# Natural Disasters and Municipal Bonds

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# Our exposure to natural disasters is increasing

- Disaster damage growing faster than GDP, number of "billion-dollar" disasters has increased consistently since 1980
- Growth in the number of disaster and emergency declarations in the US averaged 7% annually in 1990–2020
- Severity of extreme weather events will continue to grow (IPCC 2021)
- Physical climate risk ranks as the top climate finance risk over next 30 years (Stroebel and Wurgler 2021)
- Understanding of the role physical risk plays in asset markets is limited

# How do municipal bond prices respond to natural disasters?

- US municipal bonds: $4 trillion market in 2022
- Geographic diversification to protect against physical climate risk is not feasible
- Focus on prices allows for diff-in-diff-style analysis, comparing same bonds before and after disasters
  - Ex-post analysis has implications for ex-ante pricing of risk
- Heterogeneity of response along various dimensions helps understand mechanisms

# Preview of results: post-disaster dynamics

- Following a severe natural disaster, uninsured municipal bond returns decrease by 31 basis points (0.31%) on average
  - Estimated investor losses are big: $9.25 million per disaster-affected county ($9.6 billion across all counties in our sample)
- Estimated effects depend on:
  - Whether bonds are insured
  - Whether bonds are financed by general or project-specific revenue
  - Disaster severity
  - Post-disaster aid
  - Local government's financial health and revenue diversification

# Contributions

- Comparing prices of same set of bonds avoids potential endogeneity of post-disaster bond issuance (Jerch, Kahn, and Linn 2021)
- Rich heterogeneity analysis allows better understanding of mechanisms (e.g., role of federal aid)
- Study complements those of muni market response to sea level rise (Painter 2020; Goldsmith-Pinkham, Gustafson, Lewis, and Schwert 2021) and heat risk (Acharya et al. 2022)
  - Less salient than occurrence of natural disasters
  - Cannot be studied using the same set of bonds
  - SLR affects smaller set of communities

# Municipal bond data

- Municipal Securities Rulemaking Board (MSRB): 2005–2020
  - Reports each municipal bond transaction, including bond, date, and price
  - Aggregate to bond-by-week level
  - Exclude bond prices one week after issuance
- Mergent Municipal Bond Database: 1960–2016
  - Bond characteristics (e.g., source of repayment, coupon frequency, coupon rate)
  - Consider only tax-exempt bonds with fixed or zero coupons
  - Classify bonds as general obligation (GO) or revenue (REV) based on source of repayment

# Spatial Hazard Events and Losses Database for the United States (SHELDUS): 1960–2018

- Event type, year and month of occurrence, affected counties
- Estimated property and crop damage, injuries, and fatalities
- Exact event date is not available $\Longrightarrow$ assume disaster occurs on the last day of the month
- Focus on climatological disasters

# Federal Emergency Management Agency (FEMA) Database: 2005–2018

- Date and reason for major disaster declaration
- Amounts of Individual Assistance (ZIP level), Public Assistance (county level) and Hazard Mitigation funds (county level)
- Aggregate to county-year, normalize by reported SHELDUS damage

# County-level economic and financial data

- Regional Economic Information System (REIS): population, personal income
- Bureau of Labor Statistics: unemployment rate
- Census of Governments: local government debt, cash and securities, and tax revenue

Summary statistics

# Defining a natural disaster

- SHELDUS includes many small events: 191,177 county-months with "disasters" in the 2005–2018 period
- $\Longrightarrow$ calculate real per-capita property and crop damage, use \$3 as the cutoff for what constitutes a "disaster"
  - $\approx$ top 25% of events (25,426 county-months)
  - results robust to considering top 10% or top 20% of events by per-capita damage

# Measuring bond prices

- Municipal bonds are rarely traded ($< 3$ times per year) $\Longrightarrow$ high-frequency event studies with raw data are impossible
- But there are tens of thousands of bond issuers (as many as 50,000)
- Solution: employ the repeat sales approach to obtain weekly bond returns for many US counties
  - Motivated by real-estate literature (e.g., Case and Shiller 1987)
  - Has been successfully applied to corporate bonds (Spiegel and Starks 2016; Robertson and Spiegel 2017)

# Estimation of weekly return series

$$p_{i,s} = p_{i,b} \prod_{t=b+1}^{s} (1 + r_t^c)\varepsilon_{i,t}$$

- $p_{i,s}$ and $p_{i,b}$: prices of bond $i$ in weeks $s$ and $b$ $(s > b)$, respectively
- $r_t^c$: overall weekly return in county $c$ and week $t$
- $\varepsilon_{i,t}$: bond-specific idiosyncratic return component

- Take logs and rearrange...

# Repeat sales approach for municipal bonds

$$R_{i,b:s} = \sum_{t=b+1}^{s} R_t^c + e_{i,b:s}$$

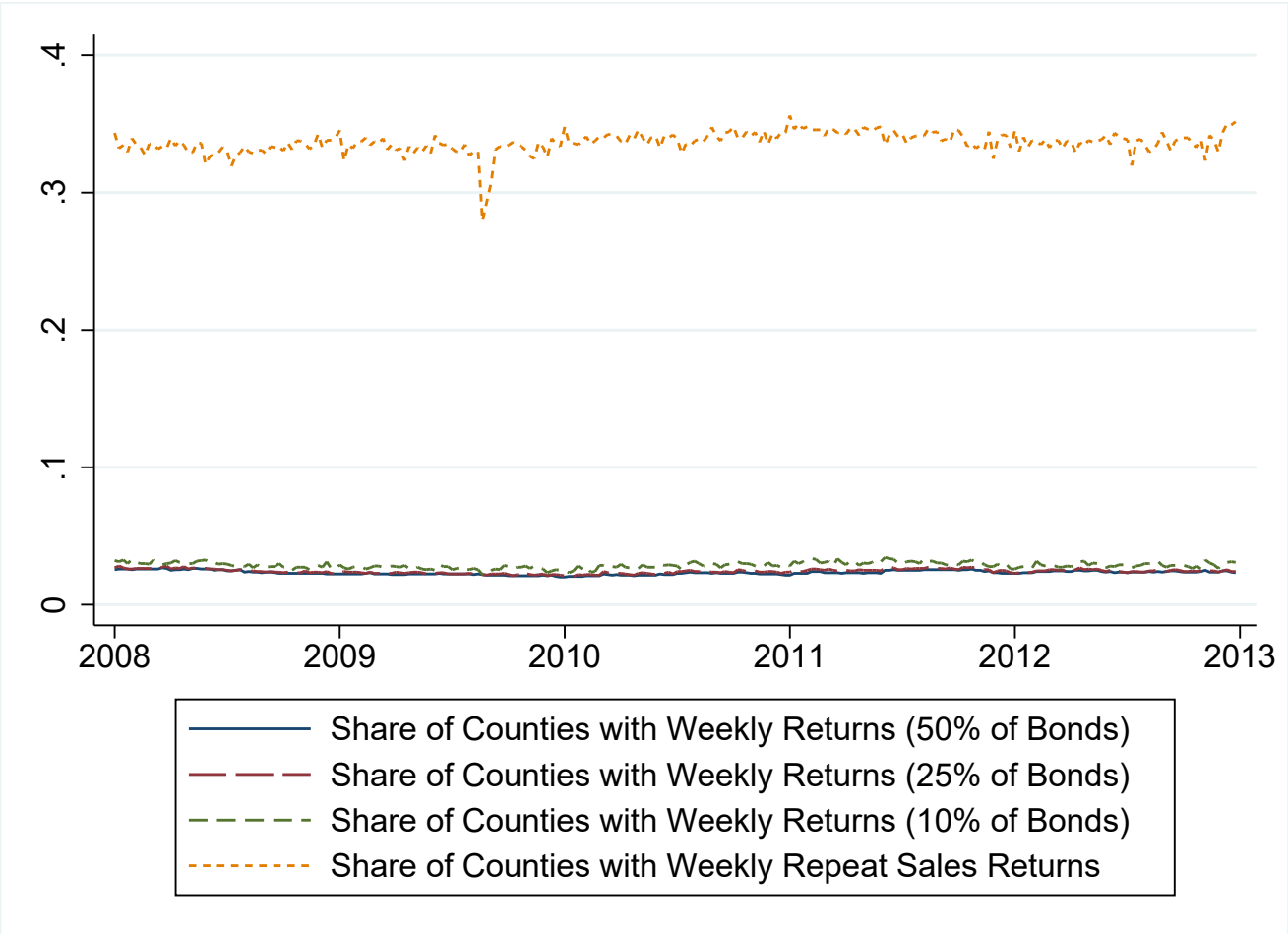
- $R_{i,b:s} = \log(p_{i,s}/p_{i,b})$ is log return of bond $i$ issued by county $c$ from week-year $b$ to $s$
- $R_t^c = \log(1 + r_t^c)$ is county-level weekly log returns at week-year $t$
- $e_{i,b:s} = \sum_{t=b+1}^{s} \log(\varepsilon_{i,t})$

- Quantity of interest: $R_t^c$

# Repeat sales estimation

- For each county $c$, regress individual bond log returns ($R_{i,b:s}$) on week-year indicators that equals 1 if $b < t \leq s$
  - Effectively estimating time fixed effects of bonds issued by county $c$
- Weight by par value of bond and the square root of time between $b$ and $s$
- Use five-year rolling window $[y-2, y+2]$ to estimate returns in year $y$ (results similar with three-year rolling window)
- Do for all bonds issues by a county and for REV/GO bonds separately

# Repeat sales vs raw return data



# Constructing cumulative abnormal returns

- For each extreme weather event indexed by $(c, t)$, the weekly cumulative abnormal return at week $\tau$ from $t - 15$ is:

$$WCAR_{c,t,\tau} = \sum_{s=-15}^{\tau} (R^c_{t+s} - R^b_{t+s})$$

- $R^b_{t+s}$: Average repeat sales return of 20 benchmark counties
  - Chosen among disaster-unaffected counties 500+ miles away that most closely match: lagged average coupon, credit rating, maturity, population, per-capita income, and unemployment rate

# Event study estimation

$$WCAR_{c,t,\tau} = \sum_{t' \in [-15,20], t' \neq -2} \beta(t') W_{c,t,\tau}(t') + \sum_{p=-5}^{50} \gamma(p) D_{c,t,\tau}(p) + \sum_{q=0}^{40} \delta(q) E_{c,t,\tau}(q) + \alpha_c + \epsilon_{c,t,\tau},$$

- $W_{c,t,\tau}(t') = 1$ if $\tau$ weeks from the disaster
- $D_{c,t,\tau}(p) = 1$ if another disaster in the same county at $t + \tau - p$
- $E_{c,t,\tau}(q) = 1$ if another disaster within 200 miles at $t + \tau - q$
- $\alpha_c$: county fixed effect

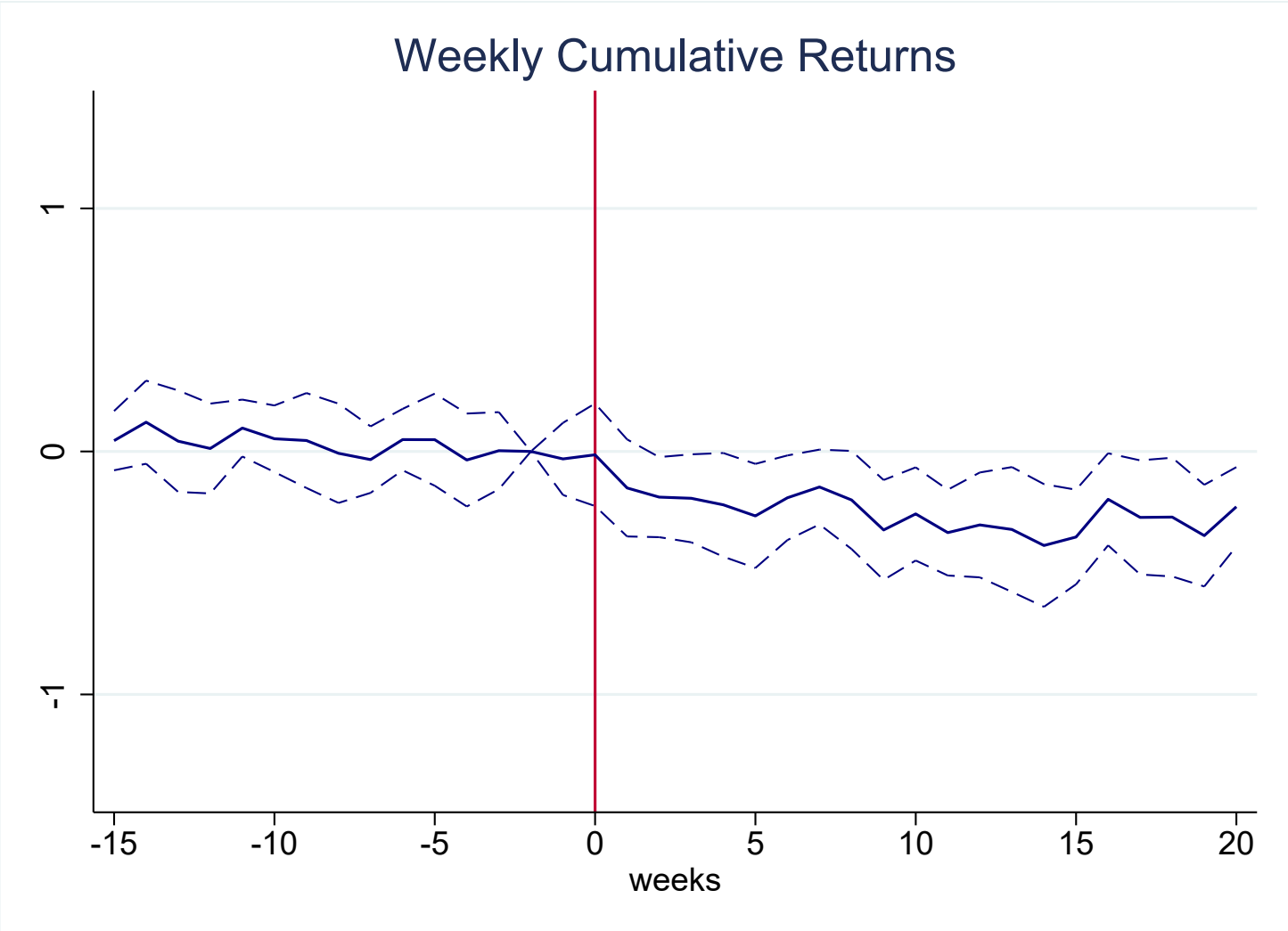
# Monthly estimates

- For brevity and statistical power, compare monthly CAR at $t-2$ to CAR at $t+4$

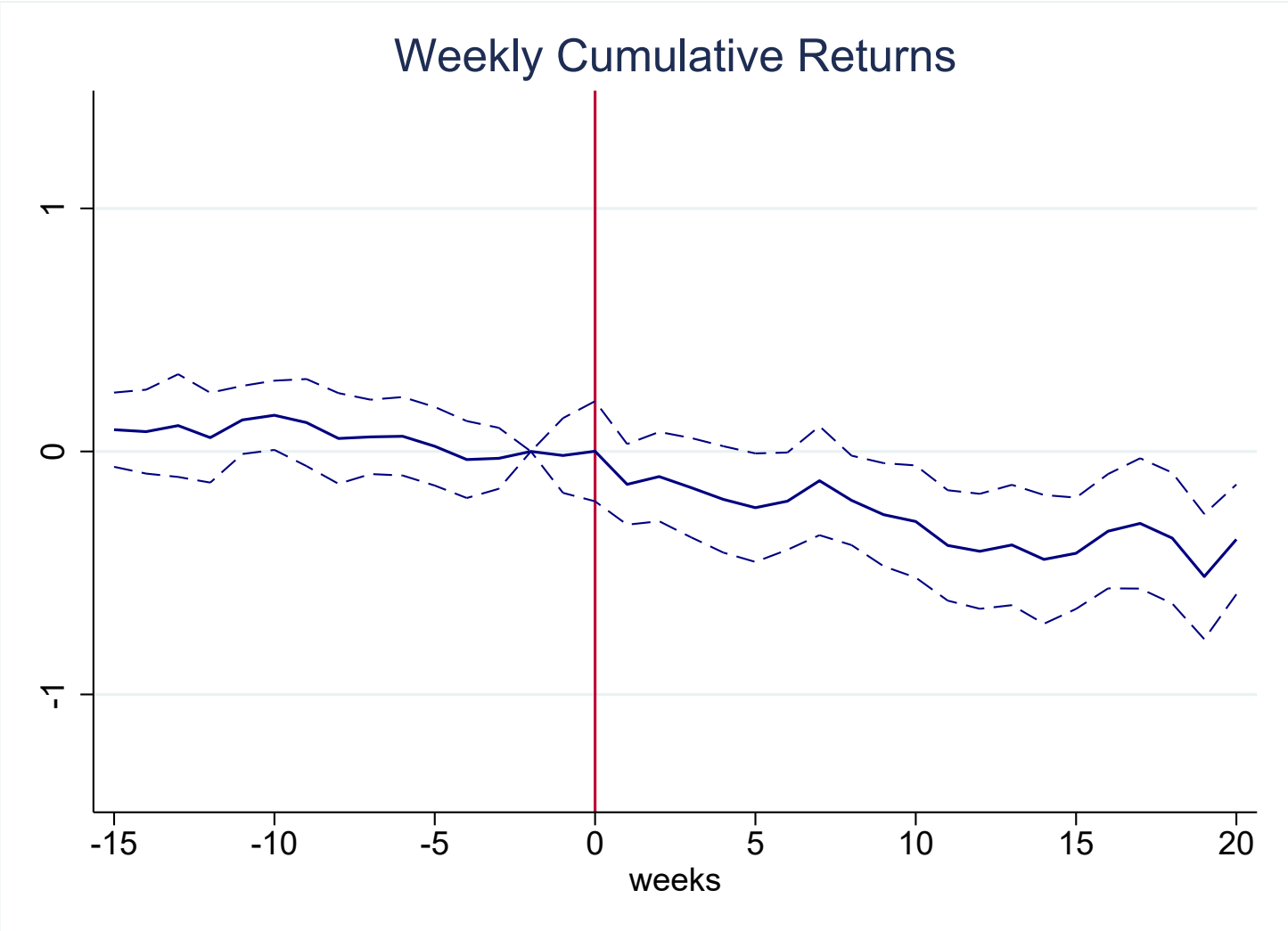
$$MCAR_{c,t,\tau} = \beta Post_{c,t,\tau} + \sum_{p=-1}^{12} \gamma(p) D^{M}_{c,t,\tau}(p) + \sum_{q=0}^{10} \delta(q) E^{M}_{c,t,\tau}(q) + \alpha_c + \epsilon_{c,t,\tau}$$

- $Post_{c,t,\tau} = 1$ four months after the disaster
- (Month-by-month estimates in paper)

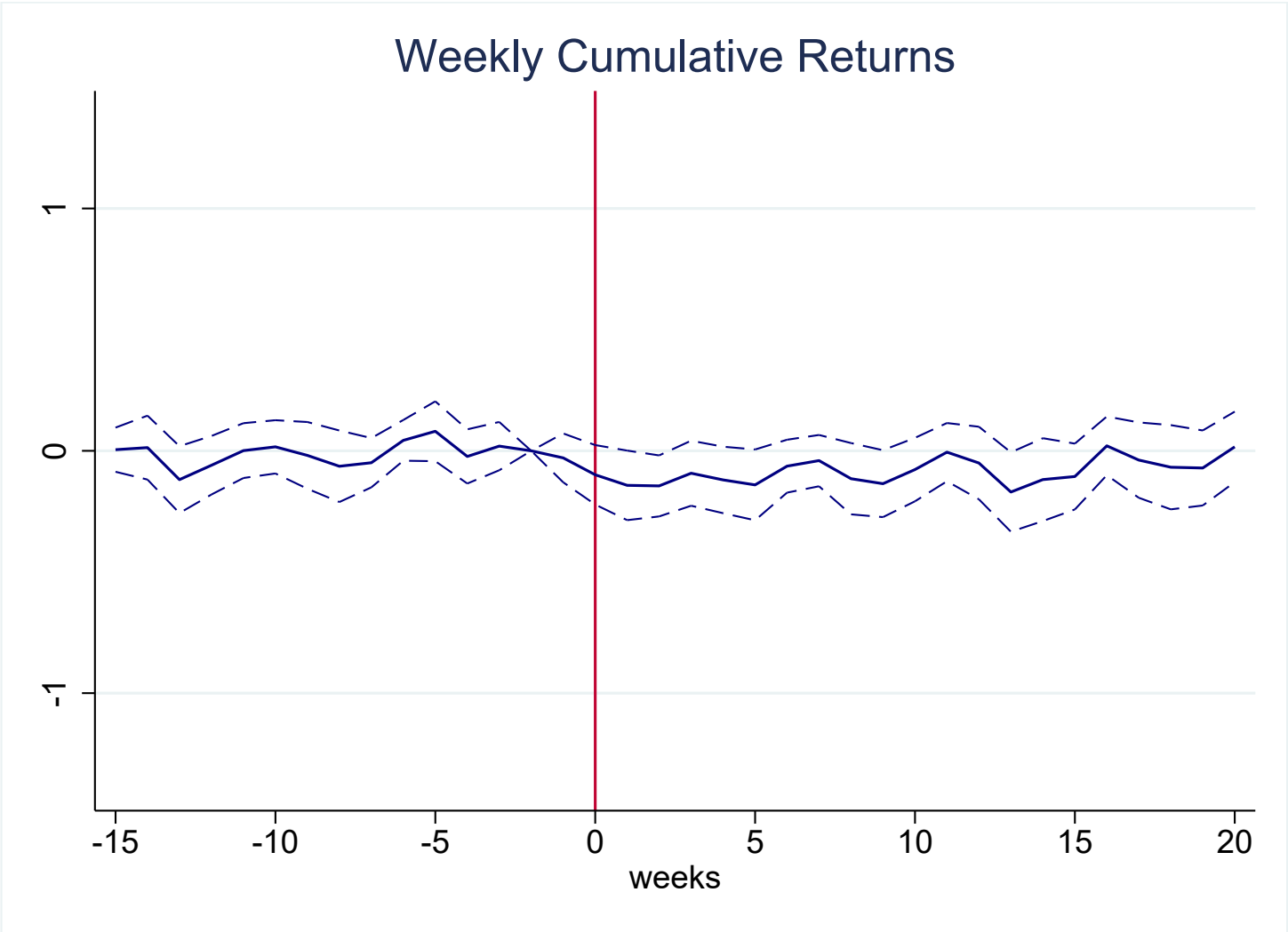
# Cumulative abnormal returns of uninsured bonds decrease slowly following a disaster



# Prices of uninsured revenue (REV) bonds show a larger post-disaster decline



# Uninsured general-obligation (GO) bonds are unaffected



# CAR around natural disasters: monthly estimates

| Dep Var: CR | All Bonds | REV Bonds | GO Bonds |
|---|---|---|---|
| Post | -0.3144** | -0.5089** | -0.1277 |
| | (-2.3279) | (-2.5602) | (-1.0594) |
| County FE | YES | YES | YES |
| No. of Obs. | 1996 | 1185 | 1316 |
| Adj. R-Squared | 0.31 | 0.32 | 0.3 |

Estimated investor losses are big: \$9.25 million per disaster-affected county or \$9.6 billion across all counties in our sample

# The repeat sales method is essential in our setting

Natural Disasters and Bond Returns Using the Conventional Approach

| Dep Var: CR | Raw Returns | |
|---|---|---|
| | REV Bonds | GO Bonds |
| Post | -1.2733 | -0.0127 |
| | (-1.0952) | (-0.0015) |
| County FE | YES | YES |
| No. of Obs. | 38 | 15 |
| Adj. R-Squared | 0.22 | 0.1 |

# Natural disasters affect income and employment, but not tax revenue

| Dep Var: | Income per Capita | Unemployment | Tax Revenue |
|---|---|---|---|
| Current | -1394.4858*** | -0.0826 | -0.0047 |
| | (-6.2512) | (-1.4271) | (-0.1986) |
| Short-term | 356.0371 | 0.0655 | -0.0235 |
| | (1.4267) | (1.0350) | (-0.9895) |
| Long-term | 836.3147*** | 0.1311** | 0.0468 |
| | (3.3395) | (2.0213) | (1.1444) |
| County FE | YES | YES | YES |
| Year FE | YES | YES | YES |
| No. of Obs. | 7809 | 7851 | 2275 |
| Adj. R-Squared | 0.93 | 0.87 | 0.98 |

# Bond insurance protects muni investors from natural disasters

| Dep Var: CR | All Bonds | REV Bonds | GO Bonds |
|---|---|---|---|
| Post | -0.099 | -0.1419 | -0.06 |
| | (-1.2862) | (-1.5319) | (-0.5195) |
| County FE | YES | YES | YES |
| No. of Obs. | 3191 | 2052 | 1987 |
| Adj. R-Squared | 0.25 | 0.2 | 0.3 |

# Physical damage is an important determinant of the post-disaster price response of REV bonds

| | Below Med | Above Med | Below Med | Above Med |
|---|---|---|---|---|
| Dep Var: CR | REV Bonds | REV Bonds | GO Bonds | GO Bonds |
| Post | -0.3502 | -0.6132* | -0.1243 | -0.1986 |
| | (-1.5429) | (-1.8343) | (-0.7799) | (-1.3201) |
| County FE | YES | YES | YES | YES |
| No. of Obs. | 594 | 591 | 658 | 658 |
| Adj. R-Squared | 0.36 | 0.43 | 0.37 | 0.37 |

Above-median damage: average per-capita damage is \$528, median is \$44.1
Below-median damage: average per-capita damage is \$6.14, median is \$5.53

# Federal disaster aid mitigates negative effect on REV bonds

| Dep Var: CR | Zero Aid | Below Med | Above Med |
|---|---|---|---|
| | REV Bonds | REV Bonds | REV Bonds |
| Post | -1.1954* | -0.7086** | -0.2969 |
| | (-1.9769) | (-2.3249) | (-1.2096) |
| County FE | YES | YES | YES |
| No. of Obs. | 242 | 537 | 648 |
| Adj. R-Squared | 0.29 | 0.34 | 0.37 |

Zero aid: average per-capita damage is $54
Some aid: average per-capita damage is $336

# Federal disaster aid doesn't change the price (non)response of GO bonds to natural disasters

| Dep Var: CR | Zero Aid | Below Med | Above Med |
|---|---|---|---|
| | GO Bonds | GO Bonds | GO Bonds |
| Post | -0.0458 | -0.2433 | -0.1557 |
| | (-0.1882) | (-1.3574) | (-1.1077) |
| County FE | YES | YES | YES |
| No. of Obs. | 314 | 560 | 756 |
| Adj. R-Squared | 0.44 | 0.45 | 0.29 |

# When local revenue is geographically concentrated, severe disasters negatively affect GO bond returns

| Dep Var: CR | Low Severity | High Severity | Low Severity | High Severity |
|---|---|---|---|---|
| | GO Bonds | GO Bonds | REV Bonds | REV Bonds |
| Post×Concentrated | 0.2266 | -0.5454* | 0.2388 | -0.01 |
| | (0.7484) | (-1.9232) | (0.3992) | (-0.0176) |
| Post | -0.3643 | -0.0652 | -0.4649 | -0.8143 |
| | (-1.3679) | (-0.2497) | (-0.8535) | (-1.2748) |
| County FE | YES | YES | YES | YES |
| No. of Obs. | 276 | 262 | 238 | 220 |
| Adj. R-Squared | 0.52 | 0.49 | 0.5 | 0.58 |

- High (Low) Severity: Counties in the top (bottom) tercile of severity
- Concentrated: Counties in the top tercile of local revenue share of total revenue

# When the local debt-to-tax-revenue is high, severe disasters negatively affect GO bond returns

| Dep Var: CR | Low Severity | High Severity | Low Severity | High Severity |
|---|---|---|---|---|
| | GO Bonds | GO Bonds | REV Bonds | REV Bonds |
| Post × Levered | -0.0548 | -0.5517** | -0.0635 | 0.2924 |
| | (-0.2199) | (-2.3262) | (-0.1459) | (0.6155) |
| Post | -0.1518 | -0.0142 | -0.4773* | -0.5838* |
| | (-0.9086) | (-0.0600) | (-1.7731) | (-1.6831) |
| County FE | YES | YES | YES | YES |
| No. of Obs. | 456 | 398 | 408 | 379 |
| Adj. R-Squared | 0.41 | 0.53 | 0.46 | 0.5 |

- High (Low) Severity: Counties in the top (bottom) tercile of severity
- Levered: Counties in the top tercile of debt-to-tax ratio

# Conclusion

- We study how natural disasters affect municipal bond returns using the repeat sales methodology
- Municipal bond investor losses from historic natural disasters are high
- Diversified bond revenue sources, insurance, and federal financial assistance provide meaningful protection to investors
- Climate change likely to pose additional challenges/costs to municipalities

# Summary statistics: bond returns and natural disasters

[Weekly Bond Returns]

| Variable | Mean | Stdev | p25 | p50 | p75 | N |
|---|---|---|---|---|---|---|
| Ret, All Bonds (%) | -0.001 | 1.542 | -0.51 | 0.004 | 0.562 | 339391 |
| Ret, REV Bonds (%) | 0.002 | 1.894 | -0.551 | 0 | 0.609 | 218304 |
| Ret, GO Bonds (%) | -0.002 | 1.39 | -0.509 | 0.008 | 0.571 | 247898 |

[Natural Disasters]

| Variable | Mean | Stdev | p25 | p50 | p75 | N |
|---|---|---|---|---|---|---|
| Injuries | 2.961 | 27.329 | 0 | 0 | 0 | 1033 |
| Fatalities | 0.567 | 4.047 | 0 | 0 | 0 | 1033 |
| Property Damage ($M) | 137.1 | 1226 | 1.127 | 4 | 14.002 | 1033 |
| Crop Damage ($M) | 2.553 | 16.5844 | 0 | 0 | 0 | 1033 |
| Per-capita Damage ($) | 269.137 | 2392.438 | 5.319 | 11.042 | 39.248 | 1033 |

# Summary statistics: county characteristics

| Variable | Mean | Stdev | p25 | p50 | p75 | N |
|---|---|---|---|---|---|---|
| Avg Insured GO (%) | 50.47 | 32.78 | 19.28 | 50.23 | 80.84 | 990 |
| Avg Insured REV (%) | 56.95 | 30.59 | 30.26 | 59.57 | 85.28 | 1025 |
| Avg Maturity GO | 6.85 | 2.63 | 5.28 | 6.61 | 8.4 | 990 |
| Avg Maturity REV | 7.83 | 2.58 | 6.35 | 7.79 | 9.33 | 1025 |
| Avg Rating GO | 2.49 | 1.05 | 1.58 | 2.44 | 3.18 | 974 |
| Avg Rating REV | 3.59 | 1.3 | 2.92 | 3.52 | 4.15 | 1014 |
| # of Bonds Outstanding | 1181.78 | 1571.3 | 360 | 750 | 1367 | 1033 |
| Population (000s) | 616.68 | 827.64 | 176.58 | 383.54 | 745.46 | 1033 |
| Income Per Cap ($K) | 40.08 | 11.99 | 32.02 | 38.2 | 46.03 | 1033 |
| Unemployment (%) | 6.38 | 2.62 | 4.4 | 6 | 7.9 | 1033 |
| Federal Aid ($M) | 9.51 | 50.4 | 0.01 | 0.76 | 4.2 | 1033 |
| Debt/Cash and Security | 1.61 | 0.94 | 1.07 | 1.4 | 1.87 | 1025 |
| Debt/Tax Revenue | 3.47 | 3.1 | 1.98 | 3.03 | 4.13 | 1025 |

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