract

Using a sample of bonds issued by school districts in coastal counties, we show that municipal bond markets began pricing sea level rise (SLR) exposure following upward revisions in SLR projections in 2013. The effect is concentrated on the East Coast where SLR risk is greatest, is increasing in states' belief in climate change, and is driven largely by a district's exposure to worst-case SLR scenarios. Although statistically significant, the pricing effects are economically small and indicate that financial markets do not anticipate a high probability of SLR-induced default in the near future.

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†Yale University; paul.goldsmith-pinkham@yale.edu.
‡Pennsylvania State University; mtg15@psu.edu.
§University of Colorado; Ryan.C.Lewis@colorado.edu.
¶The Wharton School, University of Pennslyvania; schwert@wharton.upenn.edu.

1 Introduction

Since the 2007 Intergovernmental Panel on Climate Change (IPCC) report, end-of-century sea level rise (SLR) projections have increased more than fourfold, with current upper-bound SLR projections of 2.5 meters by 2100 (e.g., Stocker et al. (2013); Sweet et al. (2017); DeConto and Pollard (2016)). Should these projections manifest, coastal communities will be greatly impacted. Hauer, Evans, and Mishra (2016) finds that a 1.8 meter SLR would inundate areas currently home to six million Americans, while Rao (2017) estimates that nearly one trillion dollars of coastal residential real estate is at risk. Moreover, the systemic and location-specific nature of SLR exposure risk presents challenges to diversification.

In this paper, we use the municipal bond market to study how news of SLR risk is priced in financial markets. Three features of the municipal bond market make it an ideal laboratory to examine this question. First, as in other financial markets, municipal bond prices reflect investors' expectations of future outcomes. Second, the payoff profile of bonds makes the likelihood of large negative shocks a key driver of prices, which reflect an issuer's ability to repay the debt (i.e., by rolling it over). Third, the sources of repayment for municipal bonds are local in nature, especially so for the school district bonds that comprise our sample and are backed by taxes on local real estate.

Our empirical strategy uses local variation in municipalities' SLR exposure to estimate how municipal bond prices changed as projections for end-of-century SLR were revised upwards and the awareness of SLR risk increased. This strategy leverages two sources of variation: i) geographic heterogeneity in SLR exposure and ii) time-series variation in SLR projections and awareness. Our source of geographic variation comes from differences in SLR exposure across issuers (i.e., school districts) within the same county. This allows us to control for time-varying local economic shocks with county-year-month fixed effects. In our baseline specification, we estimate the difference in bond spreads between issuers within the same county-year-month before and after IPCC reports that adjusted forecasts of future SLR. These reports occurred in 2001, 2007 and 2013, with stable projections in the first two reports and a substantial increase in the 2013 report that coincided with a significant increase in SLR awareness (e.g., Bernstein, Gustafson, and Lewis (2018)).

Using this empirical strategy, we find no significant relation between a municipality's SLR exposure and its bond credit spreads prior to or in the years following the 2007 IPCC report when SLR projections were negligible. This suggests that after the inclusion of county-year-month fixed effects, there are no persistent differences in the spreads of SLR exposed and unexposed municipalities in the early part of our sample. We do, however, find a significant positive relation between SLR exposure and municipal bond credit spreads between 2014 and 2017. We corroborate this finding with a more flexible year-by-year analysis. We find no evidence of a significant relation between SLR exposure in any year from 2001 through 2012. However, the estimated relation between SLR exposure and yield spreads monotonically increases from 2009 through 2016 and is statistically significant in four of the last five years of our sample. The emergence of SLR exposure as a determinant of credit spreads towards the end of our sample suggests that the flurry of SLR-related scientific and news articles in 2013 and 2014 drives the relation between SLR exposure and municipal bond spreads that we observe.

Our estimates imply that a ten percentage point (approximately 1.1 standard deviations) increase in the fraction of SLR exposed properties is accompanied by a 2 basis point (bps) increase in municipal bond credit spreads after 2013. This response during the post-2013 period amounts to only 3% of the average municipal bond spread in our sample (64 bps), which suggests that bond investors do not believe there is a high probability of SLR-induced default occurring over the life of their bonds (ten years on average). Nonetheless, this magnitude is of the same order as other effects on municipal bond yields identified in the academic literature, such as the 5 bps difference in yields between states that do and do not authorize Chapter 9 bankruptcy uncovered by Gao, Lee, and Murphy (2019).

We also examine heterogeneity in the pricing of municipal bonds. We identify geographic differences in the pricing of SLR exposure by municipal bond investors. Some of this variation appears rational in the sense that it is consistent with scientific predictions regarding how regional sea levels will be affected by global sea level rise. In the U.S., seas on the East Coast have and are expected to continue rising approximately twice as fast as the seas on the West Coast. Consistent with the market understanding this distinction, the entire post-2013 increase in the sensitivity of credit spreads to SLR exposure is concentrated on the East Coast. On average, a ten percentage point increase in the number of SLR exposed properties in an East Coast school district predicts a

4 bps increase in municipal bond spreads after 2013. Long-maturity bonds of East Coast issuers exhibit a significant premium for SLR exposure as early as 2011 and short-maturity bonds begin showing price effects two years later.

Next, we examine whether the extent to which SLR exposure is priced in the municipal bond market relates to an area's beliefs regarding climate change, which Bernstein, Gustafson, and Lewis (2018) and Baldauf, Garlappi, and Yannelis (2019) find to be a significant predictor of how SLR exposure is priced in real estate markets. We measure climate change beliefs at the state level since state-level tax laws lead to segmentation in the municipal bond market (Schultz (2012)). Within East Coast markets (where SLR exposure is priced), the post-2013 increase in the price effect of SLR exposure is substantially higher in states that are more worried about the expected impact of climate change. Thus, heterogeneity in investor beliefs across markets is a significant determinant of how climate risks manifest in bond prices.

In our final set of tests, we replicate our main analysis with a more flexible measure of SLR projections based directly on individual scientific studies during our sample period. This provides a continuous measure of SLR projections over the sample period and allows us to examine whether average or worst-case SLR scenarios are more important to municipal bond investors. Given the extremely low historical default rate of municipal bonds (Schwert (2017)), it is natural to think that catastrophic climate outcomes will be necessary to induce default. In separate regressions, measures of SLR exposure based on both average and worst-case projections are associated with higher credit spreads. When both measures are considered in the same model, we find that the right tail of the SLR forecast distribution drives the positive effect on spreads.

Taken together, our findings provide evidence on how the financial markets view the sharp rise in expected SLR that has occurred over the past decade. SLR exposure risk has emerged as an increasingly important determinant of municipal bond prices over this period. Intuitive cross-sectional and time-series patterns in the relation between SLR exposure and bond yields lend credence to the idea that our empirical strategy is precisely identifying SLR exposure as a new consideration among municipal bond investors.

Our findings contribute to the emerging literature on the financial implications of climate risk. Environmental risks have been linked to the valuation of firms (e.g., Bansal, Kiku, and Ochoa (2017), Berkman, Jona, and Soderstrom (2019), Hong, Li, and Xu (2019)) and their cost of capital (e.g., Sharfman and Fernando (2008), Chava (2014)), as well as their operating performance (e.g., Barrot and Sauvagnat (2016), Addoum, Ng, and Ortiz Bobea (2019)) and financial policies (e.g., Dessaint and Matray (2017)). With respect to capital supply, research has shown that climate risk affects the allocation of credit by banks (e.g., Cortés and Strahan (2017), Brown, Gustafson, and Ivanov (2019)) and the beliefs of institutional investors (Krueger, Sautner, and Starks (2018)). Giglio, Maggiori, and Stroebel (2014) and Giglio et al. (2015) show that low discount rates should be used to discount the long-run risks of climate change. We build on this body of work by showing that the cost of debt financing depends on location-specific exposure to climate risk.

Our paper is closely related to Painter (2018), who also studies the relation between climate change-induced flood risk and the cost of municipal financing. Specifically, Painter (2018) compares the cost of issuing municipal bonds in metropolitan areas shown to be exposed to future flood risk (according to Hallegatte et al. (2013)) to other bonds issued during the same state-year and finds a positive relation between flood exposure and municipal bond issuance fees and initial yields. In addition to our analyses of geographic and belief-based heterogeneity, our findings differ in two important ways. First, consistent with evidence in Bernstein, Gustafson, and Lewis (2018) and Baldauf, Garlappi, and Yannelis (2019) that long-run SLR risk already impacts the coastal property values that underlie municipal debt, we find that the credit spreads of both the short- and long-maturity bonds are affected by SLR exposure in the period after the 2013 IPCC release.[1] In contrast, Painter (2018) finds no effect of SLR exposure on short-term bonds. Second, we find no evidence of SLR exposure being priced prior to 2011, whereas Painter (2018) finds pricing effects beginning in October 2006.

Differences in our empirical approach may explain the incongruity of our findings. Crucially, we measure SLR exposure at the school district level, which allows us to plausibly disentangle the effect of underlying economic conditions from the effect of SLR exposure on municipal bond credit spreads by comparing the spreads of school districts' bonds within the same county and month. We find that the inclusion of county-year-month fixed effects significantly changes the estimated relation between SLR exposure and municipal bond spreads. In contrast, Painter (2018) compares the costs of initial bond offerings within a state-year, using a measure of climate risk

[1] Murfin and Spiegel (2019) find no significant relation between relative SLR (i.e., the difference between SLR and local elevation changes) and real estate prices.

that is only observed for coastal metropolitan counties. This measure has two drawbacks: there is substantial noise in this measure (e.g., Galveston, TX is grouped with the Houston metropolitan area), and the comparison group for exposed counties includes both non-metro coastal counties and non-coastal counties. These estimates of the effect of climate risks on municipal bonds may include non-climate-induced factors if the treatment and control areas are differentially impacted by economic shocks, such as the financial crisis and recession that occurred shortly after the 2007 IPCC release. Another difference between our empirical methods is that we focus on secondary market transactions, whereas Painter (2018) examines initial fees and yields. Our analysis of secondary market transactions, which involve bonds that were issued months or years ago, is less subject to selection bias related to the effect of SLR projections on the type, amount, or timing of capital that municipalities raise.

Although we do not take a stand in the scientific debate on sea level rise, our findings have the potential to extend and contribute to this debate in several ways. First, although investors are almost certainly less informed than scientists about climate risk, markets are a useful tool for aggregating opinions. Investors are trained to think in terms of probability distributions, as opposed to dichotomous beliefs, so financial market prices should reflect the marginal investors' beliefs regarding the probabilities of various future states. Second, unlike scientific opinions regarding climate change, our estimates embed investors' expectations regarding economic costs, which implicitly address both how much seas will rise and how costly SLR will be. Finally, whether or not investors are correct in these estimates, the manner in which markets are pricing SLR exposure is important from a policy perspective because it represents potential value that can be unlocked as SLR remediation efforts are undertaken.

The remainder of the paper is organized as follows. Section 2 surveys the scientific debate on sea level rise. Section 3 describes the sample of municipal bonds and our identification strategy. Section 4 discusses the empirical results on expected SLR exposure and municipal bond yields. Section 5 extends our analysis to consider cross-sectional dispersion in scientific projections regarding SLR. Section 6 concludes.

2 The Threat of Sea Level Rise

The extent to which sea level rise represents a material and immediate threat to U.S. coastal communities is an increasingly important and hotly debated policy question. On one hand, when addressing the United Nations in 2009, President Barack Obama called climate change an urgent and growing threat and said that rising seas are threatening every coastline ((Obama, 2009)). On the other hand, President Donald Trump has described climate change as a hoax created to make U.S. manufacturing non-competitive (e.g., (Merica, 2017)), and removed the United States from the Paris Agreement to fight climate change.

This disagreement among politicians is mirrored in the scientific community, where there is substantial debate regarding how high and fast seas will rise over the next century. It is widely recognized that the 20th century saw seas rise by 1-2 millimeters per year, with some areas such as the eastern U.S. experiencing significantly more SLR than others. Disagreement arises when translating these past trends into projections of the future. For their 2007 report, the IPCC considered a variety of emissions scenarios and concluded that seas were likely to rise by between 0.18 and 0.59 meters by 2100. Around the same time, Church and White (2006) reported that extrapolating the current rate of SLR acceleration through the year 2100 would result in approximately 0.3 meters of SLR. Since 2007, opinions on end-of-century SLR have diverged substantially, in large part due to the consideration of new environmental factors that substantially increased upper-bound estimates. Many scientists predict negligible SLR this century (e.g., Hansen, Aagaard, and Kuijpers (2015)), but worst-case scenario SLR projections have been increasing.

Over a period covering the second half of 2013 and the first half of 2014, the IPCC released a sequence of reports that nearly doubled its likely range of end-of-century SLR projections, raising the 83rd percentile of the distribution of forecasts to 1 meter of global average SLR.[2] This report acknowledges that end-of-century SLR may fall outside this likely range and discusses additional worst-case scenarios that could lead to a substantially higher upper bound. Many of the worst-case scenarios involve different ways of modeling the melting of Antarctic ice sheets. Parris et al. (2012) examined a variety of scenarios and estimated that end-of-century global mean SLR would fall in the [0.2, 2] meter range.

[2]The 2013 IPCC report was released in stages, with the first working group report on September 30, 2013, two subsequent reports on March 31 and April 15, 2014, and a synthesis report on November 2, 2014.

Due to geographic factors, such as where ice is melting and tectonic movements that cause land to rise or sink, there is substantial regional variation around these global SLR projections. Sweet et al. (2017) adjusted the Parris et al. (2012) range of global SLR projections upward to [0.3, 2.5] meters, and found that "for almost all future global mean SLR scenarios, regional SLR is projected to be greater than the global average along the coasts of the U.S. Northeast." Krasting et al. (2016) corroborate the disproportionate exposure of the U.S. East Coast, arguing that it may be particularly vulnerable to near-future SLR from present-day greenhouse gas emission rates.

In this paper, we take a markets-based approach to aggregating opinions regarding these recent updates in SLR expectations. Municipal bond prices should reflect investors' expectations regarding future local economic conditions. Since municipal bonds are historically low-risk investments, the municipal bond market will largely price the probability of a significant economic downside, enhancing the importance of variation in upper-bound SLR projections. To the extent that market participants have changed their view regarding the probability of economic downturns in coastal economies as worst-case SLR projections have increased, we expect the relation between SLR exposure and bond yields to become more positive. This relation will particularly increase for municipalities on the U.S. East Coast if investors also internalize evidence suggesting that SLR represents a more immediate threat in these areas.

3 Sample and Empirical Methods

Our empirical analysis studies the effect of SLR exposure on school district bond credit spreads. We focus on bonds issued by school districts for two reasons. First, much of the funding for public schools in the U.S. comes from taxes on local real estate, so there is a direct economic link between school districts' ability to repay debts and the anticipated effects of SLR on property values (Bernstein, Gustafson, and Lewis (2018) and Baldauf, Garlappi, and Yannelis (2019)). Second, public education is an important use of municipal bond proceeds, amounting to 27% of new bond issues and 14% of the dollar amount issued from 2001 to 2017, so we are able to construct a large sample of school district bonds.[3]

Municipal bond yields are drawn from the intersection of the Mergent Municipal Bond Terms and Conditions database and historical transaction price data from the Municipal Securities Rule-

[3] Cestau et al. (2017) also focus on school bonds in their study on the costs of negotiated underwriting.

making Board (MSRB). We select school district bonds from these data by screening on primary and secondary education as the use of proceeds. Following past literature (Schwert (2017)), we restrict attention to fixed-coupon tax-exempt bonds that trade at least ten times, to ensure uniformity and a minimum level of liquidity. Additionally, we exclude the first three months after issuance and the last year before maturity because these are times when yields are especially noisy (Green, Hollifield, and Schurhoff (2007)).

We use the Municipal Market Advisors AAA-rated curve ("MMA curve") as a tax-exempt benchmark for the municipal bond credit spread calculation. This curve is available on Bloomberg from 2001 onward, so our sample spans 2001 to 2017. Using the transaction-level data from the MSRB, we construct a monthly panel of volume-weighted yields at the bond level and compute credit spreads as the difference between these yields and the maturity-matched yields from the MMA curve. Our results are qualitatively similar using unadjusted municipal bond yields.

We then restrict the sample to coastal counties. To determine the SLR exposure for each school district issuer within coastal counties, we identify the underlying geography for each school district. Using this geography, we can identify and link it to the expected SLR measures from Bernstein, Gustafson, and Lewis (2018). In order to identify the underlying school districts for each bond issuer, we link the bond issuers names to school district names.[4]

After merging with the data on SLR exposure, our final sample consists of 559,579 bond-month observations of 59,661 bonds from 1,525 school district issuers. Appendix Table A1 shows the sample breakdown by year. The number of observations grows between 2001 and 2009, leveling off from 2009 onward at between 36,000 and 46,000 bond-month observations per year. Appendix Table A2 presents a similar breakdown with respect to the issuing municipality's state. There are 19 states in our sample, but the observation count is skewed towards more populous states, with California, Texas, New Jersey, and New York accounting for 83% of the bond-month observations and nearly three-quarters of the school districts. To ensure that the distribution of observation across states is not driving our results, we replicate our main results using weighted regressions in which each state is equally represented.

[4]This name matching proceeds in multiple steps. First, we clean and make consistent state names and common abbreviations. We then remove all exact matches, and with the remaining issuers, we remove stop words (e.g. "vocational", "technical" and "elementary") and match issuers and names using these stripped down names. We match remaining issuers by hand when we deem the names a close enough match and exclude observations we cannot match. Code for linking the districts and issuers is available upon request.

To identify the relation between an area's SLR exposure and its municipal bond yields, we regress the yields implied by secondary market municipal bond transactions on a variable measuring the percentage of residential properties within a school district that would be inundated by a six foot SLR, which is approximately the upper-bound projection for end-of-century SLR. As we discuss and report in the Appendix, our findings are qualitatively similar using the percentage of residential properties within a school district that would be inundated by a three foot SLR as the explanatory variable of interest. Our findings are also similar using measures of the percentage of property value that is exposed to SLR.

To construct the percent exposed measure we obtain property-level data from the real estate assessor and transaction datasets in the Zillow Transaction and Assessment Dataset (ZTRAX). We then determine each property's SLR exposure using the NOAA SLR viewer (Marcy et al. (2011)). Importantly, we use the NOAA's SLR calculator, which accounts for the fact that tidal variation and other coastal geographic factors affect the impact of global oceanic volume increases on local SLR.[5] SLR exposure is highly skewed, even in our sample, which is restricted to counties near the coast. Most school districts in our sample do not have any SLR exposed properties. The 75th, 90th, and 95th percentiles of Pct. Exposed are approximately 1%, 10%, and 20%, respectively.

Table 1 summarizes the variables used in our analysis. In total, we have 559,579 bond-month observations in oastal counties, of which 257,411 are issued by school districts that will experience at least some chronic inundation after six feet of global average sea level rise. On average, 7% of properties are exposed at the the six foot level in these districts. The average municipal bond-month observation in our sample has a yield of 3.33%, which is 64 bps over the AAA-rated benchmark curve. It has ten years to maturity, has aged four years since issuance, and has $509,540 monthly trading volume (conditional on non-zero trade). We find little unconditional difference in these characteristics between the exposed and full sample. Housing prices are about 7% higher in exposed districts and dollar bond volumes are about 20% higher than in the full sample. After winsorizing at the 1% level, municipal bond credit spreads range from -24 bps to 243 bps relative to the MMA benchmark. The dispersion in spreads is narrow relative to other credit markets (e.g., corporate bonds) because of the extremely low historical default rate (Schwert (2017)).

The empirical question that we examine is when or if municipal bond markets begin pricing

[5] See Bernstein, Gustafson, and Lewis (2018) for more details regarding this SLR exposure definition.

SLR exposure. Although we incorporate time-series variation in SLR projections in a variety of ways throughout our analysis, we begin with a baseline specification that has three distinct periods punctuated by IPCC releases: 2001-2007, 2007-2013, and post-2013. If markets respond to the substantial increase in the IPCC's projections at the end of 2013, but not to the IPCC's affirmation of low SLR risk in 2007, then SLR should have a positive impact on bond credit spreads after the 2013 release but should have a negligible impact on spreads before then. To test this hypothesis, we estimate the following specification:

$$\begin{aligned} \text{Bond Yield}_{ijkt} = c_{jkt} + \alpha_1 \text{Pct. Exposed}_{ij} + \alpha_2 \big(\text{Post-2006} \times \text{Pct. Exposed}_{ijt}\big) \\ + \alpha_3 \big(\text{Post-2013} \times \text{Pct. Exposed}_{ijt}\big) + \beta X_{ijt} + \epsilon_{ijkt}, \end{aligned} \tag{1}$$

for a bond issued by school district i, located in county j, of bond type k, trading in year-month t. The explanatory variables of interest are the interaction between the indicators for the post-2006 and post-2013 periods and Pct. Exposed, where Pct. Exposed is the percentage of properties within school district i that would be inundated with a six foot rise in sea levels. Importantly, the post-2013 interaction measures the incremental increase in the effect of the Pct. Exposed variable in the post-2013 period relative to the interim period between 2007 and 2013.

We mitigate the possibility that SLR exposure relates to unobserved aspects of the area's economy in two ways. First, we include county-year-month-bond type fixed effects throughout our analyses, such that we identify the effect of SLR exposure on bond yields by comparing the yields on similar bonds from different school districts within the same county, traded in the same month.[6] Second, we exploit the fact that SLR projections and awareness have significantly increased over the 2001 to 2017 sample period by focusing on intertemporal variation in the relation between SLR exposure and municipal bond yields. To the extent that a relation between SLR exposure and municipal bond yields emerges or increases as SLR projections become more dire and salient, it is unlikely that the relation we observe is driven non-SLR related factors.

In addition to county-year-month fixed effects, our empirical specifications include a variety

[6] School districts issue various types of bonds that differ in their sources of repayment. These type include general obligation (limited and unlimited), lease/rent, sales/excise tax, special tax, and revenue bonds. Most variation in these types is across states (e.g., Florida has a high proportion of lease/rent bonds) and is absorbed by our geographic fixed effects. Nevertheless, we interact all of our fixed effects with bond type to ensure differences in security design are not driving our results.

of bond-month-level control variables that have been shown to predict yields. We allow these control variables to have different coefficients before and after each IPCC report, although results are similar without this added flexibility. We control for a bond's time to maturity, coupon, age, the natural log of its monthly volume, and the standard deviation of its price. We also control for the log value of homes in the school district to disentangle the contemporaneous effect of reduced property values (Bernstein, Gustafson, and Lewis (2018)) from the future risks associated with SLR.

We also consider a more flexible analysis of the municipal bond pricing of SLR exposure over time by replacing the Post-2006 and Post-2013 variables with year-by-year coefficients on SLR exposure:

$$\text{Bond Yield}_{ijkt} = c_{jkt} + \sum_{s=2001}^{2017} \alpha_s \text{Pct. Exposed}_{ij} + \beta X_{ijt} + \epsilon_{ijkt}. \tag{2}$$

We then report the α_s's (and their corresponding confidence intervals) graphically to highlight the change in the effect of Pct. Exposed. One benefit to this approach is that it is completely agnostic as to when scientific opinions are updated, letting the data show when SLR exposure begins to be priced. In Section 5, we introduce another way of exploiting time-series variation in projected SLR exposure that relies directly on the release of scientific studies over time.

Finally, we consider a traditional event study analysis around the spike in Google searches for "sea level rise" in May 2014, which followed the release of a series of IPCC reports that increased SLR projections (see Figure A1). This approach is limited by the low trading volume in the municipal bond market, which is largely populated by retail investors who follow a buy-and-hold strategy. We report this analysis, which finds an insignificant effect of SLR exposure on returns and a positive effect on trading volume around the revision in SLR projections, in Appendix Table A3.

4 Empirical Results

Table 2 presents estimates of how SLR exposure relates to municipal bond credit spreads throughout our 2001 to 2017 sample period. In our baseline specification, we examine the interactions between SLR exposure and the three periods in our sample separated by two IPCC releases: the pre-2007 period, the 2007-2013 interim period, and the post-2013 period. The interaction between the Post-2006 dummy and Pct. Exposed estimates the change in the sensitivity of credit spreads to SLR exposure in the interim period, while the interaction between the Post-2013 dummy and Pct. Exposed estimates the increase in the sensitivity of spreads to SLR exposure after 2013 relative to the interim period. The sum of these interaction coefficients is the estimated total change over the pre-2007 and post-2013 periods relative to the pre-2007 period.

Across Columns 1 through 4, we incrementally add controls to the specification, including our bond-level controls, year-month-bond type fixed effects, and county fixed effects. We find no evidence of a consistent significant relation between SLR exposure and municipal bond credit spreads. An important limitation to these analyses is that they do little to control for the time-varying local economic conditions. For instance, these estimates are confounded by the effects of the 2007-2009 recession to the extent that it differentially affected SLR exposed areas.

In Column 5, we address this issue and control for time-varying local economic conditions by interacting the year-month-bond type fixed effects with county fixed effects. Here, we identify the percent exposed coefficient from differences in credit spreads on bond trades that occur in the same month and represent bonds issued from school districts in the same county. The identifying variation is that the bonds differ in school district-level SLR exposure. With these location-time fixed effects, a consistent pattern emerges. Municipal bond credit spreads have become significantly more positively related to SLR exposure since the 2013 IPCC release. The coefficient of 17.8 in Column 5 suggests that since the beginning of 2014, a ten percentage point (or approximately 1.1 standard deviation) increase in the number of SLR exposed properties within a school district is accompanied by a 1.8 bps increase in municipal bond credit spreads, compared to the period between 2007 and 2013. When compared to the statistically insignificant increase that occurred after the 2007 IPCC release, when SLR projections were held steady, we see that the overall post-2013 effect is approximately three times larger than the change in sensitivity from before 2007 to the 2007-2013 interim period.

Column 6 shows that our results are qualitatively similar after reweighting the sample so that each of the 19 coastal states in our sample are equally represented. Appendix Table A4 also presents similar patterns measuring SLR exposure as the percentage of properties that would be inundated in response to a three-foot global sea level rise (as opposed to the six-foot threshold used in our primary measure). Unreported analyses further corroborate this evidence measuring SLR exposure as the percentage of property value (as opposed to the number of properties) that would be inundated with a six-foot SLR.

Panel A of Figure 1 reports the year-by-year estimates effect of SLR exposure on municipal bond spreads in our sample period. The last three years of our sample period exhibit the three largest and the only three positively significant estimates of the relation between SLR exposure and municipal bond spreads. Moreover, there is no evidence of any increased relation between SLR exposure and bond spreads around the 2007 IPCC release. This result contrasts with the evidence in Painter (2018) indicating that the municipal bond market was pricing SLR beginning in October 2006.

We next examine the empirical question of whether the pricing of SLR exposure risk depends on the bond's maturity. If market participants view SLR exposure as a long-term risk, the long-maturity bonds may be more affected. On the other hand, since municipal bonds are largely supported by taxes on the value of local property, which should incorporate expectations of future outcomes, even short-maturity bonds may be affected. For example, Bernstein, Gustafson, and Lewis (2018) find that SLR exposed coastal real estate already trades at a 7% discount relative to observably similar unexposed properties, which suggests that it may become increasingly difficult to role over short-term debt that is based on the value of coastal economies.

Panel A of Figure 2 examines when the market began to price SLR exposure for long- and short-maturity bonds, where we split maturity on bonds with maturity length longer than ten years. The figure provides little conclusive evidence of differential pricing for long- and short-maturity bonds. Few of the annual estimates are statistically significant and both long- and short-maturity bonds appear to track the full sample trends in Figure 1. Taken together, there is mixed support at best for the idea that the municipal bond markets are pricing SLR exposure more in longer maturity bond markets.

The main takeaway thus far is that municipal bond markets began pricing SLR exposure around the time of the 2013 IPCC release. This timing also coincides with substantial increases in scientific and media attention to SLR. In addition to the IPCC report that doubled the projection for SLR over the next century, between 2013 and 2015 Rohling et al. (2013), Hinkel et al. (2015), and Grinsted et al. (2015) all validated the upper-bound SLR projections established by Parris et al.

(2012) and dramatically increased the lower bound. Moreover, the potential for glacial collapse in Antarctica became a topic of conversation in the popular press in May 2014. Bernstein, Gustafson, and Lewis (2018) show that this sequence of events was accompanied by a spike Google trends search intensity, peaking in May 2014 (see Appendix Figure A1).

The above result indicates that municipal bond investors do factor SLR expectations into their investment decisions. However, the relatively small magnitude of the effect suggests that bond investors believe the probability of a catastrophic event occurring over the life of their bond is relatively small. Consistent with SLR exposure not being a first-order determinant of the cost of municipal debt during our sample period, we find no significant relation between SLR exposure and the quantity of municipal debt a school district issues.

4.1 Regional Heterogeneity

We next examine whether there is heterogeneity across regions of the U.S. in how municipal bond markets price SLR, focusing on effects in the period after the 2013 IPCC report. Such heterogeneity may arise from multiple sources. First, there is substantial variation in historical SLR across the United States, which Piecuch et al. (2018) argue is primarily due to geological processes that will persist for centuries. According to NOAA data, East Coast sea levels have been rising by between approximately 2 mm/year (e.g., in Maine) and over 4.5 mm/year (e.g., in Virginia), which is approximately twice as fast as seas have risen on the West Coast.[7] Second, state perceptions about the dangers posed by climate change vary dramatically across the United States, which may impact the beliefs of the marginal municipal bond investor. Finally, areas with more vulnerable property tax bases may view the risk of SLR exposure risk differently than economically prosperous areas.

In Table 3, we investigate the extent to which the effect of SLR on bond spreads varies across to geographic regions. Columns 1 and 2 restrict the sample to the East Coast, Columns 3 and 4 to the Gulf Coast, and Columns 5 and 6 to the West Coast. Using either the unweighted or state-weighted regression specifications, we find that the East Coast markets price in a yield premium for SLR exposure after 2013. The magnitude of the premium is approximately twice as large as the full sample estimates presented in Table 2, with a ten percentage point increase in the number of SLR exposed properties accompanied by a 4.3 bps increase in municipal bond credit spreads,

[7] See the NOAA's sea level trends data at https://tidesandcurrents.noaa.gov/sltrends/sltrends.html.

compared to the period before 2013. We find statistically insignificant and economically small positive estimates for states on the Gulf Coast and find no evidence that West Coast markets price the risk of sea level rise after 2013.

Panel B of Figure 1 reports the year-by-year estimates of SLR exposure on the municipal bond spreads over our sample period for states on the East Coast. Similar to the full sample, the last years in the sample indicate significant effects of SLR exposure on the bond spreads, with limited pre-2013 effects. The coefficients between 2001 and 2009 exhibit no particular pattern, oscillating between small, statistically insignificant positive and negative estimates. The coefficients between 2009 and 2012 remain statistically insignificant but start a trend of monotonically increasing coefficients that continues through 2016. The coefficient becomes statistically significant after the increase in SLR projections and media attention in 2013. By 2016, the estimated effect is a 5 bps increase in credit spreads for a ten percentage point increase in the number of exposed properties in a district. This pattern is consistent with the East Coast municipal bond markets incorporating news about SLR exposure risk into bond prices around the time that such news was released.

In Panel B of Figure 2 we examine whether East Coast markets price SLR exposure differently in long- and short-maturity bonds. The triangle markers, which denote the Pct. Exposed coefficient each year for the subsample of bonds with over ten years to maturity, reveal that long-maturity bonds priced SLR exposure risk slightly earlier than short-maturity bonds, which are marked by circles. However, we find little evidence that the municipal bond market is incorporating greater effects of SLR exposure at longer maturities, with the short- and long-maturity subsamples exhibiting effects of similar magnitude and statistical significance.

Next, we explore the role of regional beliefs in determining how SLR exposure is priced in the municipal bond markets. Bernstein, Gustafson, and Lewis (2018) and Baldauf, Garlappi, and Yannelis (2019) both find that climate change beliefs affect how real estate markets price SLR exposure. It is reasonable to expect that local beliefs will also matter for municipal bond pricing because buyers are often local retail investors, due to tax advantages of in-state ownership. To measure an area's beliefs about climate change we merge our data with the Yale Climate Opinions map data (Howe et al. (2015)). Specifically, we aggregate 2014 county-level survey data on responses to the question "worried about global warming" to the state-level (on an equal-weighted basis by school district). To form our State Worry measure, we then subtract the average state's level of worry and divide by the standard deviation, resulting in a standardized measure that ranges from -2.39 to 0.87.[8]

In Table 4 we augment the specification from equation (1) by adding the Post × Pct. Exposed × State Worry triple interaction (along with interactions between State Worry and both Post and Pct. Exposed). In Columns 1 and 2, we report the effect for the full sample again, with Column 1 reporting the main full regression, and Column 2 equal-weighting states. We continue to see the strong positive effect of SLR exposure on yields post-2013, but there is no significant effect of state worry on the SLR exposure premium over the full sample.

In Columns 3 and 4, we repeat Columns 1 and 2, but focus on the East Coast portion of the sample. Here, we continue to find strong positive effects of SLR exposure on yields after 2013, but no significant effect before then. We also estimate a positive and statistically significant triple interaction, which indicates that on the East Coast (where SLR exposure is being actively priced) there is a positive relation between how municipal bond markets price SLR exposure and the reported level of concern over global warming in the state. As a point of comparison, for those states that are completely unconcerned about global warming (roughly -2.39 in our measure), the effect of Pct. Exposed would be zero, while for those states with high levels of worry (0.87), the effect would be 48% higher than for the average state. This suggests that local beliefs about sea level rise materially affect the price response of bond spreads to the updated SLR projections in 2014.

In our last test of regional heterogeneity, we examine whether the SLR exposure spread premium that emerged since 2013 relates to an area's population growth rate. The motivation for this analysis is that school district bonds are typically backed by an area's property taxes, making population growth an indicator for the assets that finance bond repayment and the ease with which debt can be rolled over. Table 5 is identical to Table 4 except that we interact the Post × Pct. Exposed interaction with population growth instead of worry about climate change. We measure population growth at the county-level from 2008 through 2013. We standardize the measure by subtracting the sample-wide average and dividing by the standard deviation.[9]

[8]An area's beliefs regarding the expected impact of climate change are negatively correlated with an area's projected level of SLR.

[9]We find qualitatively similar results if we measure population growth over a shorter period or use an indicator for above-median growth.

The results in Table 5 show that the price effects of SLR exposure are concentrated in areas with below average population growth. Columns 1 and 2 provide mixed evidence as to whether an area with average population growth exhibits a post-2013 SLR exposure spread premium over the full sample. The Post × Pct. Exposed is insignificant in Column 1 and a significant estimate of 0.21 in Column 2. Both columns, however, indicate that the SLR exposure spread premium is larger in areas with weaker population growth.

Columns 3 and 4 present results to a similar analysis using the East Coast sample. Notably, the mean standardized population growth within the East Coast sample is -0.47. Inserting this average into the estimates in Column 3 indicates that an East Coast county with average population growth exhibits an approximately 3.5 bps increase in spreads after 2013 in response to a ten percentage point increase in SLR exposed properties.

Taken together, the heterogeneity that we document in the emerging SLR exposure spread premium provides important insights as to where value can be created from SLR abatement initiatives. Our findings indicate that municipalities and investors in the bonds of municipalities that are on the East Coast may benefit today from SLR mitigation strategies. This is especially likely in areas that are concerned about climate change or are declining in population.

5 SLR Projections and Disaster Risk

In our motivation, we discussed the idea that the payoff structure of municipal bonds makes catastrophic risks the most relevant risk to municipal bond investors. In this section, we test this hypothesis by introducing a more granular measure of SLR projections. By relying more directly on scientific projections, we can measure an average and a worst-case projection at any given point in time, which we then use to gauge which scenario matters more for the response of credit spreads.

5.1 The Evolution of SLR Projections

To quantify the evolution of scientific SLR projections we use information provided in Garner et al. (2018) to construct a panel of scientific papers that project global average sea level rise into 2100. Their paper highlights a total of 73 different reports from which we select a consistent sample.

The predictions of these reports vary according to the data and models used, but a few things remain consistent across them. First, most studies model their SLR projections based on agreed-upon emissions scenarios. However, these agreed-upon scenarios change in 2012 with the release of Representative Carbon Pathways. In order to standardize our analysis, before 2012 we examine A2 (high) and B1 (medium) emissions scenarios and, after 2012 we focus on the RCP8.5 (high) and RCP4.5 (medium) scenarios. Since the emissions pathways of A2 are similar to that of RCP8.5, and the emissions pathways of B1 are similar to RCP4.5, focusing on these models provides continuity from before to after the RCP standardization.

We then narrow the universe of reports by imposing the following criteria:

1. We require that the study be semi-empirical, probabilistic, or part of the IPCC or NOAA analysis papers. These methods have become the state-of-the-art in the 21st century and allow for a consistent comparison group.

2. We require that the study explores both medium and high emissions scenarios (e.g., A2 and B1 or RCP8.5 and RCP 4.5)

3. The study must have sufficient information to calculate the mean and variance of global average SLR at the end of the century.

4. We exclude any studies that impose explicit constraints on projection variables or utilize non-standard temperature projections.

We are left with 22 studies released between 2001 and 2017. To construct a time series which maps the evolution of SLR projections, we must make assumptions on how long a particular study is considered relevant. In some cases, researchers update their analysis, so we simply use their latest report. For instance, when the IPCC releases its 2007 report, the 2001 report becomes obsolete. Other reports appear only once in our sample, in which case we treat a report as relevant for five years after the publication date. Finally, we equally weight across studies and scenarios to identify the average prediction and confidence bounds for each year from 2001 to 2017.[10]

[10] Appendix Table A5 provides details on how we translate the results of each scientific study into a confidence bound for SLR projections. Most studies provide direct estimates of the probability distribution associated with their forecasts that follow an approximately normal distribution, as shown in Figure 5 of Garner et al. (2018). To compare across studies, we assume normality and use the distribution points provided by each study to determine the mean and standard deviation of its SLR forecast.

Figure 3 shows the evolution of SLR projections over our sample period. Consistent with the use of 2013 as a cutoff point, we find a significant increase in predictions beginning in 2012, which increases the 99th percentile scenario from 3 feet of SLR to over 4 feet by 2013. At around the same time, a number of studies argued that the potential for glacial collapse in Antarctica may be significantly higher than previously thought. Following these developments, Sea Level Rise became a topic of conversation in the popular press in May 2014. Bernstein, Gustafson, and Lewis (2018) show that this sequence of events was accompanied by a spike in Google searches for "sea level rise" (see Appendix Figure A1). In contrast, while there is an increase in the average SLR prediction in 2007, much of the increase comes due to an increase in the 1st percentile shifting upwards, rather than a larger rightward shift of the 99th percentile.

5.2 Price Effects of Average versus Worst-Case Projections

We use this time series of scientific projections to enrich our conclusions in several ways. First, we show that the results focused on changes in spreads around the IPCC reports are consistent with a setup that slowly adjusts expected SLR exposure as new scientific evidence enters the public domain. In this setting, we do not take a stand on the exact date when the information set of market participants changes, but instead assume that they learn gradually as climate researchers release new forecasts.

We calculate two measures of time-varying SLR exposure using the summary data provided in Figure 3. The first measure is the Pct. Exposed Mean SLR Prediction, defined as the percent of properties in a school district exposed to end-of-century sea level rise conditional on the mean prediction of SLR researchers. The second measure is Pct. Exposed 99th Pctl. SLR Prediction, defined as the percent of properties in a school district that are exposed by 2100 at the 99th percentile of SLR projections.

Table 6 reports estimates from regressions of bond spreads on these two measures, including the same controls and fixed effects as our earlier specifications. Panel A is based on the full sample and Panel B focuses on East Coast issuers. In Columns 1 and 2 of each panel, we report estimates for each of the exposure variables separately. We see a small and insignificant effect for both measures in the full sample. As with the analysis in Section 4, the effects are stronger when we focus on the East Coast, which is more exposed to SLR risk. In particular, we find that a one standard deviation (1.8%) increase in predicted exposure at using the mean scientific prediction results in a 1.4 bps increase in credit spreads, while a one standard deviation (4.5%) increase in predicted exposure at the 99th percentile of scientific projections is associated with an 1.9 bps increase in spreads. The latter estimate is quantitatively similar to the estimates in Table 2. This is perhaps unsurprising, given how closely the year-by-year spread effects in Figure 1 line up with changes in the 99th percentile predictions in Figure 3.

Next, we use the distribution of scientific forecasts to decompose the observed price effect into the effects of average exposure and the worst-case scenario. The non-linear nature of municipal bond payoffs suggest that a small shock to property values or cash flows is unlikely to meaningfully move spreads, but the possibility of disaster that wipes out a large percentage of properties may have a significant effect on spreads.

To test this hypothesis, we include in the regression both the fraction of exposed properties under the mean forecast as well as the difference in the fraction of exposed properties between the 99th percentile and mean forecasts. As before, we find weaker effects on the full sample, with insignificant coefficients in Column 3 of Panel A. However, once we weight the regression so each state receives equal consideration, the 99th percentile exposure loads significantly. Similarly, we find strong effects of 99th percentile exposure for the East Coast subsample in both the weighted and unweighted regressions. Overall, these estimates suggest that exposure to the worst-case scenario drives the pricing effects we observe in our earlier analysis.

6 Conclusion

Many argue that climate change is one of the biggest threats facing the world today. Yet, it is often challenging to quantify climate change risks, in part because they will manifest over centuries. Financial markets offer a unique opportunity to overcome this challenge for cases in which climate change risks affect current asset prices, which incorporate investors' future expectations.

We use the municipal bond market to examine the extent to which financial markets view increasing sea level rise projections as a material risk to U.S. coastal communities. Sea level rise projections have risen substantially over the past decade, culminating with a 2013 IPCC report that doubled end-of-century estimates to an upper-bound projection of two meters. Currently over $1 trillion of coastal real estate is at risk over the coming century.

Prior to 2014, we find no significant relation between sea level rise and municipal bond credit spreads. After the 2013 IPCC doubling of sea level rise projections, we find evidence that sea level rise exposure has become a statistically significant predictor of municipal bond spreads in coastal communities. The importance of sea level rise exposure in determining bond spreads is largest on the East Coast, where seas are rising faster, and in states that report high levels of belief in climate change.

Despite consistent evidence that municipal bond markets now price sea level rise exposure, the economic importance of sea level rise exposure as a driver of bond prices remains economically small. A ten percentage point (or approximately one standard deviation) increase in the number of SLR exposed properties within a school district is accompanied by a 2 bps increase in municipal bond spreads, equivalent to 3% of the average spread. Although these estimates are approximately twice as large on the East Coast, it appears that municipal bond investors believe that there is a small probability of a catastrophe related to sea level rise in the coming decades. Distinguishing whether this is due to the maturity of municipal bonds being measured in decades instead of centuries, because the market expects coastal communities to take on successful remediation efforts, or because markets do not expect seas to rise as much as scientists predict is an important avenue for future research.

References

Addoum, Jawad M., David T. Ng, and Ariel Ortiz Bobea. 2019. "Temperature shocks and establishment sales." *Review of Financial Studies* forthcoming.

Baldauf, Markus, Lorenzo Garlappi, and Constantine Yannelis. 2019. "Does climate change affect real estate prices? Only if you believe in it." *Review of Financial Studies* forthcoming.

Bansal, Ravi, Dana Kiku, and Marcelo Ochoa. 2017. "Price of long-run temperature shifts in capital markets."

Barrot, Jean-Noël and Julien Sauvagnat. 2016. "Input specificity and the propagation of idiosyncratic shocks in production networks." *Quarterly Journal of Economics* 131 (3):1543–1592.

Berkman, Henk, Jonathan Jona, and Naomi S. Soderstrom. 2019. "Firm-specific climate risk and market valuation." *SSRN 2775552* .

Bernstein, Asaf, Matthew Gustafson, and Ryan Lewis. 2018. "Disaster on the horizon: The price effect of sea level rise." *Journal of Financial Economics* forthcoming.

Brown, James R., Matthew Gustafson, and Ivan Ivanov. 2019. "Weathering cash flow shocks." *SSRN 2963444* .

Cestau, Dario, Richard C. Green, Burton Hollifield, and Norman Schurhoff. 2017. "The cost burden of negotiated sales restrictions: A natural experiment using heterogeneous state laws."

Chava, Sudheer. 2014. "Environmental externalities and cost of capital." *Management Science* 60 (9):2223–2247.

Church, John A. and Neil J. White. 2006. "A 20th century acceleration in global sea-level rise." *Geophysical Research Letters* 33 (1).

Cortés, Kristle Romero and Philip E. Strahan. 2017. "Tracing out capital flows: How financially integrated banks respond to natural disasters." *Journal of Financial Economics* 125 (1):182–199.

DeConto, Robert M. and David Pollard. 2016. "Contribution of Antarctica to past and future sea-level rise." *Nature* 531 (7596):591.

Dessaint, Olivier and Adrien Matray. 2017. "Do managers overreact to salient risks? Evidence from hurricane strikes." *Journal of Financial Economics* 126 (1):97–121.

Gao, Pengjie, Chang Lee, and Dermot Murphy. 2019. "Municipal borrowing costs and state policies for distressed municipalities." *Journal of Financial Economics* 132 (2):404–426.

Garner, Andra J., Jeremy L. Weiss, Adam Parris, Robert E. Kopp, Radley M. Horton, Jonathan T. Overpeck, and Benjamin P. Horton. 2018. "Evolution of 21st century sea level rise projections." *Earth's Future* 6 (11):1603–1615.

Giglio, Stefano, Matteo Maggiori, and Johannes Stroebel. 2014. "Very long-run discount rates." *Quarterly Journal of Economics* 130 (1):1–53.

Giglio, Stefano, Matteo Maggiori, Johannes Stroebel, and Andreas Weber. 2015. "Climate change and long-run discount rates: Evidence from real estate."

Green, Richard C., Burton Hollifield, and Norman Schurhoff. 2007. "Dealer intermediation and price behavior in the aftermarket for new bond issues." *Journal of Financial Economics* 86 (3):643–682.

Grinsted, Aslak, Svetlana Jevrejeva, Riccardo E.M. Riva, and Dorthe Dahl-Jensen. 2015. "Sea level rise projections for northern Europe under RCP8.5." *Climate Research* 64 (1):15–23.

Hallegatte, Stephane, Colin Green, Robert J. Nicholls, and Jan Corfee-Morlot. 2013. "Future flood losses in major coastal cities." *Nature Climate Change* 3 (9):802.

Hansen, Jens Morten, Troels Aagaard, and Antoon Kuijpers. 2015. "Sea-level forcing by synchronization of 56-and 74-year oscillations with the Moon's nodal tide on the northwest European Shelf (eastern North Sea to central Baltic Sea)." *Journal of Coastal Research* 31 (5):1041–1056.

Hauer, Mathew E., Jason M. Evans, and Deepak R. Mishra. 2016. "Millions projected to be at risk from sea-level rise in the continental United States." *Nature Climate Change* 6 (7):691.

Hinkel, Jochen, Carlo Jaeger, Robert J. Nicholls, Jason Lowe, Ortwin Renn, and Shi Peijun. 2015. "Sea-level rise scenarios and coastal risk management." *Nature Climate Change* 5 (3):188.

Hong, Harrison, Frank Weikai Li, and Jiangmin Xu. 2019. "Climate risks and market efficiency." *Journal of Econometrics* 208 (1):265–281.

Howe, Peter D., Matto Mildenberger, Jennifer R. Marlon, and Anthony Leiserowitz. 2015. "Geographic variation in opinions on climate change at state and local scales in the USA." *Nature Climate Change* 5 (6):596–603.

Krasting, John P., John P. Dunne, Ronald J. Stouffer, and Robert W. Hallberg. 2016. "Enhanced Atlantic sea-level rise relative to the Pacific under high carbon emission rates." *Nature Geoscience* 9 (3):210.

Krueger, Philipp, Zacharias Sautner, and Laura T. Starks. 2018. "The importance of climate risks for institutional investors." *Review of Financial Studies* forthcoming.

Marcy, Doug, Nate Herold, Kirk Waters, William Brooks, Brian Hadley, Matt Pendleton, Keil Schmid, Mike Sutherland, Kyle Dragonov, John McCombs, and Sean Ryan. 2011. "New mapping tool and techniques for visualizing sea level rise and coastal flooding impacts." *In Proceedings of the 2011 Solutions to Coastal Disasters Conference, Anchorage, Alaska* :474–490.

Merica, Dan. 2017. "Trump dramatically changes US approach to climate change." *CNN Politics. March* 29:2017.

Murfin, Justin and Matthew Spiegel. 2019. "Is the risk of sea level rise capitalized in residential real estate?"

Obama, Barack. 2009. "President Barack Obama at UN Climate Change Summit." .

Painter, Marcus. 2018. "An inconvenient cost: The effects of climate change on municipal bonds." *Journal of Financial Economics* forthcoming.

Parris, Adam S., Peter Bromirski, Virginia Burkett, Daniel R. Cayan, Mary Evans Culver, John Hall, Radley M. Horton, Kevin Knuuti, Richard H. Moss, Jayantha Obeysekera et al. 2012. "Global sea level rise scenarios for the United States National Climate Assessment." .

Piecuch, Christopher G., Peter Huybers, Carling C. Hay, Andrew C. Kemp, Christopher M. Little, Jerry X. Mitrovica, Rui M. Ponte, and Martin P. Tingley. 2018. "Origin of spatial variation in US East Coast sea-level trends during 1900–2017." *Nature* 564 (7736):400.

Rao, Krishna. 2017. *Climate change and housing: Will a rising tide sink all homes?* URL https://www.zillow.com/research/climate-change-underwater-homes-12890/.

Rohling, Eelco J., Ivan D. Haigh, Gavin L. Foster, Andrew P. Roberts, and Katharine M. Grant. 2013. "A geological perspective on potential future sea-level rise." *Scientific Reports* 3:3461.

Schultz, Paul. 2012. "The market for new issues of municipal bonds: The roles of transparency and limited access to retail investors." *Journal of Financial Economics* 106 (3):492–512.

Schwert, Michael. 2017. "Municipal bond liquidity and default risk." *Journal of Finance* 72 (4):1683–1722.

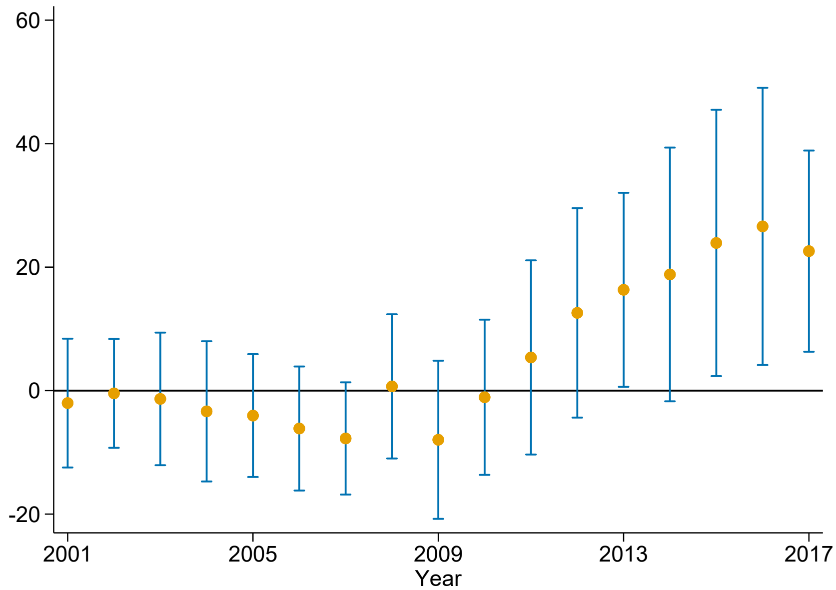
Sharfman, Mark P. and Chitru S. Fernando. 2008. "Environmental risk management and the cost of capital." *Strategic Management Journal* 29 (6):569–592.

Stocker, T.F., D. Qin, G.-K. Plattner, M. Tignor, S.K. Allen, J. Boschung, A. Nauels, Y. Xia, V. Bex, and P.M. Midgley, editors. 2013. *Summary for Policymakers*, book section SPM. Cambridge, United Kingdom and New York, NY, USA: Cambridge University Press, 1–30. URL www.climatechange2013.org.

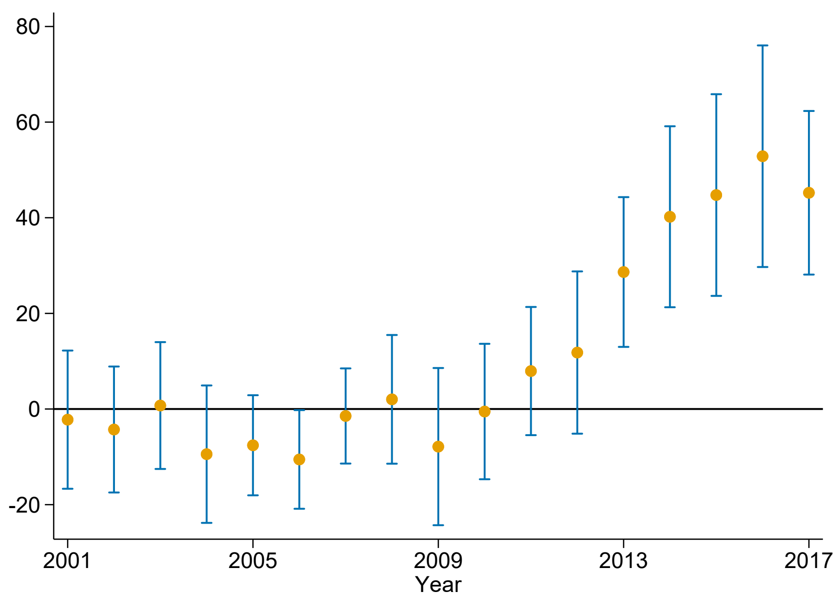
Sweet, William V., Robert E. Kopp, Christopher P. Weaver, Jayantha Obeysekera, Radley M. Horton, E. Robert Thieler, and Chris Zervas. 2017. "Global and regional sea level rise scenarios for the United States." .

Figure 1: Effect of Sea Level Rise on Bond Spreads

Panel A: Full Sample



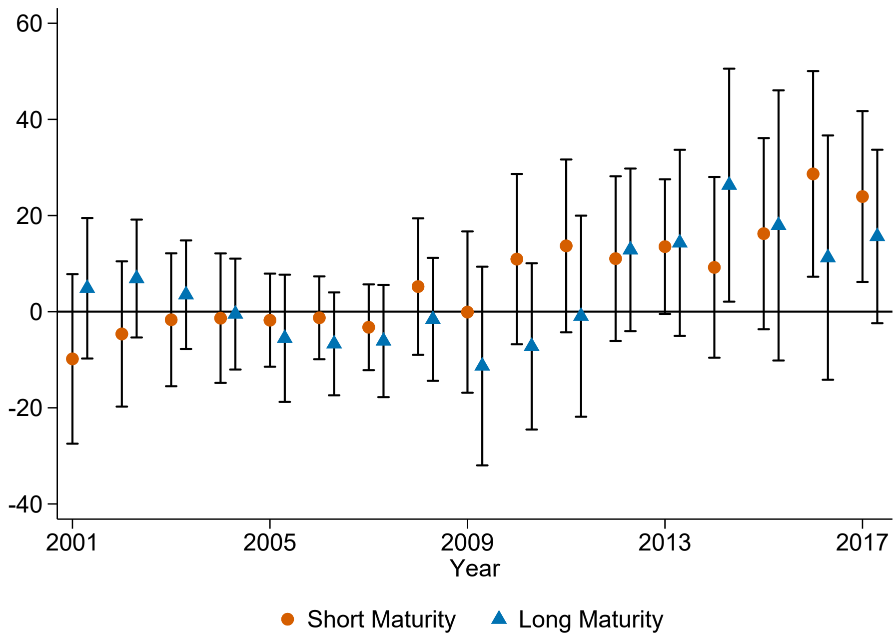
Panel B: East Coast Sample



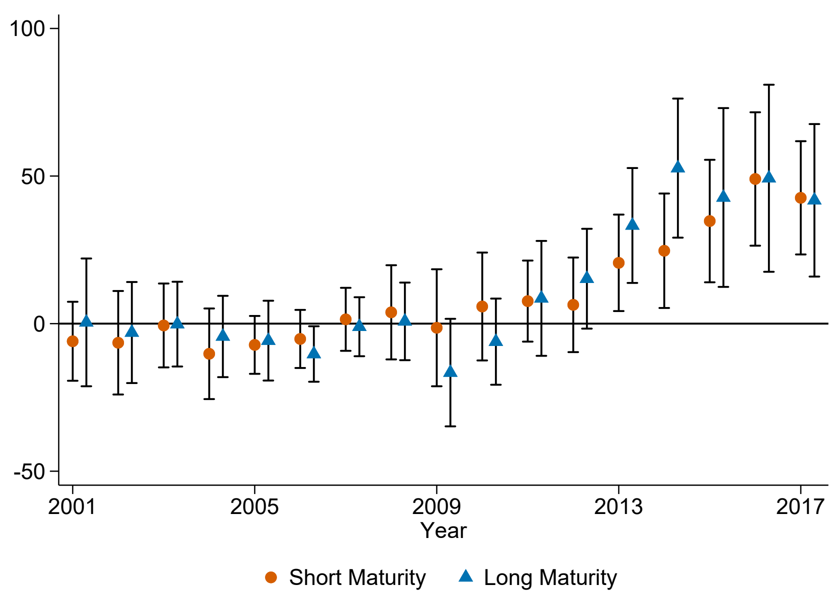
Note: This figure plots the year-by-year effect of Pct. Exposed on municipal bond spreads. Spread is defined as the difference between yield-to-maturity and the maturity-matched yield from the Municipal Market Advisors AAA-rated tax-exempt benchmark curve. The coefficients come from a similar regression to equation (1), with Pct. Exposed and the control variables interacted with dummies for each calendar year to obtain estimates of the SLR effect on spreads in each year on the x-axis. Pct. Exposed is defined as the percentage of residential properties that would be inundated by six feet of sea level rise. The vertical bars reflect the 95% confidence intervals, where standard errors are clustered by school district and month.

Figure 2: Heterogeneous Effects of Sea Level Rise on Bond Spreads by Maturity

Panel A: Full Sample

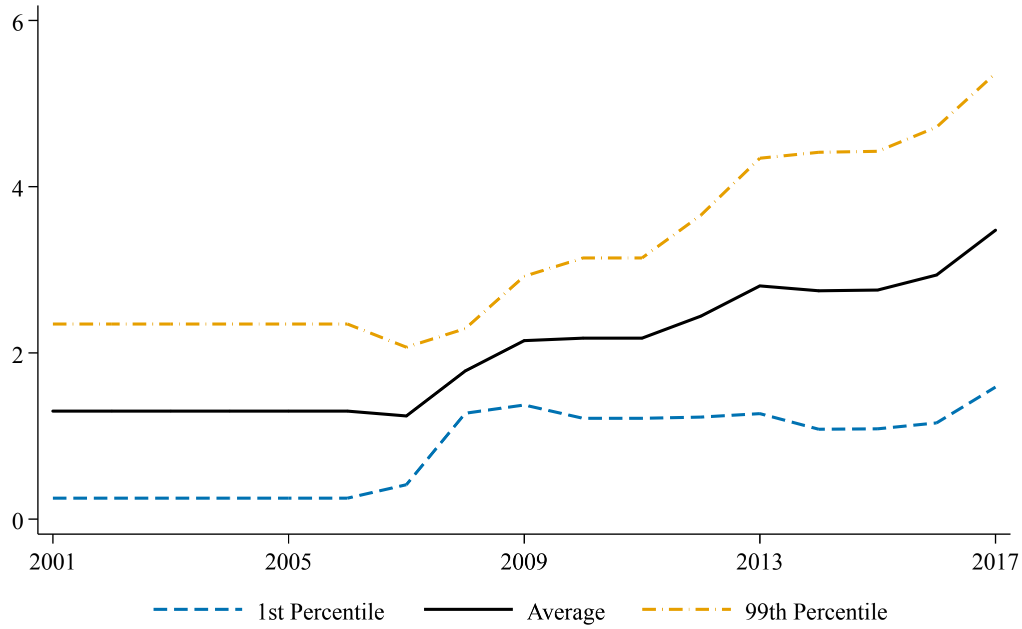


Panel B: East Coast Sample



Note: This figure plots the year-by-year effect of Pct. Exposed on municipal bond spreads for long and short-maturity bonds. Spread is defined as the difference between yield-to-maturity and the maturity-matched yield from the Municipal Market Advisors AAA-rated tax-exempt benchmark curve. The coefficients come from a similar regression to equation (1), with Pct. Exposed, its interaction with a dummy for long-maturity bonds, and the control variables interacted with dummies for each calendar year to obtain estimates of the SLR effect on spreads in each year on the x-axis. Pct. Exposed is defined as the percentage of residential properties that would be inundated by six feet of sea level rise. Long maturity is defined as greater than 10 years, and is denoted by the blue triangles. Short maturity is denoted by the orange circles. The vertical bars reflect the 95% confidence intervals, where standard errors are clustered by school district and month.

Figure 3: Aggregated time series of SLR Predictions



Note: This figure aggregates the mean, 1st and 99th percentiles of SLR forecasts across major scientific studies from 2001 to 2017. Our methodology for aggregating forecasts is described in Section 5.1.

Table 1: Summary Statistics

	(1) *Full Coastal Sample*			(2) *SLR Exposed Districts*		
	Mean	Std.Dev.	Obs	Mean	Std.Dev.	Obs
Percent of Properties Exposed (3ft SLR)	0.01	0.03	559,579	0.02	0.04	257,411
Percent of Properties Exposed (6ft SLR)	0.04	0.10	559,579	0.08	0.13	257,411
Average Price, Single Family Home ($000s)	395.23	434.95	559,579	422.12	538.97	257,411
Yield-to-Maturity (%)	3.33	1.23	559,579	3.31	1.21	257,411
Spread over MMA Curve (bps)	64.06	57.54	559,579	64.30	56.98	257,411
Time to Maturity	10.00	6.26	559,579	9.79	6.11	257,411
Bond Age	3.95	2.70	559,579	3.96	2.68	257,411
Monthly Trading Volume ($000s)	509.54	3098.87	559,579	616.98	4021.92	257,411
Monthly SD of Price	0.91	0.71	494,881	0.92	0.71	228,731
Observations	559,579			257,411		

Note: This table reports the summary statistics for the main variables used in this paper. Observations are at the bond-year-month level. Sea Level Rise exposures are measured within school districts and represent the percent of residential properties that would be inundated after a given level of global average sea level rise. SLR Exposed Districts are school districts with non-zero exposure to six feet of sea level rise.

Table 2: Sea Level Rise and Bond Spreads

	(1)	(2)	(3)	(4)	(5)	(6)
Pct. Exposed	8.702	-6.187	-0.833	15.631**	-3.095	-7.017*
	(1.43)	(-1.34)	(-0.08)	(2.46)	(-0.76)	(-1.80)
Post-2006=1 X Pct. Exposed	-5.396	-0.514	-2.419	-16.226**	6.171	11.632
	(-0.28)	(-0.05)	(-0.15)	(-2.27)	(1.04)	(1.63)
Post-2013=1 X Pct. Exposed	-2.586	7.083	-0.052	15.897	17.792**	29.626***
	(-0.15)	(0.57)	(-0.00)	(1.50)	(1.97)	(3.22)
Controls	N	Y	N	Y	Y	Y
Year-Month F.E.	N	N	Y	Y	N	N
County F.E.	N	N	Y	Y	N	N
County-Year-Month F.E.	N	N	N	N	Y	Y
Equal-Weighted	N	N	N	N	N	Y
Outcome Mean	64.060	64.958	64.060	64.962	65.049	65.049
Outcome SD	57.543	57.743	57.543	57.743	57.703	57.703
Observations	559,579	494,881	559,577	494,646	488,168	488,168

t statistics in parentheses

* p<0.10, ** p<0.05, *** p<0.01

Note: This table reports estimates of equation (1) in the full sample of bonds issued by school districts in coastal states. Observations are at the bond-year-month level. The dependent variable is the volume-weighted average spread of a municipal bond. Spread is defined as the difference between yield-to-maturity and the maturity-matched yield from the Municipal Market Advisors AAA-rated tax-exempt benchmark curve. Pct. Exposed is defined as the percentage of residential properties that would be inundated by six feet of sea level rise. Post-2006 and Post-2013 are indicators equal to one for observations occurring strictly after the years 2006 and 2013, respectively. Controls include the log average value of residential properties in the district and the bond's time to maturity in years, coupon rate, years since issuance, log trading volume, and standard deviation of transaction prices. The control variables are interacted with the Post-2006 and Post-2013 indicators to allow for time-varying coefficients. All fixed effects are interacted with bond type dummies to account for differences across general obligation and revenue bonds. Equal-Weighted denotes regressions weighted by the inverse of the bond-year-month observation count in the state-year block. Standard errors are clustered by school district and year-month.

Table 3: Effect of Sea Level Rise and Bond Spreads by Regional Sample

	(1)	(2)	(3)	(4)	(5)	(6)
Pct. Exposed	1.487	-0.003	5.019	-8.837	-8.244	-3.933
	(0.36)	(-0.00)	(0.42)	(-0.84)	(-0.83)	(-0.65)
Post-2013=1 X Pct. Exposed	43.213***	41.708***	17.365	31.638	-16.599	-21.461**
	(4.76)	(4.59)	(0.92)	(1.20)	(-1.51)	(-2.37)
Sample	East	East	Gulf	Gulf	West	West
Controls	Y	Y	Y	Y	Y	Y
County-Year-Month F.E.	Y	Y	Y	Y	Y	Y
Equal-Weighted	N	Y	N	Y	N	Y
Outcome Mean	57.741	57.741	65.796	65.796	72.393	72.393
Outcome SD	53.481	53.481	57.175	57.175	61.177	61.177
Observations	203,775	203,775	90,826	90,826	193,480	193,480

t statistics in parentheses

* p<0.10, ** p<0.05, *** p<0.01

Note: This table reports estimates of equation (1) with the sample split into three regions. Observations are at the bond-year-month level. East includes Connecticut, Florida, Georgia, Maine, Maryland, Massachusetts, New Jersey, New York, North Carolina, Rhode Island, South Carolina, and Virginia. Gulf includes Alabama, Mississippi, Louisiana, and Texas. West includes California, Oregon, and Washington. The dependent variable is the volume-weighted average spread of a municipal bond. Spread is defined as the difference between yield-to-maturity and the maturity-matched yield from the Municipal Market Advisors AAA-rated tax-exempt benchmark curve. Pct. Exposed is defined as the percentage of residential properties that would be inundated by six feet of sea level rise. Post-2013 is an indicator equal to one for observations occurring strictly after the year 2013. Controls include the log average value of residential properties in the district and the bond's time to maturity in years, coupon rate, years since issuance, log trading volume, and standard deviation of transaction prices. The control variables are interacted with the Post-2013 indicators to allow for time-varying coefficients. All fixed effects are interacted with bond type dummies to account for differences across general obligation and revenue bonds. Equal-Weighted denotes regressions weighted by the inverse of the bond-year-month observation count in the state-year block. Standard errors are clustered by school district and year-month.

Table 4: Heterogeneity in Effect of Sea Level Rise on Bond Spreads by Sentiment

	(1)	(2)	(3)	(4)
Pct. Exposed	2.250	-1.516	2.041	-0.677
	(0.58)	(-0.40)	(0.50)	(-0.15)
Post-2013=1 X Pct. Exposed	20.449**	36.251***	39.626***	43.501***
	(2.15)	(4.36)	(4.08)	(4.79)
Post-2013=1 X Pct. Exposed X State Worry	-1.276	6.131	21.667**	16.306**
	(-0.13)	(0.88)	(2.15)	(2.39)
Sample	Full	Full	East	East
Controls	Y	Y	Y	Y
County-Year-Month F.E.	Y	Y	Y	Y
Equal-Weighted	N	Y	N	Y
Outcome Mean	65.049	65.049	57.741	57.741
Outcome SD	57.703	57.703	53.481	53.481
Observations	488,168	488,168	203,775	203,775

t statistics in parentheses

* p<0.10, ** p<0.05, *** p<0.01

Note: This table reports estimates of equation (1) in the full sample, adding an interaction with state residents' level of concern about global warming. Observations are at the bond-year-month level. The dependent variable is the volume-weighted average spread of a municipal bond. Spread is defined as the difference between yield-to-maturity and the maturity-matched yield from the Municipal Market Advisors AAA-rated tax-exempt benchmark curve. Pct. Exposed is defined as the percentage of residential properties that would be inundated by six feet of sea level rise. State Worry is a standardized measure of global warming concerns from the Yale Climate Opinions map. Post-2013 is an indicator equal to one for observations occurring strictly after the year 2013. Controls include the log average value of residential properties in the district and the bond's time to maturity in years, coupon rate, years since issuance, log trading volume, and standard deviation of transaction prices. The control variables are interacted with the Post-2013 indicators to allow for time-varying coefficients. All fixed effects are interacted with bond type dummies to account for differences across general obligation and revenue bonds. Equal-Weighted denotes regressions weighted by the inverse of the bond-year-month observation count in the state-year block. Standard errors are clustered by school district and year-month.

Table 5: Heterogeneity in Effect of Sea Level Rise on Bond Spreads by Population Growth

	(1)	(2)	(3)	(4)
Pct. Exposed	2.340	2.366	8.951	7.154
	(0.44)	(0.59)	(1.14)	(1.39)
Post-2013=1 X Pct. Exposed	5.557	21.062***	21.576***	25.402***
	(0.73)	(2.85)	(2.97)	(2.87)
Post-2013=1 X Pct. Exposed X Population Growth	-34.710***	-31.839***	-27.485***	-29.047***
	(-3.51)	(-3.47)	(-3.38)	(-2.96)
Sample	Full	Full	East	East
Controls	Y	Y	Y	Y
County-Year-Month F.E.	Y	Y	Y	Y
Equal-Weighted	N	Y	N	Y
Outcome Mean	65.049	65.049	57.741	57.741
Outcome SD	57.703	57.703	53.481	53.481
Observations	488,168	488,168	203,775	203,775

t statistics in parentheses

* p<0.10, ** p<0.05, *** p<0.01

Note: This table reports estimates of equation (1), adding an interaction with population growth from 2008 to 2013. Observations are at the bond-year-month level. The dependent variable is the volume-weighted average spread of a municipal bond. Spread is defined as the difference between yield-to-maturity and the maturity-matched yield from the Municipal Market Advisors AAA-rated tax-exempt benchmark curve. Pct. Exposed is defined as the percentage of residential properties that would be inundated by six feet of sea level rise. Population Growth is a standardized measure of the percentage change in population from 2008 through 2013. Post-2013 is an indicator equal to one for observations occurring strictly after the year 2013. Controls include the log average value of residential properties in the district and the bond's time to maturity in years, coupon rate, years since issuance, log trading volume, and standard deviation of transaction prices. The control variables are interacted with the Post-2013 indicators to allow for time-varying coefficients. All fixed effects are interacted with bond type dummies to account for differences across general obligation and revenue bonds. Equal-Weighted denotes regressions weighted by the inverse of the bond-year-month observation count in the state-year block. Standard errors are clustered by school district and year-month.

Table 6: Average and 99th Percentile SLR Exposure

Panel A. Full Sample

	(1)	(2)	(3)	(4)
Pct. Exposed, Mean SLR Prediction	-7.784		-30.310	-24.850
	(-0.40)		(-1.30)	(-1.01)
Pct. Exposed, 99th Pctl. SLR Prediction		7.804		
		(0.69)		
Pct. Exp. 99th Pctl. - Pct. Exp. Mean			26.946	42.042**
			(1.36)	(2.43)
Controls	Y	Y	Y	Y
County-Year-Month F.E.	Y	Y	Y	Y
Equal-Weighted	N	N	N	Y
Outcome Mean	65.067	65.067	65.067	65.067
Outcome SD	57.741	57.741	57.741	57.741
Observations	489,868	489,868	489,868	489,868

Panel B. East Coast

	(1)	(2)	(3)	(4)
Pct. Exposed, Mean SLR Prediction	74.451***		12.732	-6.158
	(3.37)		(0.40)	(-0.17)
Pct. Exposed, 99th Pctl. SLR Prediction		39.396***		
		(3.75)		
Pct. Exp. 99th Pctl. - Pct. Exp. Mean			50.268**	46.219**
			(2.52)	(2.31)
Controls	Y	Y	Y	Y
County-Year-Month F.E.	Y	Y	Y	Y
Equal-Weighted	N	N	N	Y
Outcome Mean	57.736	57.736	57.736	57.736
Outcome SD	53.511	53.511	53.511	53.511
Observations	204,597	204,597	204,597	204,597

t statistics in parentheses

* p<0.10, ** p<0.05, *** p<0.01

Note: This table reports the estimates of time varying SLR exposure variables that account for changing scientific projections as described in Section 5.1. Pct. Exposed, Mean SLR Prediction and Pct. Exposed, 99th Pctl SLR Prediction are the percent of properties in a school district that would be exposed to chronic tidal flooding at the projected mean and 99th percentile of SLR projections averaged across temporally relevant scientific studies. Panel A assesses the full sample while Panel B focuses on the East Coast. Controls include the log average value of residential properties in the district and the bond's time to maturity in years, coupon rate, years since issuance, log trading volume, and standard deviation of transaction prices. The control variables are interacted with the Post-2013 indicators to allow for time-varying coefficients. All fixed effects are interacted with bond type dummies to account for differences across general obligation and revenue bonds. Equal-Weighted denotes regressions weighted by the inverse of the bond-year-month observation count in the state-year block. Standard errors are clustered by school district and year-month.

Online Appendix for

Sea Level Rise and Municipal Bond Yields

Paul Goldsmith-Pinkham Matthew Gustafson Ryan Lewis Michael Schwert

Table A1: Sample Breakdown by Year

Year	Bond-Year-Month Observations
2001	10,177
2002	12,781
2003	19,369
2004	23,749
2005	26,432
2006	30,688
2007	32,038
2008	34,089
2009	39,941
2010	44,064
2011	46,257
2012	41,063
2013	44,723
2014	38,693
2015	36,652
2016	36,963
2017	41,900

Note: This table reports the number of observations by year.

Table A2: Sample Breakdown by State

State	Bond-Year-Month Observations
Alabama	108
California	218,457
Connecticut	8,512
Florida	34,783
Georgia	2,985
Louisiana	2,967
Maine	1,663
Maryland	792
Massachusetts	16,566
Mississippi	2,684
New Jersey	83,145
New York	68,075
North Carolina	4,005
Oregon	1,168
Rhode Island	1,462
South Carolina	15,126
Texas	96,925
Virginia	134
Washington	22

Note: This table reports the number of observations by state.

Table A3: Event Study Analysis around SLR Information Releases

	Price Return		Change in Log(Volume)	
	(1)	(2)	(3)	(4)
Pct. Exposed	-0.004	0.009	1.894***	2.165**
	(-0.47)	(0.65)	(3.05)	(2.54)
FIPS FE	N	Y	N	Y
R^2	0	0	0	0
Observations	220	176	220	176

Note: This table reports the results of an event study analysis around the spike in Google searches for "sea level rise" in May 2014. We calculate the monthly return and change in log trading volume by school district over the month of May 2014, relative to the prior month, to capture the effects of the spike in SLR-related queries on the pricing and trading activity of bonds issued by districts more exposed to sea level rise. District-level returns and changes in log volume are computed as principal-weighted averages of bond-level returns and log volume changes. The sample is limited to bonds that trade in both April and May 2014. Pct. Exposed measures the share of homes that would be inundated with a six foot SLR.

Table A4: Sea Level Rise and Bond Spreads - Three-Foot SLR Exposure

	(1)	(2)	(3)	(4)	(5)	(6)
Pct. Exposed	6.402	-2.970	17.336	28.993**	1.852	-5.371
	(0.56)	(-0.31)	(1.16)	(2.28)	(0.25)	(-0.63)
Post-2006=1 X Pct. Exposed	-68.489***	-49.811***	-45.968**	-45.834***	-10.578	6.999
	(-2.96)	(-2.63)	(-2.18)	(-2.87)	(-0.74)	(0.40)
Post-2013=1 X Pct. Exposed	30.192	53.578**	19.766	52.478*	49.672**	85.951***
	(0.76)	(2.03)	(0.46)	(1.87)	(2.24)	(3.21)
Controls	N	Y	N	Y	Y	Y
Year-Month F.E.	N	N	Y	Y	N	N
County F.E.	N	N	Y	Y	N	N
County-Year-Month F.E.	N	N	N	N	Y	Y
Equal-Weighted	N	N	N	N	N	Y
Outcome Mean	64.060	64.958	64.060	64.962	65.049	65.049
Outcome SD	57.543	57.743	57.543	57.743	57.703	57.703
Observations	559,579	494,881	559,577	494,646	488,168	488,168

t statistics in parentheses

* p<0.10, ** p<0.05, *** p<0.01

Note: This table reports estimates of equation (1) in the full sample of bonds issued by school districts in coastal states. Observations are at the bond-year-month level. The dependent variable is the volume-weighted average spread of a municipal bond. Spread is defined as the difference between yield-to-maturity and the maturity-matched yield from the Municipal Market Advisors AAA-rated tax-exempt benchmark curve. Pct. Exposed is defined as the percentage of residential properties that would be inundated by three feet of sea level rise. Post-2006 and Post-2013 are indicators equal to one for observations occurring strictly after the years 2006 and 2013, respectively. Controls include the log average value of residential properties in the district and the bond's time to maturity in years, coupon rate, years since issuance, log trading volume, and standard deviation of transaction prices. The control variables are interacted with the Post-2006 and Post-2013 indicators to allow for time-varying coefficients. All fixed effects are interacted with bond type dummies to account for differences across general obligation and revenue bonds. Equal-Weighted denotes regressions weighted by the inverse of the bond-year-month observation count in the state-year block. Standard errors are clustered by school district and year-month.

Table A5: List Sea Level Rise Studies

Author	Type	Year	Scenario	Type	Mean	S.D.	
Church et al., 2001	IPCC Assessment Report	2001	SRES B1	Mid	0.33	0.12	
Church et al., 2001	IPCC Assessment Report	2001	SRES A2	High	0.45	0.15	
Meehl et al., 2007	IPCC Assessment Report	2007	SRES B1	Mid	0.28	0.05	
Meehl et al., 2007	IPCC Assessment Report	2007	SRES A2	High	0.43	0.11	
R. Horton et al., 2008	Semi-empirical	2008	SRES B1	Mid	0.65	0.05	
R. Horton et al., 2008	Semi-empirical	2008	SRES A2	High	0.79	0.05	
Vermeer & Rahmstorf, 2009	Semi-empirical	2009	SRES B1	Mid	0.9	0.21	
Vermeer & Rahmstorf, 2009	Semi-empirical	2009	SRES A2	High	1.07	0.25	
Grinsted et al., 2010	Semi-empirical	2010	SRES B1	Mid	0.9	0.09	
Grinsted et al., 2010	Semi-empirical	2010	SRES A2	High	0.95	0.21	
Hunter, 2010	Semi-empirical	2010	SRES B1	Mid	0.34	0.08	
Hunter, 2010	Semi-empirical	2010	SRES A2	High	0.46	0.12	
Jevrejeva et al., 2010	Semi-empirical	2010	SRES B1	Mid	0.85	0.13	
Jevrejeva et al., 2010	Semi-empirical	2010	SRES A2	High	0.9	0.31	
Jevrejeva et al., 2012	Semi-empirical	2012	RCP4.5	Mid	0.81	0.15	
Jevrejeva et al., 2012	Semi-empirical	2012	RCP8.5	High	1.23	0.21	
Parris et al., 2012	Literature Synthesis	2012	NOAA	Mid	0.45	0.13	*
Parris et al., 2012	Literature Synthesis	2012	NOAA	High	1.25	0.38	*
Rahmstorf et al., 2012	Semi-empirical	2012	RCP4.5	Mid	0.92	0.24	
Rahmstorf et al., 2012	Semi-empirical	2012	RCP8.5	High	1.29	0.38	
Church et al., 2013	IPCC Assessment Report	2013	RCP4.5	Mid	0.54	0.18	**
Church et al., 2013	IPCC Assessment Report	2013	RCP8.5	High	0.82	0.27	**
Perrette et al., 2013	Semi-empirical	2013	RCP4.5	Mid	0.89	0.22	**
Perrette et al., 2013	Semi-empirical	2013	RCP8.5	High	1.15	0.33	**
Jevrejeva et al., 2014	Probabilistic	2014	RCP4.5	Mid	0.55	0.08	
Jevrejeva et al., 2014	Probabilistic	2014	RCP8.5	High	1.13	0.34	
Kopp et al., 2014	Probabilistic	2014	RCP4.5	Mid	0.65	0.15	**
Kopp et al., 2014	Probabilistic	2014	RCP8.5	High	0.87	0.18	**
Grinsted et al., 2015	Probabilistic	2015	RCP4.5	Mid	0.56	0.09	**
Grinsted et al., 2015	Probabilistic	2015	RCP8.5	High	1.14	0.35	**
Jevrejeva et al., 2016	Probabilistic	2016	RCP4.5	Mid	0.55	0.08	**
Jevrejeva et al., 2016	Probabilistic	2016	RCP8.5	High	1.16	0.32	**
Kopp et al., 2016	Semi-empirical	2016	RCP4.5	Mid	0.59	0.13	**
Kopp et al., 2016	Semi-empirical	2016	RCP8.5	High	0.92	0.2	**
Bakker et al., 2017	Probabilistic	2017	RCP4.5	Mid	0.76	0.11	
Bakker et al., 2017	Probabilistic	2017	RCP8.5	High	2	0.19	
Kopp et al., 2017	Probabilistic	2017	RCP4.5	Mid	1.04	0.28	**
Kopp et al., 2017	Probabilistic	2017	RCP8.5	High	1.68	0.38	**
Le Bars et al., 2017	Probabilistic	2017	RCP4.5	Mid	1.04	0.28	**
Le Bars et al., 2017	Probabilistic	2017	RCP8.5	High	1.84	0.32	**
Nauels, Rogelj, et al., 2017	Probabilistic	2017	RCP4.5	Mid	0.64	0.31	**
Nauels, Rogelj, et al., 2017	Probabilistic	2017	RCP8.5	High	0.94	0.34	**
Wong et al., 2017	Probabilistic	2017	RCP4.5	Mid	0.93	0.19	**
Wong et al., 2017	Probabilistic	2017	RCP8.5	High	1.58	0.25	**

* NOAA report, distribution assumed across scenarios.

** Asymmetric distribution around mean

Note: This table reports a list of studies considered in creating the time-varying expectations of SLR risk described in Section 5.1. Studies themselves report portions of the distribution (most commonly 5th and 95th percentile) or direct distributional information. In order to aggregate across studies, we assume normality to calculate the mean and standard deviation (in meters of SLR) from the distributional information supplied by each study. In some cases the distributions are right-skewed, so our assumption of normality induces a downward bias in our estimate of right-tail events. For a comprehensive overview of sea level rise research, see Garner et al. (2018).

Figure A1: Google Search Trend Index for “Sea Level Rise"