Sea Level Rise and Municipal Bond Yields*

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

May 2019

Abstract

This paper examines the effects of climate change on the financing costs of state and local governments in the U.S. Using a sample of bonds issued by school districts in coastal states, we show that greater exposure to sea level rise (SLR) is associated with higher bond yields after controlling for time-varying local economic conditions. We find that SLR is only priced after the sharp upward revision in SLR projections in 2013. The effect is concentrated on the East and Gulf coasts and stronger at long maturities. While the pricing effects of sea level rise are statistically significant, they are economically small and indicate that financial markets do not currently anticipate a high probability of default induced by catastrophe in coastal communities over the next two decades.

*We thank Elaine Yao for excellent research assistance.
†Yale University; paul.goldsmith-pinkham@yale.edu.
‡Penn 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 (see 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 makes it difficult for coastal communities to diversify the risks associated with SLR exposure.

In this paper, we use the municipal bonds 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, the market prices of municipal bonds reflect investors' expectations of future outcomes. Second, the payoff profile of bonds makes the likelihood of large negative shocks a key driver of yields. 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' exposure to SLR to measure how municipal bond prices changed as expectations for sea-level rise were revised upwards. During our sample, two key reports were released by the IPCC: in 2007, when the IPCC projected that sea level would rise by only 0.18 to 0.59 meters by the end of the century; and in 2013, when the IPCC doubled its previous projections, and the U.S.-based National Oceanic and Atmospheric Administration (NOAA) supplying an upper bound SLR projection of two meters. A key difficulty in identifying the effect of these reports is that geographic areas with similar SLR exposure may face time-varying shocks that are correlated with SLR exposure. This is particularly true in 2007, as the financial crisis hit immediately afterwards. To address this concern, we exploit variation in SLR exposure across municipalities within the same county, using county-by-year-month fixed effects, and estimate how the relative pricing of bonds issued by SLR exposed municipalities shifted following the release of the different IPCC reports.

We examine the impact of SLR exposure on municipal bond pricing in three periods. First, we find no significant relation between a municipality's SLR exposure and its municipal bond yields prior to

2007. This suggests that our county-year-month fixed effects absorb any differences in the economic conditions in exposed and unexposed municipalities. Second, from 2007 to 2013, we *also* find no significant differences between exposed and unexposed municipalities, suggesting no shift in prices in response to the 2007 IPCC report. In contrast, we find a significant positive relation between SLR exposure and municipal bond yields between 2014 and 2017. The emergence of SLR exposure as a determinant of bond yields suggests that the flurry of SLR-related scientific and news articles in 2013 and 2014 drove the rise in municipal bond yields, rather than other omitted variables.

Our estimates imply that a 10 percentage point (approximately 1.1 standard deviations) increase in the number of SLR exposed properties is accompanied by a 2.4 basis point increase in municipal bond yields, equivalent to two percent of the standard deviation of the yield. This indicates that municipal bond investors do accoutn for SLR expectations. 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. Indeed, in additional unreported results, we find no significant relation between SLR exposure and the quantity of municipal debt issued.

We also examine heterogeneity in the pricing of municipal bonds. We identify geographic differences as a function of projected SLR (i.e. regions much more exposed to aggregate shifts), and find that the the entire post-2013 increase in the sensitivity of bond yields to SLR exposure was concentrated on the East Coast, where oceans are projected to rise more than twice as fast as on the West Coast. We also examine an area's beliefs regarding climate change. Within East Coast markets, the post-2013 increase in the price effect of SLR exposure is substantially higher in areas that are more worried about the expected impact of climate change. As municipal bonds tend to be held more locally, this likely reflects those beliefs magnified in the financial prices.

Taken together, our findings provide the evidence on how the financial markets view the sharp rise in expected sea-level rise that has occurred over the past decade. The SLR exposure risk has emerged as an increasingly important determinant of bond pricing over this period, but is still economically meaningful. Nevertheless, intuitive cross-sectional and time-series variation 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 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 yields. Our paper differs in two important ways: first, consistent with evidence in Bernstein, Gustafson, and Lewis (2018) that long-run SLR risk already impacts the coastal property values that underly municipal debt, we find that the yields of both the short- and long-maturity bonds are affected by SLR exposure by the end of our sample period whereas 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. On the East Coast, where yields are most related to SLR exposure, the differential pricing of exposed area bonds does not emerge until 2011 for long-maturity bonds and 2014 for shorter maturity bonds.

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 disentangle the effect of underlying economic conditions from the effect of SLR exposure on municipal bond yields by comparing the yield of two school districts' bonds within the same county and month. In contrast, Painter (2018) compares the costs of initial bond offerings within a state-year, using a measure of climate risk that is only observed for coastal metropolitan counties. As a result, the comparison group for these counties is 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. This is particularly crucial during the onset of the Great Recession in 2007.

Overall, our findings suggest that financial markets are aware of SLR exposure when pricing municipal bonds. Around 2013 when the IPCC doubled their SLR projections, SLR exposure became a statistically significant factor in pricing municipal bond markets. SLR exposure still is not a first-order determinant of municipal bond prices by the 2017 end of our sample, suggesting that municipal bond investors estimate a low probability of catastrophic loss due to SLR in the coming decades.

2 Sample and Empirical Methods

Our empirical analysis studies the effect of SLR exposure on school district bond yields. We focus on bonds issued by school districts for two key 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)). 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 1999 to 2017, so we are able to construct a large sample of school district bonds.

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 Rulemaking Board (MSRB). We select school district bonds from these data by screening on primary and secondary education as the use of proceeds. We restrict the sample to general obligation bonds that are backed by the taxing power of the issuer, excluding bonds that are backed by revenues from specific projects. After applying these criteria, our sample consists of 637,328 bonds from 10,871 issuers.

We construct a monthly panel of volume-weighted yields at the bond level. 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 volatile. After applying these filters, the monthly panel consists of 2,220,994 observations for 231,735 bonds.

To link SLR exposures for these issuers, we identify the underlying geography for each school district. Using this geography, we can identify and link it to the expected sea-level rise 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.[1]

After merging with the data on SLR exposure, our final sample consists of 544,071 observations of 68,241 bonds from 1,532 school district issuers. There are 18 states in our sample, but the observation count is skewed towards more populous states, with California, Texas, New Jersey, and New York accounting for 88% of the bond-month observations and 75% of the school districts. After winsorizing at the 1% level, the bond yields range from 0.74% to 5.73%, with an average yield of 3.38%. The dispersion in municipal bond yields is narrow relative to other bond markets (e.g. corporates) because of the extremely low historical default rate.

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 an indicator for the percentage of properties within a school district that would be inundated by a 6-foot SLR, which is approximately the upper bound projection for end of century SLR. We mitigate the possibility that SLR

[1] 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. Finally.... Code for linking the districts and issuers is available upon request.

exposure relates to unobserved aspects of the area's economy in two primary ways. First, we include county-year-month fixed effects throughout our analyses, such that we identify the effect of SLR exposure on bond yields by comparing the yields on bonds from different school districts within the same county, traded in the same month. Second, we exploit the fact that SLR projections and awareness have significantly increased over the 1999 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 our first set of analyses, we pool the years following 2013 into a single indicator to capture the average change in the relationship between SLR exposure and yields following the 2014 IPCC report. We expect this to be the largest period of growth for multiple reasons: first, in early 2014, the IPCC released their 2013 climate assessment where they nearly doubled the projection for SLR over the next century; second, 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. Finally, in addition, the potential for glacial collapse in Antarctica became a topic of conversation in the popular press in May of 2014. Bernstein, Gustafson, and Lewis (2018) show that this sequence of events was accompanied by a spike Google trends search intensity, peaking in May of 2014. For these tests, we estimate the following specification:

$$\text{Bond Yield}_{ijt} = c_{jt} + \alpha_1 \text{Pct. Exposed}_{ij} + \alpha_2 (\text{Post} \times \text{Pct. Exposed}_{ijt}) + \beta X_{ijt} + \epsilon_{ijt}, \tag{1}$$

for a bond issued by school district i, located in county j and trading in year-month t. The explanatory variable of interest is the interaction between Post and Pct. Exposed, where Post is an indicator for observations after 2013 and Pct. Exposed is the percentage of properties within school district i that would be inundated with a 6-foot rise in sea levels.

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 properties 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.[2] The

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

measure we use is the percentage of homes in an area that would be inundated by a 6-foot SLR, since that is approximately the upper bound projections for year 2100 SLR and the largest SLR exposure reported on the NOAA website [3] 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.

To better understand how the relation between SLR exposure and municipal bond prices evolves around the two IPCC reports, released in 2007 and 2014, we then conduct separate regressions for each year of our sample period of the form:

$$\text{Bond Yield}_{ijt} = c_{jt} + \alpha_{1,t}\text{Pct. Exposed}_{ij} + \beta_t X_{ijt} + \epsilon_{ijt}, \quad (2)$$

for a bond issued by school district i, located in county j and trading in month t.

Table 1 summarizes the primary variables utilized in our analysis. In total we have 544,071 district by month observations in coastal counties, 238,360 of which have properties that will experience chronic inundation after 6 feet of global average sea level rise. On average, 7% of properties are exposed at the the 6 foot level in these districts. Municipal bonds issued by school districts in our sample average 3.36% for all districts and 3.38% for exposed districts. We find little difference in maturity, age and bond price variance between the exposed and full sample. Housing prices are approximately 10% higher in exposed districts and dollar bond volumes are approximately 20% higher than in the full sample.

3 Empirical Results

In Columns 1 and 2 of Table 2, we estimate Equation 1 over our full sample from 1998 to 2017, and a shorter 10-year sample concentrated around the post-2013 rise in the projections and publicity of SLR. In both cases, the Pct. Exposed main effect is statistically insignificant and small compared to the Post × Pct. Exposed interaction, which is positive and statistically significant. The small main effect suggests that there are limited differences across municipal bond yields in exposed and unexposed counties prior to the 2014 IPCC release. This bolsters our preferred interpretation of the positive and significant Post × Pct. Exposed interaction as the increased importance of SLR exposure risk in determining municipal bond yields since the 2014 IPCC release.

[3] We find qualitatively similar results using the percentage of properties exposed to a 3 foot SLR.

The estimated coefficient on the Post × Pct. Exposed interaction is 0.24 in both columns. This suggests (1) that our choice regarding the pre-period length does not affect our inferences, and (2) that the 2007 IPCC release had a limited effect on the relation between SLR exposure and municipal bond yields.

The estimates in Columns 1 and 2 imply that since the beginning of 2014, a 10 percentage point (or approximately 1.1 standard deviation) increase in the number of SLR exposed properties within a school district is accompanied by a 2.4 basis point or 0.5% increase in municipal bond yields. 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, we find no significant relation between SLR exposure and the quantity of municipal debt a school district issues.

In Columns 3 to 5 of Table 2, we investigate the extent to which pricing varies according to geographic regions. Such differences may arise from multiple sources. First, there is substantial heterogeneity in historical SLR across the United States, which Piecuch et al. (2018) argue is primarily due to geological processes that will persist for centuries. East coast sea levels have been rising by between 1.70 mm/year (in Massachusetts and Maine) and 3.89 mm/year (in New Jersey, New York, Connecticut, Rhode Island, Maryland, and Virginia), which is approximately twice as fast as on the west coast. 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. Consistent with both sources of heterogeneity, results from Bernstein, Gustafson, and Lewis (2018) suggest that the home price discount from SLR exposure is concentrated in the East Coast where SLR projections are more pessimistic. School district bond yields follow a similar pattern with pricing effects evident on the eastern seaboard but not on the Pacific coast. We find that the estimated coefficient on Post × Pct. Exposed interaction is 0.36 in the East Coast sample and close to zero in the West Coast and Gulf implying that our full sample results are driven entirely by the East Coast.

In Figure 1, we decompose the pre- and post-periods to provide evidence on the timing with which East Coast municipal bond markets began pricing SLR exposure. Each point on the solid line represents the estimated coefficient on Pct. Exposed obtained from estimating Equation 2 over the year indicated on the x-axis.[4] The dashed lines present the 95% confidence interval on this coefficient

[4]By estimating separate regression each year we allow the coefficients on control variables to vary by year, meaning that the estimated coefficients in the figure need not average to those reported in Table 2.

estimate.

The figure shows that the coefficient is only significant during two of the seventeen years prior to the 2014 IPCC release. Moreover, the coefficients between 1998 and 2013 exhibit no particular pattern, oscilating between 0.05 and -0.15. Since the increased SLR projections and media attention in 2014, however, the Pct. Exposed coefficient has been consistently positive and significant. In 2014, the coefficient rose to approximately 0.18 (from approximately 0.01 in 2013), and since 2014 the coefficient has been stable at over 0.3. 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.

3.1 Additional Heterogeneity

In Table 3, we conduct two sets of tests to better understand what geographical characteristics predict the extent to which the municipal bond market prices SLR exposure. First, we more directly examine the role of past SLR, which also proxies for expected future SLR (see e.g., Piecuch et al. (2018)). To do this, we interact Pct. Exposed with a continuous measure of a state's historical SLR. We use a standardized measure of state-level SLR exposure, which we denote State SLR. Specifically, we obtain the historical state-level SLR reported by the NOAA, subtract the sample-wide average, and divide by the standard deviation.[5]

In Columns 1 and 2 of Table 3, the primary coefficient of interest is that on the triple interaction between Post × Pct. Exposed × State SLR. The positively significant coefficient on this triple {interaction} indicates that SLR exposure becomes increasingly important in pricing municipal bonds following the 2014 IPCC release in areas with faster rising sea levels. The statistically insignificant Post × Pct. Exposed interaction indicates that there is no increased role of SLR exposure in municipal bond pricing following the 2014 IPCC release in the U.S. regions with average past SLR.

This result is interesting because in theory, our measure of exposure reflects the effect of a 6-foot global sea level rise, accounting for the accompanying regional differences in SLR. Nevertheless, this could be a rational response if bond prices are responding to the low probability of catastrophic loss, since such losses are measured with a high degree of uncertainty due to the unpredictability of SLR

[5] According to the NOAA's Regional Sea Levels and Future Scenarios maps, the extent of recent SLR varies considerably across states, with SLR on the East and Gulf coasts ranging from 1.70 mm/year (in Massachusetts and Maine) to 3.89 mm/year (in New Jersey, New York, Connecticut, Rhode Island, Maryland, and Virginia) and SLR on the West Coast ranging from 1.28 mm/year in Oregon and Washington to 1.73 mm/year in California.

exposure in more inland regions, which will disproportionately impact areas with faster rising seas.[6]

In Columns 3 and 4, we investigate whether regional beliefs regarding the impact of climate change affect the manner in which municipal bond markets price SLR exposure. Bernstein, Gustafson, and Lewis (2018) and Baldauf, Garlappi, and Yannelis (2018) both find evidence of climate changes beliefs affecting 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, in part because the tax advantages to municipal bond purchases are often largest for local clientele. 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 the respondents' answer' 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 -2.68 to 0.79.

These columns augment the standard 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). The positive and statistically significant triple interaction in Column 4 indicates that on the East Coast and Gulf 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. However, we do not find the same relation in the West Coast, which makes the triple interaction in the full sample statistically insignificant.

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 risk 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, evidence in Bernstein, Gustafson, and Lewis (2018) that SLR exposed coastal real estate already trades at a 7% discount relative to observably similar unexposed properties suggests that it may become increasingly difficult to role over short-term debt that is based on the value of coastal economies.

Figure 2 illustrates the relation between bond maturity and the extent to which the municipal bond market appears to price SLR exposure. The figure is constructed in the same manner as Figure 1, except that each regression is run only on the subsample of bonds with remaining maturity of less

[6] See the discussion in Bernstein, Gustafson, and Lewis (2018) regarding the imprecision with with SLR exposure is measured, especially in areas farther from the coast.

than 10 years (dashed line) or greater than 10 years (solid line). For legibility, we do not report standard error bands in the figure, but as in Figure 1, few of the observations prior to 2012 are statistically significant. Thus, we find no evidence that the municipal bond markets were pricing SLR exposure risk for either short or long maturity bonds prior to 2012.

The solid line, which plots the Pct. Exposed by year for the sample of bonds with over ten years in remaining maturity spikes in 2012 to a statistically significant estimate of approximately 0.15. It then increases in the following year to approximately 0.25 and continues to rise over the remainder of our sample to over 0.3. The dashed line indicates that the market did not start pricing SLR exposure risk in the short-maturity municipal bond market until several years later, in 2015. Since 2015, the short maturity bond market has priced SLR exposure risk similarly to the long-run bond market.

Finally, in Table 4 we both corroborate the evidence from Figure 2 in a regression framework and examine the potential channels for our effect. In particular, Bernstein, Gustafson, and Lewis (2018) shows a negative house price associated with SLR risk within a similar set of geographic regions and following a similar time horizon as the effect we document here. Perhaps the higher yields on municipal bonds simply reflect this the degradation of the underlying assets that form an exposed communities taxable base (e.g. houses). Column 1 specifically addresses this concern by including a local house price index. We do find a negative coefficient on district house prices (e.g. an increase in house prices results in a decrease in bond yields) but this effect is completely orthogonal to the relation between SLR risk and yields. The coefficient on Post $\times$ Pct. Exposed remains at 0.24 in the specifications with or without house prices. This finding is consistent with a rational channel where bond market participants are responding to a shock to expected volatility of the underlying housing stock associated with SLR risk. It is also consistent with a model of segmented markets where municipal bond holders price SLR risk without considering the immediate house price movements.

While our regressions control for a suite of potential drivers, additional concerns remain that unobservable district level effects are responsible for the pricing results. However, given the long term nature of SLR risk, we should also expect a differential effect between long and short maturity bonds in response thus allowing us to more directly control for district level unobservables In Column 2, we perform the same setup as in Table 1 but include a triple interaction between Post $\times$ Pct. Exposed $\times$ Time to Maturity. We show that the increased yields for SLR exposed districts is larger for securities with longer maturities. However, this specification allows us to further mitigate concerns about unobservable drivers of municipal yields by including district by month fixed effects (this absorbs Post × Pct. Exposed). In Column 3, we find a significant and positive coefficient on the triple interaction term Post × Pct. Exposed × Time to Maturity indicating that longer term bonds are more sensitive to the increasingly pessimistic SLR forecasts for exposed districts.

4 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. Currently over $1 trillion of coastal real estate is at risk over the coming century.

Prior to 2013, we find no significant relation between sea level rise and municipal bond yields. After the 2013 IPCC doubling of sea level rise projections, we find consistent that sea level rise exposure has become a statistically significant predictor of municipal bond yields in coastal communities. The importance of sea level rise exposure in determining bond yields is largest on the east coast (where seas have been are expected to continue 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 an input into bond prices remains small. A 10-percentage point (or approximately 1.1 standard deviation) increase in the number of SLR exposed properties within a school district is accompanied by a 2.4 basis point increase in municipal bond yields, equivalent to 0.5% of the average yield. Thus, municipal bond investors appear to believe that there is a small probability of a sea level rise related catastrophe in the coming decades. Whether this is due to the maturity of municipal bonds being measured in decades instead of centuries or because the market expects coastal communities to take on successful remediation efforts is an important question for future research.

References

Baldauf, Markus, Lorenzo Garlappi, and Constantine Yannelis. 2018. "Does Climate Change Affect Real Estate Prices? Only If You Believe in it." *Review of Financial Studies Forthcoming* .

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

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

Grinsted, Aslak, Svetlana Jevrejeva, Riccardo EM 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.

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.

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.

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.

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/`.

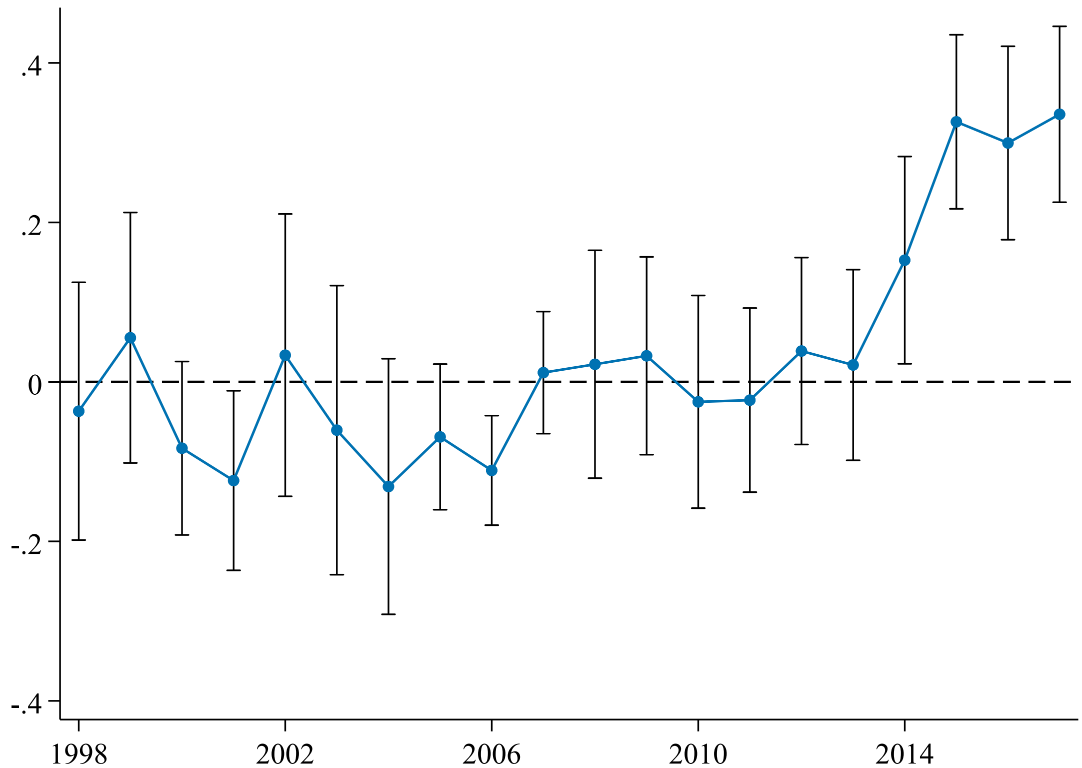
Rohling, Eelco J, Ivan D Haigh, Gavin L Foster, Andrew P Roberts, and Katharine M Grant. 2013. "A geological perspective on potential future sea-level rise." *Scientific reports* 3:3461.

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

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`.

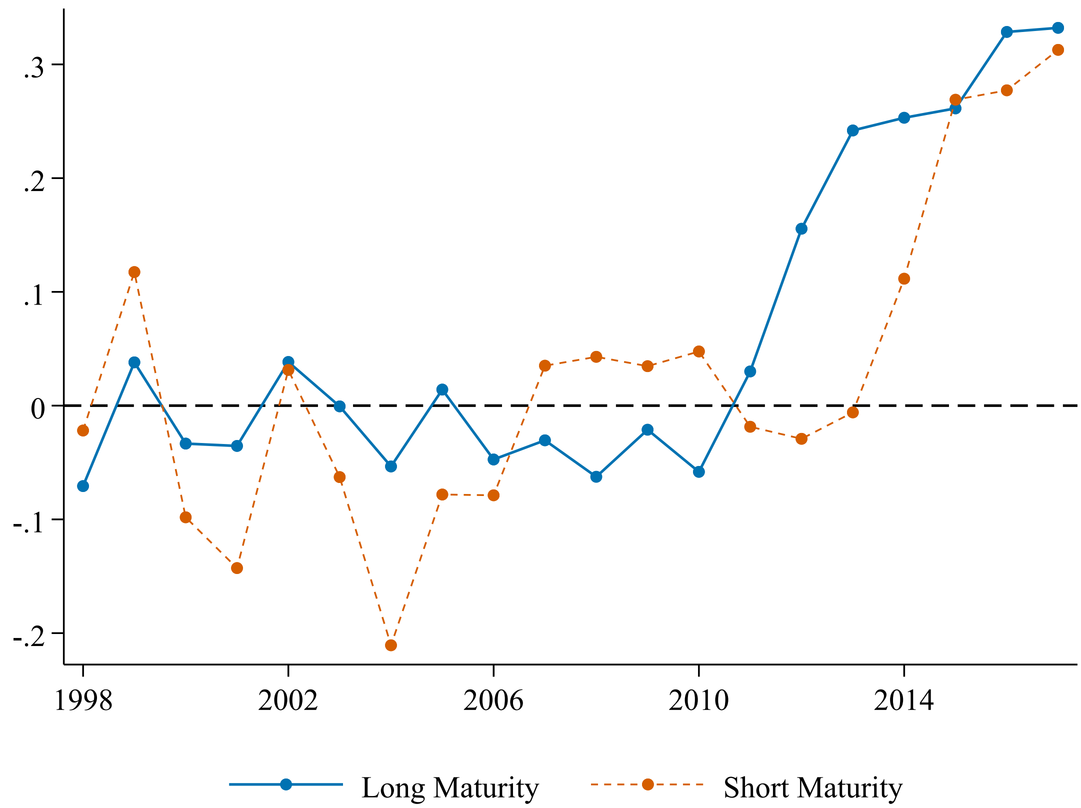
Sweet, William V, Robert E Kopp, Christopher P Weaver, Jayantha Obeysekera, Radley M Horton, E Robert Thieler, and Chris Zervas. 2017. "Global and regional sea level rise scenarios for the United States." .

Figure 1: Effect of Sea Level Rise on Bond Yields



Note: This figure plots the year-by-year effect of Pct. Exposed on municipal bond yields. The coefficients come from a regression identical to that in Equation 1, except instead of including a Post × Pct. Exposed interaction, we restrict the sample to only bonds traded during the year indicated on the x-axis. The vertical bars reflect the 95% confidence intervals, where standard errors are clustered at the county-level.

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



Note: This figure plots the year-by-year effect of Pct. Exposed on municipal bond yields for long and short-maturity bonds. The coefficients come from a regression identical to that in Equation 1, except instead of including a Post × Pct. Exposed interaction, we restrict the sample to only bonds traded during the year indicated on the x-axis. Long maturity is defined as greater than 10 years, and is denoted by the solid line. Short maturity is denoted by the dashed line. The vertical bars reflect the 95% confidence intervals, where standard errors are clustered at the county-level.

Table 1: Summary Statistics

	Full Coastal Sample			*SLR Exposed Districts*		
	Mean	Std.Dev.	Obs	Mean	Std.Dev.	Obs
Percent of Properties Exposed (3ft GASLR)	1.08	3.26	544,071	2.47	4.56	238,360
Percent of Properties Exposed (6ft GASLR)	3.18	9.12	544,071	7.26	12.65	238,360
Average Price, Single Family Home ($000s)	404.91	447.44	544,071	442.60	564.11	238,360
Bond Yield to Worst1	3.38	1.25	544,071	3.36	1.25	238,360
Time to Maturity	10.10	6.35	544,071	9.92	6.21	238,360
Bond Age	3.90	2.69	544,071	3.89	2.66	238,360
Monthly Trading Volume ($mm)	509.26	3138.31	544,071	624.75	4157.25	238,360
Monthly SD of Price	0.91	0.72	480,004	0.92	0.72	211,061

Note: This table reports the summary statistics for the main variables used in this paper. Observations are at the district by month frequency. Sea Level Rise exposures are measured within school districts and represent the percent of residential properties that would be inundated after a X feet of global average sea level rise.

Table 2: Effect of Sea Level Rise on Bond Yields

	Full Sample		East	Gulf	West
	(1)	(2)	(3)	(4)	(5)
Pct. Exposed	-0.015	0.029	0.022	0.123	-0.156
	(-0.31)	(0.40)	(0.46)	(0.60)	(-1.51)
Post X Pct. Exposed	0.240**	0.240**	0.438***	0.037	-0.039
	(2.34)	(2.41)	(4.15)	(0.20)	(-0.26)
Time to Maturity	0.129***	0.146***	0.135***	0.121***	0.129***
	(41.64)	(48.67)	(34.11)	(35.91)	(31.95)
Log(Average Value)	-0.022**	-0.028**	-0.015*	0.036	-0.074**
	(-2.29)	(-2.24)	(-1.93)	(1.01)	(-2.55)
Coupon	0.066***	0.110***	-0.031***	0.215***	0.078***
	(6.82)	(10.56)	(-3.31)	(9.82)	(6.96)
Bond Age	0.091***	0.104***	0.088***	0.112***	0.089***
	(18.03)	(18.13)	(17.88)	(19.20)	(10.82)
Log(Monthly Volume)	-0.035***	-0.045***	-0.037***	-0.038***	-0.030***
	(-10.87)	(-11.96)	(-13.93)	(-11.76)	(-6.29)
Monthly SD of Price	0.094***	0.114***	0.094***	0.075***	0.097***
	(21.65)	(22.74)	(17.30)	(8.84)	(18.24)
Constant	2.020***	1.481***	2.372***	0.603	2.628***
	(14.48)	(8.01)	(23.58)	(1.34)	(6.40)
Adj. R-squared	0.802	0.800	0.832	0.791	0.789
Adj. Within R-squared	0.683	0.729	0.683	0.692	0.693
Outcome Mean	3.391	3.080	3.282	3.447	3.466
Outcome SD	1.247	1.268	1.220	1.268	1.254
Outcome Within-SD	0.960	1.068	0.853	1.016	1.024
Observations	474,363	336,241	182,154	93,683	198,437

Note: This table reports the effect of Pct. Exposed on municipal bond yields in the pre- and post-2013 period. In Column 1, we estimate Equation 1 over our full sample from 1997 to 2017. In Column 2, we estimate the same equation over a shorter 10-year sample concentrated around 2013. In Column 3, we limit the sample to school districts on the East Coast, Column 4, the Gulf Coast and Column 5 the West Coast. Pct. Exposed measures the share of homes that would be inundated with a six foot SLR.

Table 3: Heterogeneity in Effect of Sea Level Rise on Bond Yields by Sentiment

	(1)	(2)	(3)	(4)
Pct. Exposed	-0.077	-0.001	-0.024	0.010
	(-1.25)	(-0.01)	(-0.49)	(0.20)
Post X Pct. Exposed	0.106	-0.185	0.226**	0.428***
	(1.19)	(-0.87)	(2.16)	(3.86)
Post X Pct. Exposed X State SLR	0.236***	0.488***		
	(3.01)	(2.86)		
Post X Pct. Exposed X State Worry			0.138	0.363***
			(1.35)	(2.90)
Time to Maturity	0.129***	0.135***	0.129***	0.135***
	(41.60)	(34.14)	(41.62)	(34.10)
Coupon	0.067***	-0.031***	0.066***	-0.031***
	(6.84)	(-3.34)	(6.81)	(-3.29)
Bond Age	0.091***	0.088***	0.091***	0.088***
	(18.05)	(17.95)	(18.05)	(17.92)
Log(Monthly Volume)	-0.035***	-0.037***	-0.035***	-0.037***
	(-10.96)	(-13.98)	(-10.93)	(-13.99)
Monthly SD of Price	0.094***	0.094***	0.094***	0.094***
	(21.66)	(17.31)	(21.65)	(17.30)
Constant	1.760***	2.263***	1.756***	2.198***
	(25.13)	(31.50)	(24.98)	(35.87)
Sample	All	East Coast	All	East Coast
Adj. R-squared	0.802	0.832	0.802	0.832
Adj. Within R-squared	0.683	0.683	0.683	0.683
Outcome Mean	3.391	3.282	3.391	3.282
Outcome SD	1.247	1.220	1.247	1.220
Outcome Within-SD	0.960	0.853	0.960	0.853
Observations	474,363	182,154	474,363	182,154

Note: This table explores heterogeneity in the effect of Pct. Exposed on municipal bond yields in the pre- and post-2013 period. In Column 1 and 3, we use the full sample. In Column 2 and 4, e limit the sample to school districts on the East Coast. Pct. Exposed measures the share of homes that would be inundated with a six foot SLR.

Table 4: The Effect of Sea Level Rise on Bond Yields: Identification and Channel

	(1)	(2)	(3)
Post X Pct. Exposed	0.240**	-0.175	
	(2.34)	(-1.13)	
Pct. Exposed X Time to Maturity		0.004	0.016
		(0.52)	(0.65)
Post X Time to Maturity		0.007	0.007
		(1.59)	(1.53)
Post X Pct. Exposed X Time to Maturity		0.043***	0.034**
		(2.76)	(2.01)
Log(Average Value)	-0.022**		
	(-2.29)		
Constant	2.020***	1.742***	1.660***
	(14.48)	(25.81)	(24.51)
Controls	Y	Y	Y
FIPS X Month FE	Y	Y	N
District X Month FE	N	N	Y
Adj. R-squared	0.802	0.802	0.824
Adj. Within R-squared	0.683	0.684	0.696
Outcome Mean	3.391	3.391	3.396
Outcome SD	1.247	1.247	1.241
Outcome Within-SD	0.960	0.960	0.846
Observations	474,363	474,363	430,517

Note: This table explores the role of bond maturity on the effect of Pct. Exposed on municipal bond yields in the pre- and post-2013 period. In Column 1 and 2, we use the same set of county-by-month fixed effects and controls as in Table 2 and 3. In Column 3, we use school-district-by-month fixed effects. Pct. Exposed measures the share of homes that would be inundated with a six foot SLR.