Sea Level Rise Exposure and Municipal Bond Yields

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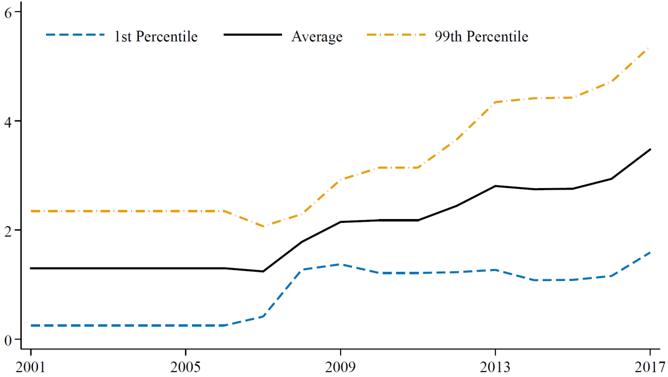
Motivation

Predicted Global Sea-Level Rise by 2100



Distribution of projected SLR (in feet) by 2100 from a sample of 22 scientific studies.

- Interest in climate risk is growing as scientific consensus worsens.
  - Worst-case projections of sea level rise (SLR) tripled since 2007
  - Experts also forecast more severe storms and associated flooding
- What are the expected economic costs of SLR?
  - Costs $\rightarrow$ understanding benefits of remediation
  - Financial asset prices are forward-looking

Literature / context:

Existing Papers

- Climate *AND*
  - Real Estate e.g. Bernstein et al. (2019), Baldauf et al. (2020), Murfin and Spiegel (2020), Gigli et al. (2014, 2018)
  - Financial markets e.g. Painter (2020), Bennet and Wang (2019), Cortés and Strahan (2017), Brown et al. (2020), Krueger et al. (2020)
  - Macro e.g. Brock et al. (2020), Barnett (2020)

Our Paper

- We study the effect of SLR exposure on municipal bond prices.
  - Bond credit spreads depend on likelihood of negative shocks
  - Source of repayment is defined geography (e.g., property tax)
  - Can translate asset price changes into estimates of real economic effects

Our Approach

1. Estimate the effect of SLR exposure on municipal credit spreads.
   - Detailed local variation based on geography of school districts.
   - Compare bonds from issuers in same county, traded in same month.
   - Term structure and regional variation shed light on nature of risk.

2. Simple model of credit risk to interpret estimates in economic terms.
   - Adapt Merton (1974) model from corporate finance literature.
   - Hedge ratios show the economic impact implied by bond yield changes.

Preview of Findings

- SLR exposure is associated with slightly higher muni bond spreads.
  - Effects are growing over time, in line with scientific consensus.
  - 1 S.D. higher SLR exposure $\Rightarrow$ 6 bps higher spreads on East/Gulf coast.

- Cross-sectional effects shed light on the underlying mechanism.
  - Driven by East and Gulf coasts,
    - where near-term storm risk is greater
    - local tax environment is very different

    and significant at both long and short maturities.
  - Concentrated in states where people are worried about climate change

- Estimates imply a non-trivial economic impact of SLR exposure.
  - Reduction of 3% to 6% in present value of local gov't cash flows, or increase of 2% to 3% in the volatility of cash flows.

Contributions to the Literature

- Cost of debt depends on location-specific exposure to climate risk.
    - Builds on prior work studying firms and real estate markets.
    - Benefits vs. housing papers: aggregation, smaller role of risk aversion.
- Application of Merton (1974) model to the municipal bond market.
    - Useful sanity check for researchers conducting similar studies.
- Differences between our results and Painter (JFE 2020):
    - **Timing:** Insignificant effect of SLR before 2014, positive afterwards. Painter's result is driven by 2009, negative or insignificant post-crisis.
    - **Magnitude:** Smaller and more consistent with model's predictions.

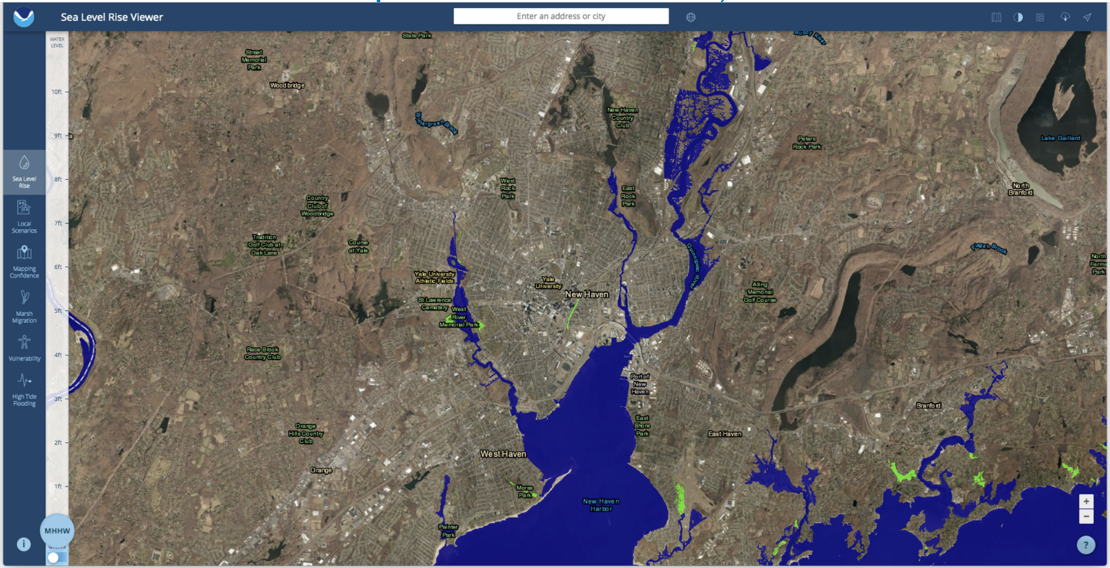
Data

- Monthly panel of school district bond prices from 2001 to 2017.
  - Issues with primary/secondary education as purpose in Mergent.
    - 27% of new municipal issues over sample period.
  - Restrict to tax-exempt bonds with $\geq$ 10 trades in MSRB data.
  - "Balanced" panel: $>$ 1 district per county, $\geq$ 1 trade per district-year.
  - Calculate volume-weighted credit spreads over AAA tax-exempt curve.
    - Similar results if we use tax-adjusted spreads over swap curve.

Data

- Merge bond issuers to geographic data on school district boundaries.
  - Restrict the sample to coastal counties to ensure uniformity.
- Key variable: Fraction of properties exposed to X feet of SLR.
  - Exact location of each residential property from Zillow.
  - NOAA offers precise maps of SLR exposure across the U.S.

Measurement of SLR Exposure - New Haven, CT



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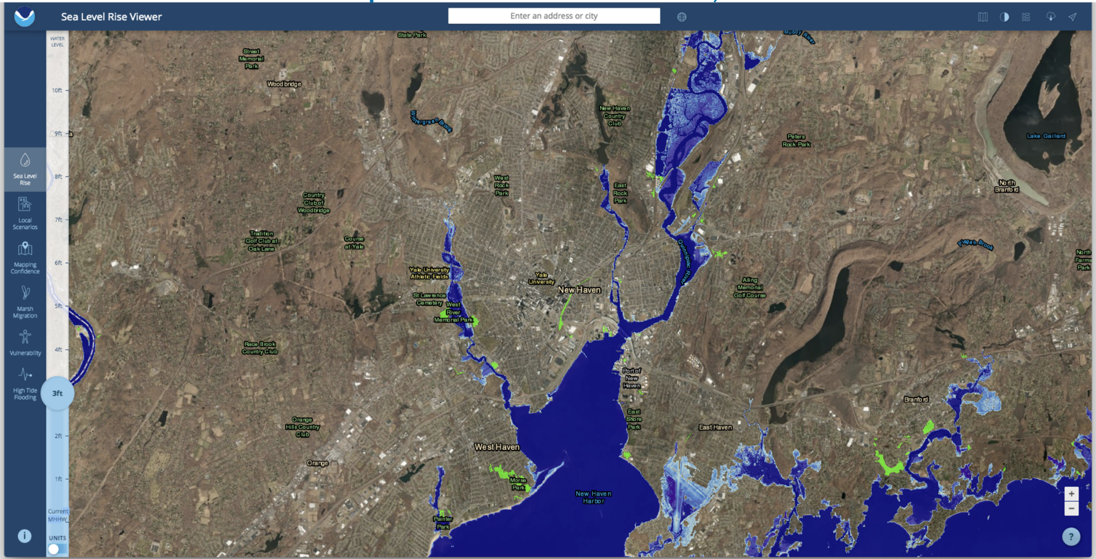

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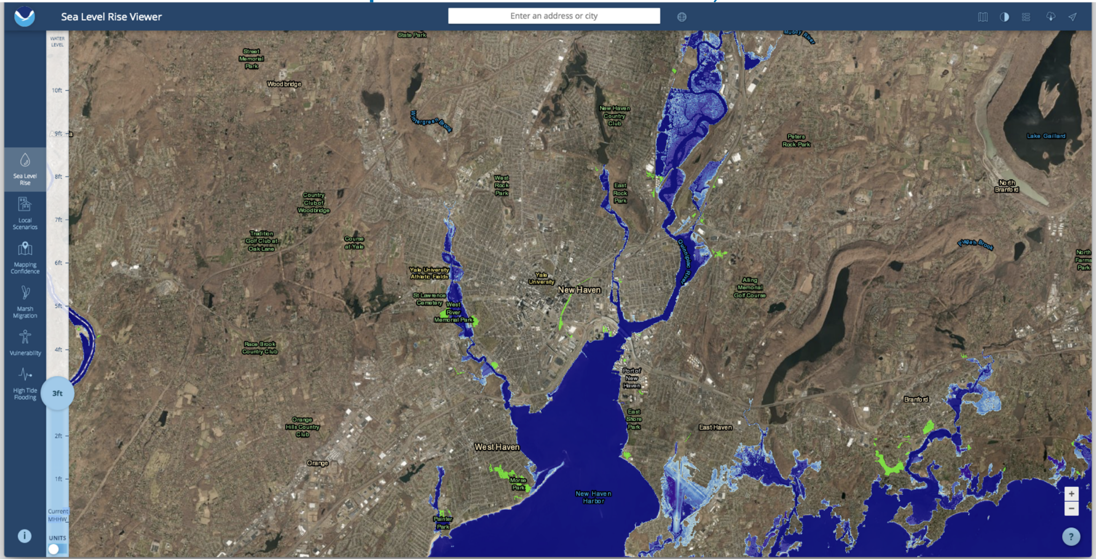
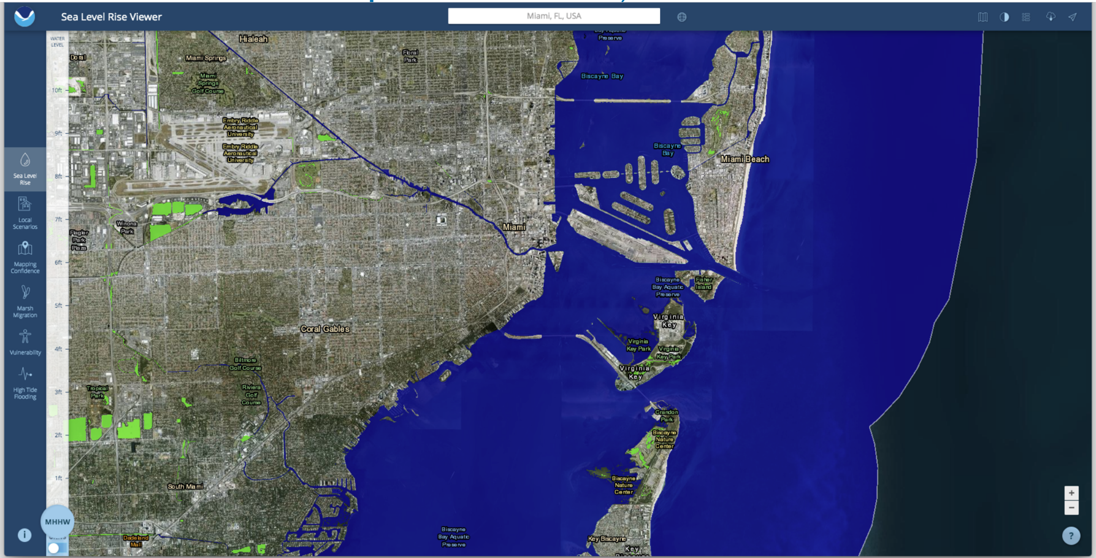


Measurement of SLR Exposure - Miami, FL



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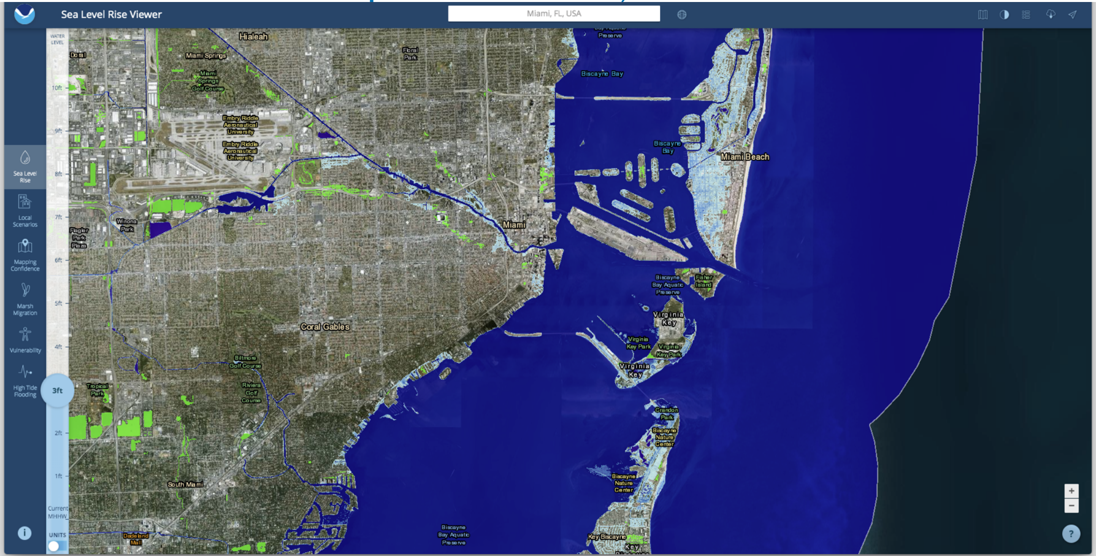

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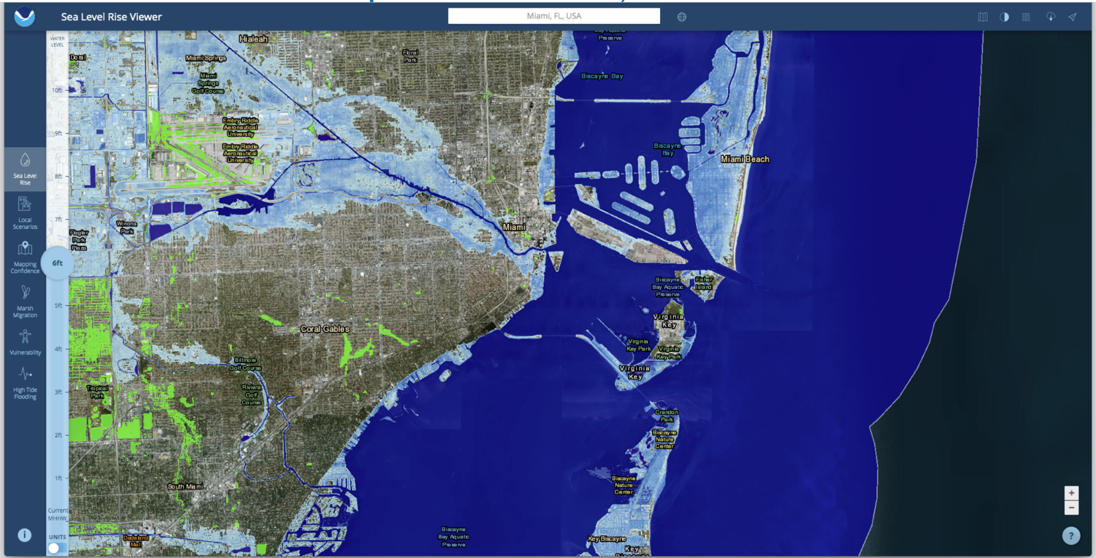
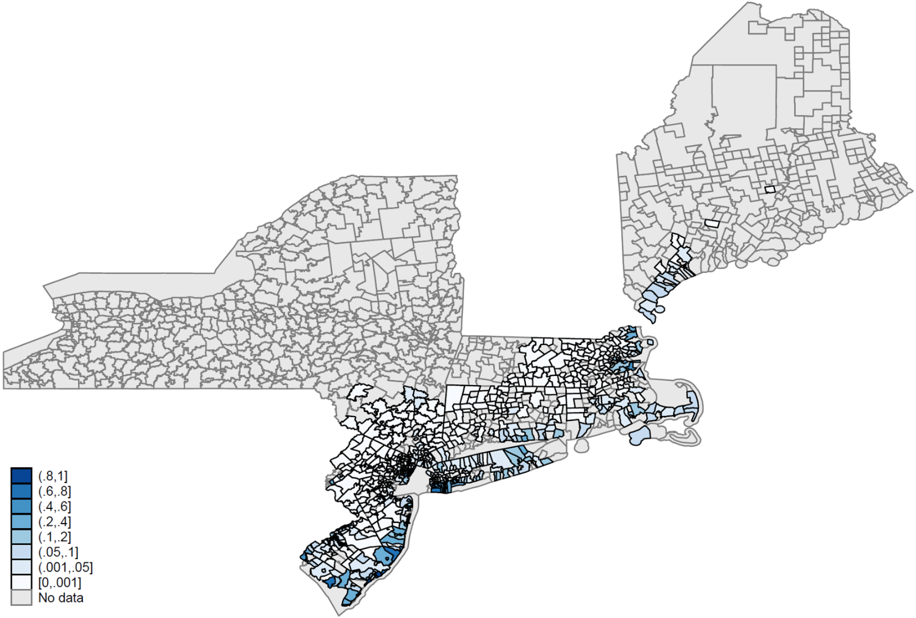


SLR Exposure in the Northeast



Sample Characteristics

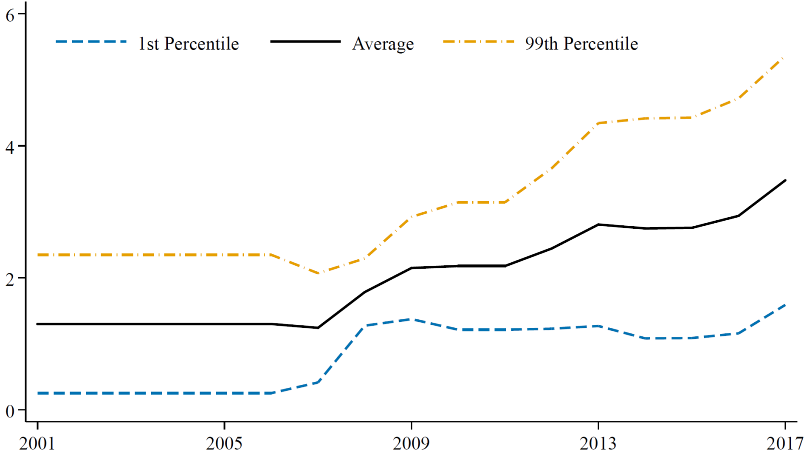
Summary statistics at the bond-month level:

	Full Coastal Sample		***SLR Exposed Districts***	
	Mean	Std.Dev.	Mean	Std.Dev.
Fraction of Properties Exposed (5 foot SLR)	0.02	0.07	0.05	0.10
Yield-to-Maturity (%)	3.32	1.26	3.27	1.25
MMA AAA-Rated Tax-Exempt Rate (%)	2.69	1.27	2.65	1.27
Spread over MMA Curve (bps)	62.67	59.14	62.49	58.72
Time to Maturity	9.87	6.25	9.60	6.08
Bond Age	4.04	2.75	3.99	2.69
Monthly Trading Volume ($MM)	0.61	3.82	0.77	5.08
Monthly Turnover	0.18	0.36	0.16	0.34
Monthly S.D. of Price (per $100)	0.91	0.72	0.91	0.71
Callable	0.62	0.48	0.62	0.49
Insured	0.54	0.50	0.54	0.50
General Obligation	0.997	0.05	0.997	0.05
Residents' Average Income ($000s)	41.21	31.39	42.79	28.66
Observations	321,735		145,993	

Top states: CA (45%), TX (25%), NJ (13%), NY (12%), SC (2%)

Hypothesis Development

Scientific projections of sea level rise have worsened over time.



Distribution of projected SLR (in feet) by 2100 from a sample of 22 scientific studies.

Prediction: SLR exposure has an increasingly positive effect on credit spreads.

Google Searches

Hypothesis Development

Several channels through which climate risk could affect bond prices:

- Long-run risk of slowly rising oceans.
  - Only very long-maturity bonds should be affected.
  - All coastal issuers should see similar effects.
- Near-term risk of more severe storm flooding.
  - Both long and short maturities should be affected.
  - Effects should be present on East and Gulf coasts, not West.
- Differences in investor beliefs across regions may also play a role.

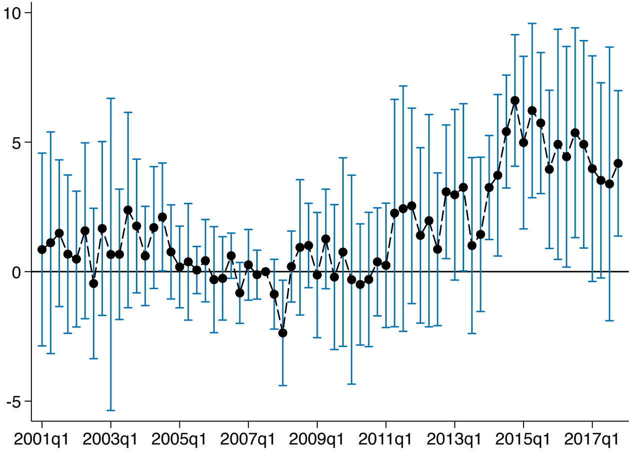
Empirical Framework

- **Goal:** Identify effect of SLR exposure on credit spreads over time.
- We estimate the following panel regression:

$$\text{Spread}_{bijt} = c_{jt} + c_i + \sum_{y=2001}^{2017} \left[\alpha_y \text{Frac. Exposed}_i + \beta_y X_{bijt} \right] + \gamma Y_{bijt} + \epsilon_{bijt}$$

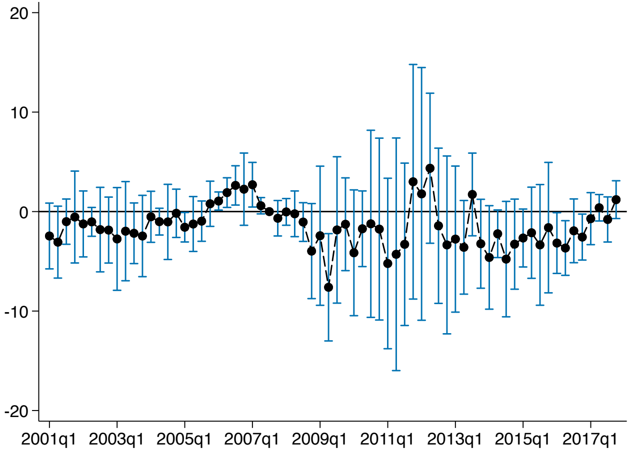
  - b indexes the bond (CUSIP)
  - i indexes the school district (issuer)
  - j indexes the county location
  - t indexes the year-month period
  - c_{jt} includes county-time fixed effects
  - c_i includes district fixed effects
  - X_{bijt} controls for maturity, callability, insured status, bond type
  - Y_{bijt} controls for liquidity and local income (from IRS)

Regression Estimates - East/Gulf Coast



- $1\sigma \uparrow$ implies 5bps increase in yields
- Highly significant, starting $\approx$2013

Regression Estimates - West Coast



- Non-existant on West Coast
- Consistent with:
  - near-term risk of storm flooding and longer-run SLR risk
  - tax structure mattering a lot (Prop 13 in CA)
  - Can we exploit maturity structure to test?

Differential Effects by Maturity & Storm-surge

	(1)	(2)	(3)	(4)	(5)
Post=1 × SLR Exposure	2.929**	6.973***	2.744**	1.421	
	(2.15)	(3.28)	(2.36)	(0.86)	
Post=1 × Storm Surge Exposure		−5.669		1.985	
		(−1.53)		(0.81)	
Post=1 × SLR Exposure × Log(Maturity)					2.723***
					(3.50)
Post=1 × Storm Surge Exposure × Log(Maturity)					−2.385*
					(−1.83)
Sample	East & Gulf	East & Gulf	East & Gulf	East & Gulf	East & Gulf
Maturity Range	> 10 years	> 10 years	< 10 years	< 10 years	All
Controls	Y	Y	Y	Y	Y
District FE	Y	Y	Y	Y	N
County-Year-Month FE	Y	Y	Y	Y	N
District-Year-Month FE	N	N	N	N	Y
Outcome Mean	58.679	58.679	56.528	56.528	57.598
Outcome SD	48.883	48.883	58.436	58.436	54.470
Observations	65,193	65,193	90,019	90,019	155,212

- Short-term SLR effect is insignificant after controlling for storm surge.
- Bottom line: Overall effect on yields is due to both short- and long-run risks.

Differential Effects by Local Beliefs

	(1)	(2)	(3)
Post=1 $\times$ SLR Exposure	5.629^{***}	-1.144	4.634^{***}
	(5.91)	(-0.53)	(4.13)
Post=1 $\times$ SLR Exposure $\times$ State Worry			3.421^{**}
			(2.61)
Sample	East & Gulf	East & Gulf	East & Gulf
Level of Concern	Worried	Not Worried	All
Controls	Y	Y	Y
District FE	Y	Y	Y
County-Year-Month FE	Y	Y	Y
Outcome Mean	53.480	61.035	57.399
Outcome SD	53.830	55.045	54.594
Observations	74,869	80,343	155,212

Measure beliefs with survey data on worries about global warming, aggregating county surveys from Howe et al. (2015) by state market.

- Worried states: NY, MA, NJ, RI, CT, ME
- Not worried: TX, SC, MS, LA

Simple Model of Municipal Credit Risk

- What do yield changes imply about the economic impact of SLR risk? To interpret our estimates, we adapt the Merton (1974) model.

- Present value of cash flows available to repay bonds follows:

$$d \ln V_t = \left(r - \frac{1}{2}\sigma^2 \right) dt + \sigma dW_t^Q$$

  - V reflects expected tax revenues, expenditures, and intergovernmental transfers (e.g., bailouts).

- Value of zero-coupon bond with face value K:

$$D = V - \left[V\Phi(d_1) - Ke^{-rT}\Phi(d_2) \right]$$

  where d_1 and d_2 are defined as in Black and Scholes (1973).

Support for Application of the Merton Model

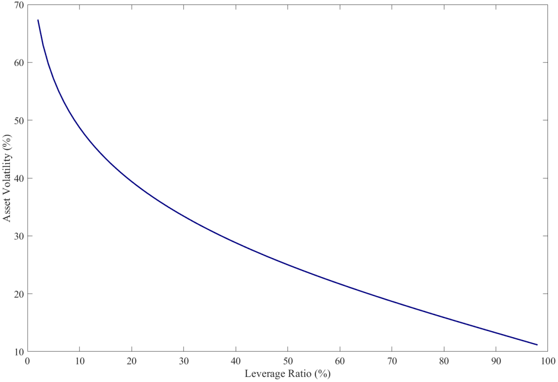
- Municipal bond prices depend on credit and non-credit factors:

$$D = D_C + D_{NC}$$

- Merton model captures the sensitivity of D_C to changes in V.
  - Schaefer and Strebulaev (2008) find support in corporate bond market.
  - Failure to match *level* of credit spreads is due to importance of D_{NC}.
  - Hedge ratios work because *changes* in V and D_{NC} are orthogonal.

- Our regression analysis identifies changes in D_C and filters out D_{NC}.
  - County-time FEs control for time-varying state-level market conditions.
  - Bond-specific controls for term structure, liquidity, embedded options.

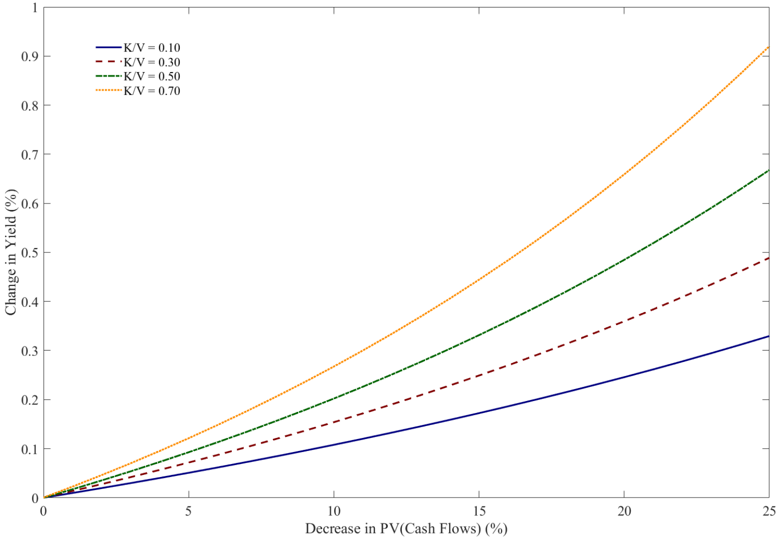
Calibration of Model Parameters



- Difficult to measure V and K in the municipal setting.
- Instead, we calibrate these parameters to match observed yields.
  - Baseline specification: $y = 3.33\%$, $r = 2.70\%$, $T = 7.5$.
  - Fix leverage ratio K/V and solve for volatility σ.

Model-Implied Effects of Loss of Economic Output

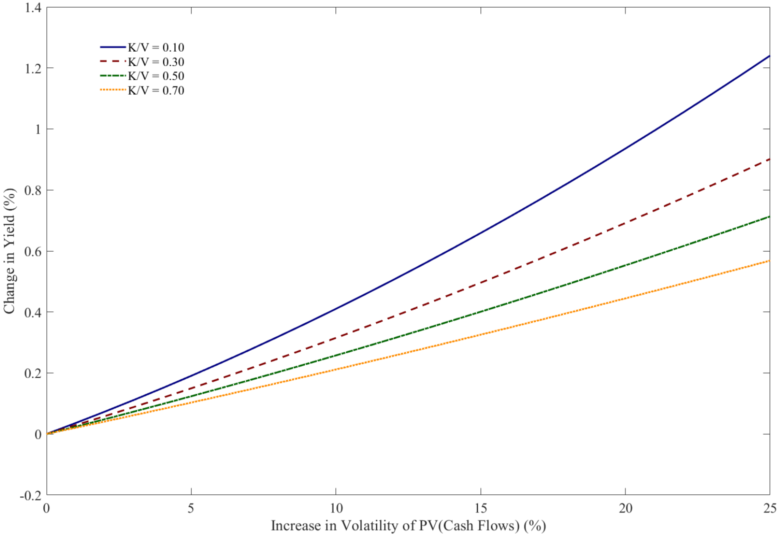
- What is the effect of a decrease in local government cash flows?



Municipal bonds have low baseline default risk, so effects are small

Model-Implied Effects of Rise in Volatility

- What is the effect of an increase in cash flow volatility?



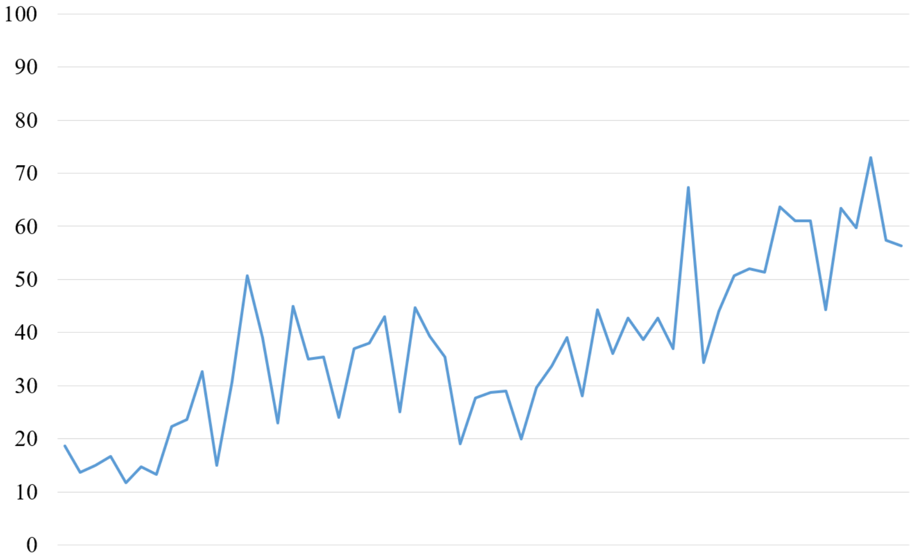
- With a long time to maturity, changes in volatility have larger effects

Conclusion

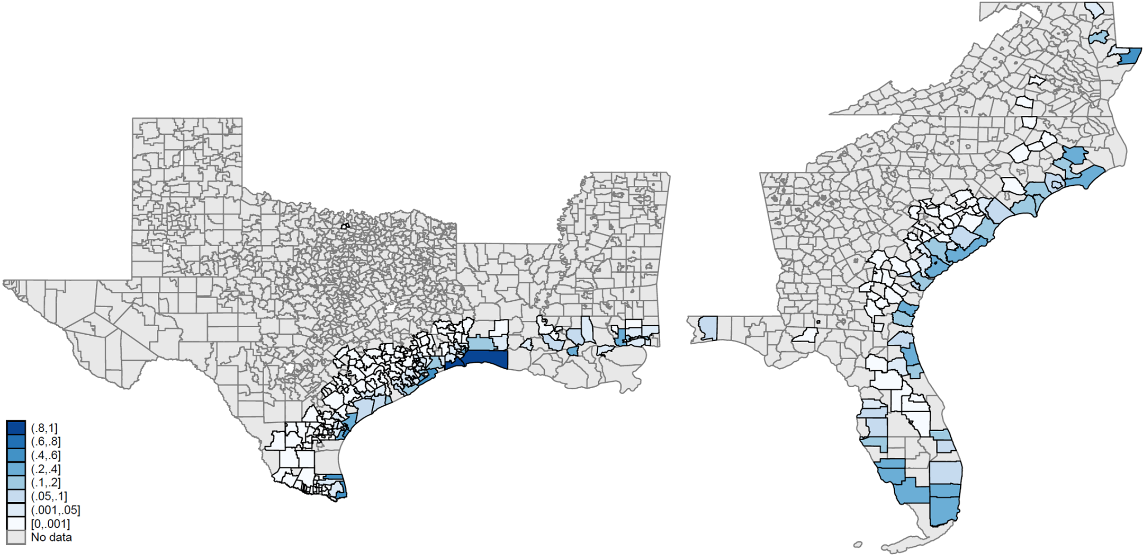
- Exposure to sea level rise is priced in municipal bond markets.
  - Effects grow over time, in line with worsening scientific projections.
  - Strongest where storm risk is high, people believe in climate change.
- Economic magnitude of effect on borrowing costs is small.
  - Market price is not implying high risk of climate-induced default in Munis
- However, the economic impact implied by bond prices is non-trivial.
  - Reduction of 3% to 6% in V, or increase of 2% to 3% in σ.
  - Approach can be used in other settings without balance sheet data.

Popular Interest in Sea Level Rise

Google search trend for “sea level rise”:



SLR Exposure in the Southeast



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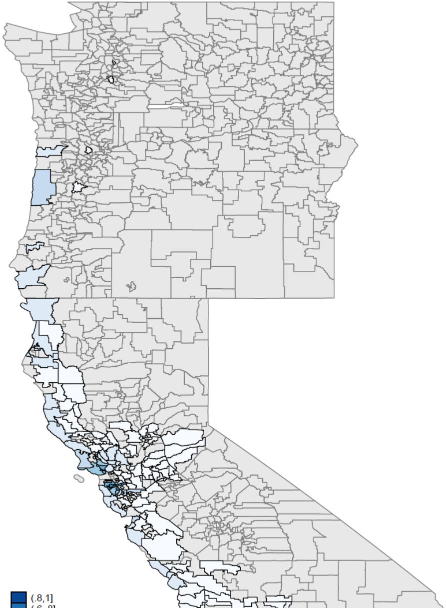
SLR Exposure on the West Coast



Time-Series of School Bond Credit Spreads