Motivation

- 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 → 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.
   - 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.
  - 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: \( \geq 1 \) 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
Measurement of SLR Exposure - New Haven, CT
Measurement of SLR Exposure - New Haven, CT
Measurement of SLR Exposure - Miami, FL
### Sample Characteristics

Summary statistics at the bond-month level:

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

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.

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

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

- \(b\) 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 $\approx 2013$
- 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

<table>
<thead>
<tr>
<th></th>
<th>(1)</th>
<th>(2)</th>
<th>(3)</th>
<th>(4)</th>
<th>(5)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Post=1 × SLR Exposure</td>
<td>2.929**</td>
<td>6.973***</td>
<td>2.744**</td>
<td>1.421</td>
<td></td>
</tr>
<tr>
<td></td>
<td>(2.15)</td>
<td>(3.28)</td>
<td>(2.36)</td>
<td>(0.86)</td>
<td></td>
</tr>
<tr>
<td>Post=1 × Storm Surge Exposure</td>
<td>−5.669</td>
<td></td>
<td>1.985</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>(−1.53)</td>
<td></td>
<td>(0.81)</td>
<td></td>
<td></td>
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<tr>
<td>Post=1 × SLR Exposure × Log(Maturity)</td>
<td></td>
<td></td>
<td></td>
<td>2.723***</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>(3.50)</td>
<td></td>
</tr>
<tr>
<td>Post=1 × Storm Surge Exposure × Log(Maturity)</td>
<td></td>
<td></td>
<td></td>
<td>−2.385*</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>(−1.83)</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Sample</th>
<th>East &amp; Gulf</th>
<th>East &amp; Gulf</th>
<th>East &amp; Gulf</th>
<th>East &amp; Gulf</th>
<th>East &amp; Gulf</th>
</tr>
</thead>
<tbody>
<tr>
<td>Maturity Range</td>
<td>&gt; 10 years</td>
<td>&gt; 10 years</td>
<td>&lt; 10 years</td>
<td>&lt; 10 years</td>
<td>All</td>
</tr>
<tr>
<td>Controls</td>
<td>Y</td>
<td>Y</td>
<td>Y</td>
<td>Y</td>
<td>Y</td>
</tr>
<tr>
<td>District FE</td>
<td>Y</td>
<td>Y</td>
<td>Y</td>
<td>Y</td>
<td>N</td>
</tr>
<tr>
<td>County-Year-Month FE</td>
<td>Y</td>
<td>Y</td>
<td>Y</td>
<td>Y</td>
<td>N</td>
</tr>
<tr>
<td>District-Year-Month FE</td>
<td>N</td>
<td>N</td>
<td>N</td>
<td>N</td>
<td>Y</td>
</tr>
<tr>
<td>Outcome Mean</td>
<td>58.679</td>
<td>58.679</td>
<td>56.528</td>
<td>56.528</td>
<td>57.598</td>
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<tr>
<td>Outcome SD</td>
<td>48.883</td>
<td>48.883</td>
<td>58.436</td>
<td>58.436</td>
<td>54.470</td>
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<tr>
<td>Observations</td>
<td>65,193</td>
<td>65,193</td>
<td>90,019</td>
<td>90,019</td>
<td>155,212</td>
</tr>
</tbody>
</table>

- 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

<table>
<thead>
<tr>
<th>Estimator</th>
<th>(1)</th>
<th>(2)</th>
<th>(3)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Post=1 × SLR Exposure</td>
<td>5.629***</td>
<td>–1.144</td>
<td>4.634***</td>
</tr>
<tr>
<td></td>
<td>(5.91)</td>
<td>(–0.53)</td>
<td>(4.13)</td>
</tr>
<tr>
<td>Post=1 × SLR Exposure × State Worry</td>
<td></td>
<td></td>
<td>3.421**</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>(2.61)</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Sample</th>
<th>East &amp; Gulf Worried</th>
<th>East &amp; Gulf Not Worried</th>
<th>East &amp; Gulf All</th>
</tr>
</thead>
<tbody>
<tr>
<td>Level of Concern</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Controls</td>
<td>Y</td>
<td>Y</td>
<td>Y</td>
</tr>
<tr>
<td>District FE</td>
<td>Y</td>
<td>Y</td>
<td>Y</td>
</tr>
<tr>
<td>County-Year-Month FE</td>
<td>Y</td>
<td>Y</td>
<td>Y</td>
</tr>
<tr>
<td>Outcome Mean</td>
<td>53.480</td>
<td>61.035</td>
<td>57.399</td>
</tr>
<tr>
<td>Outcome SD</td>
<td>53.830</td>
<td>55.045</td>
<td>54.594</td>
</tr>
<tr>
<td>Observations</td>
<td>74,869</td>
<td>80,343</td>
<td>155,212</td>
</tr>
</tbody>
</table>

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 \( V \).
  - 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 FE s 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 $\sigma$. 
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.

Estimated 6 bps increase in yield ⇒ 3% to 6% drop in V.
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.

- Estimated 6 bps increase in yield $\Rightarrow$ 2% to 3% increase in $\sigma$.
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 $\sigma$.
  - 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
SLR Exposure on the West Coast
Time-Series of School Bond Credit Spreads