A Market-based Measure of Climate Risk for Cities

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Picture: climate.nasa.gov/effects/

One of the authors commuting to work in April 2016.

Photo credit: Lee Ann Butler. Thanks, honey!

Houston, Texas: Aug. 25, 2017

Houston, Texas: Aug. 26, 2017

Houston, Texas: Aug. 27, 2017

Hurricane Harvey inflicted $125 billion in damage.


Source: i.kinja-img.com


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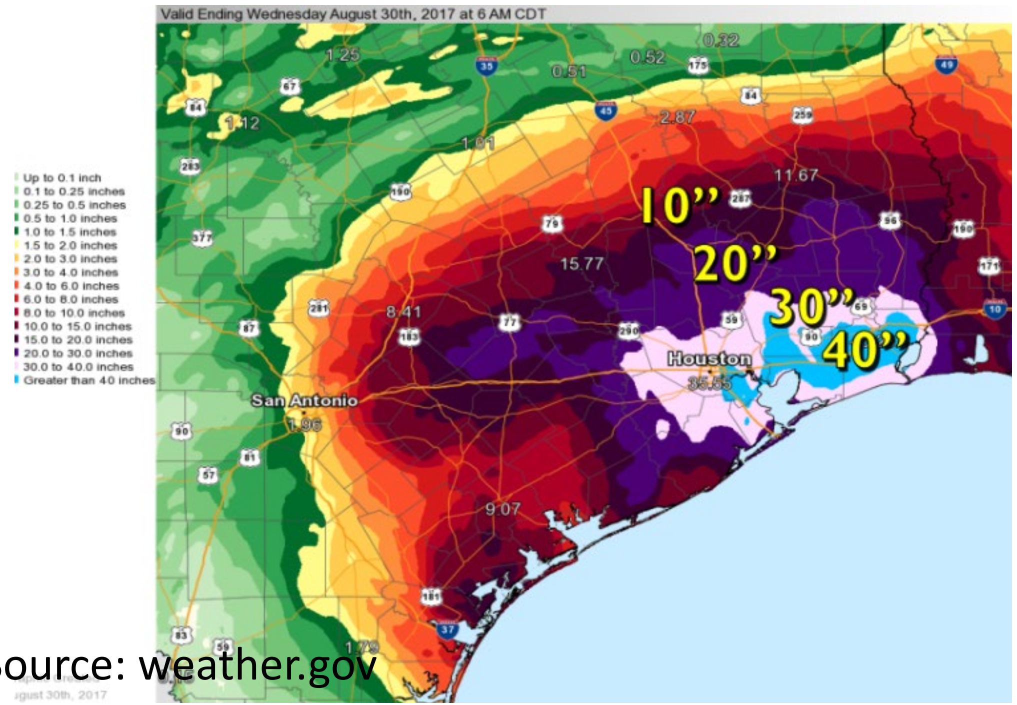


Source: weather.gov


Source: enr.com

Exposure to climate events disrupts local economic activities and increases municipal borrowing costs.

An important but narrow measure of exposure is sea level rise.

The sea level rise measure is the expected mean annual loss (% of GDP) due to a 40 cm rise in sea levels (Hallegatte et al. (2013)). Available for about 20 cities.

A one stdev increase in sea level rise exposure is associated with a 1.24% increase in long-term municipal bond yields (Painter (2020)).

Exposure to climate events disrupts local economic activities and increases municipal borrowing costs.

A more granular measure of sea level rise exposure is the % of houses in a school district exposed to six feet of sea level rise (Goldsmith-Pinkham et al. (2023)).

A one stdev increase in sea level rise exposure is associated with an 8.84% increase in muni yield spreads of both short- and long-term municipal bonds, but only after 2013.

Other geographic aspects of climate risk exposure also relate to muni borrowing costs.

Exposure to projected heat stress impacts muni yield spreads (Acharya et al. (2023)), with exposure measures estimated at the weather station level and mapped to nearby counties.

Physical exposure to climate events impacts real estate prices and mortgages.

Property values are lower in areas with higher sea level rise exposure (Bernstein, Gustafson, and Lewis (2019)).

Mortgages on properties exposed to sea level rise face higher interest rates (Nguyen et al. (2022)).

However, physical exposure is not the only climate risk that municipalities face.

Transition risks arising from moving towards a sustainable economy and the associated climate policy uncertainties may influence local economies (e.g., Giglio, Kelly, and Stroebel (2021); Bolton and Kacperczyk (2021)).

- A coastal city, such as Los Angeles CA, may be resilient to climate change if it is home to companies that benefit from net-zero carbon emissions policies.
- A nearby inland city, Bakersville CA, may have high economic exposure to climate change if its local economy relies on the production of fossil fuels, which can be left stranded as carbon taxes increase.

A holistic measure of a city's climate risk would capture multiple dimensions of exposure.

Moreover, a combination of physical risks (floods, droughts, wildfires) may influence municipalities' cost of borrowing.

And furthermore, municipalities may try to adapt, either in terms of their infrastructure, economy, or their finances.

Extreme weather events and climate change can impact local economies in a variety of ways.

Are the effects different for cities with different geographic features?

Are the effects different for cities with different economic bases?

Are the effects different for cities with different financial stability?

All of the above?

The ideal climate risk exposure measure would…

- reflect both physical and transition risks,
- incorporate all climate risk concerns in proportion to their importance,
- vary over time to reflect cities' climate risk mitigation efforts,
- and identify cross-sectional differences in climate risk exposures of cities, even those located in close proximity.

We construct a market-based measure of climate risk for cities to address these issues.

Intuition: municipal bonds whose prices decline more in response to the arrival of (negative) climate news would have greater financial exposures to climate change.

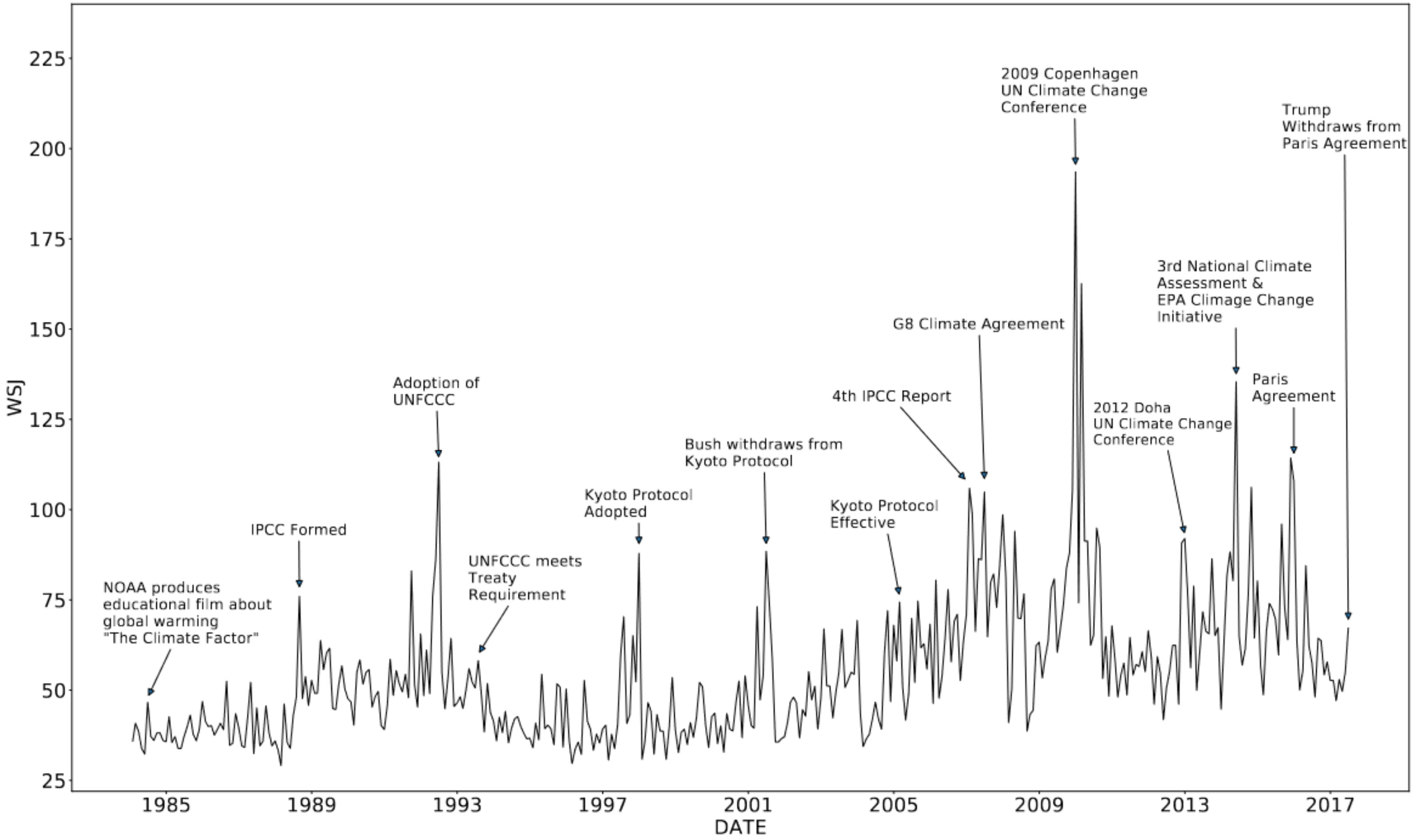
This sensitivity of a municipal bond's prices to climate news—*Climate News Sensitivity* (or *Beta*)—would reflect the bond's, and in turn its issuer's, exposure to climate risks.

We use an established climate change news index.

To estimate *Climate News Sensitivity*, we use the monthly Wall Street Journal (WSJ)-based climate change news innovation index.

- Engle et al. (2020) show that innovations in this climate news index is positively correlated with the returns of ESG-characteristic based mimicking portfolios.
- The WSJ news index is available from 1984.
- We also use a negative climate news index from Crimson Hexagon (2008-)

There is a lot of time series variation in the quantity of news: Figure 2 from Engle et al. (2020).



This figure shows the WSJ Climate Change News Index from 1984 to 2017, annotated with climate-relevant news announcements.

We estimate *Climate News Sensitivity* using 5 years of monthly returns for each bond and in each month.

$$R_{i,t} - RF_t = \alpha + \boxed{\beta_1} Climate\ News\ Innovation_t + \beta_2 (RM_t - RF_t) + \beta_3 TERM_t + \beta_4 CREDIT_t + \varepsilon_{i,t}$$

$R_{i,t}$ is the monthly return of bond *i* in month *t*. RF_t is the return on one-month Treasury bill.

Climate News Innovation$_t$ is innovations in the WSJ based climate news index.

$RM_t - RF_t$ is the excess stock market return.

$TERM_t$ is the 10-year Treasury bond return minus one-month Treasury bill return.

$CREDIT_t$ is the difference in returns of BBB-rated and AAA-rated municipal bonds.

We <u>reverse the sign</u> of *Climate News Sensitivity* so that its higher values indicate higher levels of sensitivity of abnormal returns to climate news innovations.

We use data from MSRB and Bloomberg to compute monthly municipal bond returns.

$$R_{i,t}=\frac{Price_{i,t}+Accrued\ Interest_{i,t}+Coupon\ Payment_{i,t}}{Price_{i,t-1}+Accrued\ Interest_{i,t-1}}-1$$

Secondary market municipal bond transactions are available between January 2005 and June 2022.

Price is the weighted average price on the last traded day of month.

Bond characteristics are from Bloomberg.

Our analysis period is between January 2010 and July 2017.

The municipal bond returns that we use to estimate *Climate News Sensitivity* are available since 2005.

As estimation period requires 60 months of municipal bond returns, *Climate News Sensitivity* is first estimated in January 2010.

The WSJ-based climate change news innovation index of Engle et al. (2020) is available until June 2017, allowing us to estimate *Climate News Sensitivity* by July 2017.

We estimate *Climate News Sensitivity* by regressing bond returns on climate news and traditional factors.

$$R_{i,t} - RF_t = \alpha + \boxed{\beta_1} Climate\ News\ Innovation_t + \beta_2 (RM_t - RF_t) + \beta_3 TERM_t + \beta_4 CREDIT_t + \varepsilon_{i,t}$$

We face a tradeoff: include <u>more</u> cities, measuring β_1 with <u>less</u> precision? Or <u>fewer</u> cities with <u>more</u> precision?

We choose the latter because we ultimately want to study determinants of city exposure, and prefer to minimize measurement error or outliers contaminating those analyses.

Appendix A gives details of the sample selection, highlights being: issuers are not trivially small cities, bonds are not excessively illiquid.

Our initial sample includes 49,681 municipal bond-month observations contributed by 240 US cities.

In our baseline regressions, we drop small cities with populations fewer than 50,000, and keep only those cities that contribute multiple bonds to the sample.

Our baseline sample includes 45,056 bond-month observations contributed by 104 US cities.

Robustness: including small cities doesn't change much (see Fig. 1).

Our dependent variable is *Yield Spread* measured using secondary market trades.

Yield Spread—is the difference between municipal bond yields and maturity-matched Treasury yields.

We winsorize *Yield Spread* and all other continuous variables at the 1st and 99th percentiles in each year.

Aside: muni data can be messy; winsorizing is important and impacts the estimates substantially (and sensibly). See Fig. 1.

The average *Yield Spread* is 1.4 (percentage points) with a standard deviation of 1.0. TABLE 1 excerpt

Variables	N	Mean	Median	Standard Deviation
The Primary Dependent Variable				
Yield Spread (in Percentages)	45,056	1.43	1.32	1.04
The Independent Variable of Interest				
Climate News Sensitivity	45,056	-0.22	-0.27	1.78
Bond Characteristics				
Issue Amount (in Million USD)	43,789	33.80	22.00	41.30
Time to Maturity (in Years)	45,056	10.13	8.97	6.63
AAA Rated Dummy × 100	45,056	7.64	0.00	26.57
AA Rated Dummy × 100	45,056	72.85	100.00	44.47
City Financials				
Assets (in Billion USD)	45,056	13.90	22.44	13.65
Net Income/Assets × 100	45,045	1.46	0.02	9.57
Cash/Assets × 100	44,776	24.07	21.80	18.40
Liabilities/Assets × 100	45,056	62.54	60.70	29.64

We run Fama-MacBeth regressions to study the relation between *Climate News Beta* and *Yield Spread*.

$$Yield\ Spread_i = \alpha + \beta Climate\ News\ Sensitivity_i + X_i'\gamma + \varepsilon_i$$

Bond Characteristics: *Log(Issue Amount)*, *Log(Time to Maturity)*, *Log(1+Number of Trades)*, *Competitive Offering Dummy*, *Tax Status Dummies*, *Callable Dummy*, *Sinking Fund Dummy*, *Credit Enhancement Dummy*, *Rating Dummies*

Beta Estimates: *Stock Market Beta*, *Term Spread Beta*, and *Credit Spread Beta*

City Financials: *Log(Assets)*, *Net Income/Assets*, *Cash/Assets*, and *Liabilities/Assets*

We run 91 monthly regressions between January 2010 and July 2017, and report the average coefficient estimates and their statistical significances computed using Newey-West adjusted standard errors with 3-month lags.

A one-stdev increase in *Climate News Sensitivity* relates to a 1.7% increase in avg *Yield Spread*. TABLE 2

$$Yield\ Spread_i = \alpha + \beta Climate\ News\ Sensitivity_i + X_i^{\prime}\gamma + \varepsilon_i$$

Variables	(1)	(2)	(3)	(4)
Climate News Sensitivity × 100	2.33***	1.90***	1.52***	1.40***
	(5.18)	(6.30)	(5.58)	(4.74)
Intercept	Yes	Yes	Yes	Yes
Bond Characteristics	No	Yes	Yes	Yes
Beta Estimates	No	No	Yes	Yes
City Financials	No	No	No	Yes
Number of Observations	45,056	43,789	43,789	43,521
R-Squared (%)	0.43	60.78	62.51	64.49

How big is the effect? A one-stdev change in the climate news index has a magnitude similar to a one-notch drop in credit rating.

Fixed-effects estimates are similar (but smaller), ruling out time-invariant aspects of cities confounding the climate risk effects. TABLE 3

$$Yield\ Spread_{i,t} = \alpha + \alpha_j + \alpha_{Trade\ Year\text{-}Month} + \beta Climate\ News\ Sensitivity_{i,t} + X'_{i,t}\gamma + \varepsilon_{i,t}$$

Variables	(1)	(2)	(3)	(4)
Climate News Sensitivity × 100	2.05**	1.42***	0.99**	1.08**
	(2.40)	(3.06)	(2.25)	(2.57)
Intercept + Issuer Fixed Effects	Yes	Yes	Yes	Yes
Bond Characteristics	No	Yes	Yes	Yes
Beta Estimates	No	No	Yes	Yes
City Financials	No	No	No	Yes
Number of Observations	45,056	43,789	43,789	43,521
R-Squared (%)	11.16	49.65	50.27	51.58

We run several additional tests to understand the mechanism driving our findings.

Is the positive relation between *Climate News Sensitivity* and *Yield Spread* more pronounced during periods of greater attention to climate risk?

Is this relation stronger among bonds that are more likely to be affected by climate risk?

Does *Climate News Sensitivity* vary predictably based on cities' observable climate risk characteristics?

The coefficient on *Climate News Sensitivity* is larger during/after 2013. <u>TABLE 4</u>

Sample:	Before 2013	After 2013
Variables	(1)	(2)
Climate News Sensitivity × 100	0.91	1.72***
	(1.63)	(5.71)
Intercept	Yes	Yes
Bond Characteristics	Yes	Yes
Beta Estimates	Yes	Yes
City Financials	Yes	Yes
Number of Observations	14,060	29,461
R-Squared (%)	48.39	75.04

The time series variation in the importance of climate risk is consistent with the findings of Goldsmith-Pinkham et al. (2023) and Acharya et al. (2023).

The coefficient on *Climate News Sensitivity* is larger when media coverage of climate change is high. TABLE 4

Sample:	Low Climate News Period	High Climate News Period
Variables	(3)	(4)
Climate News Sensitivity × 100	1.13**	1.67***
	(2.45)	(5.86)
Intercept	Yes	Yes
Bond Characteristics	Yes	Yes
Beta Estimates	Yes	Yes
City Financials	Yes	Yes
Number of Observations	20,992	22,012
R-Squared (%)	62.04	66.70

The influence of climate risk on *Yield Spread* is larger among longer-term bonds and riskier bonds. TABLE 5

Variables	(1)	(2)
Log(Time to Maturity) × Climate News Sensitivity × 100	0.90*	.
	(1.71)	.
Rating Number × Climate News Sensitivity × 100	.	-0.46**
	.	(-2.12)
Intercept	Yes	Yes
Bond Characteristics	Yes	Yes
Beta Estimates	Yes	No
City Financials	Yes	No
Number of Observations	43,521	43,535
R-Squared (%)	64.66	58.58

Compared to cities with the lowest *Climate News Sensitivity*, cities with the highest *Climate News Sensitivity* face an additional 5 bps (4 bps) increase in yield spreads for doubling maturity (a one-notch lower rating).

So far: *Climate News Sensitivity* relates to muni yield spreads in intuitive ways.

Bond characteristics interact with climate risk as expected: more media exposure, more default risk, longer maturity…higher yields.

Next: How do demographics and other city characteristics relate to climate risk?

The average (conditional) *Climate News Sensitivity* is 0.07 (1.79) with a standard deviation of 1.2 (1.3).

Variables	N	Mean	Median	SD
City-averaged Climate News Sensitivities				
Climate News Beta	104	0.07	-0.03	1.21
Conditional Climate News Beta	104	1.79	1.78	1.28

Some statistics about the cities in our sample: Demographics

Variables	Unit	N	Mean	Median	SD
Population (2010 census)	Thousand	104	497.98	219.80	951.69
Population Density	Thousand	79	1.86	1.33	1.65
Population in Poverty	Percent	79	18.75	17.58	8.85
Adults Believing in Global Warming	Percent	79	46.33	45.00	4.15
Voted Democrat	Percent	104	57.98	57.09	13.29

Not tabulated in the paper. Computing means at the bond level instead of city level shows higher avg population (big cities issue more bonds) and comparable levels of poverty and beliefs.

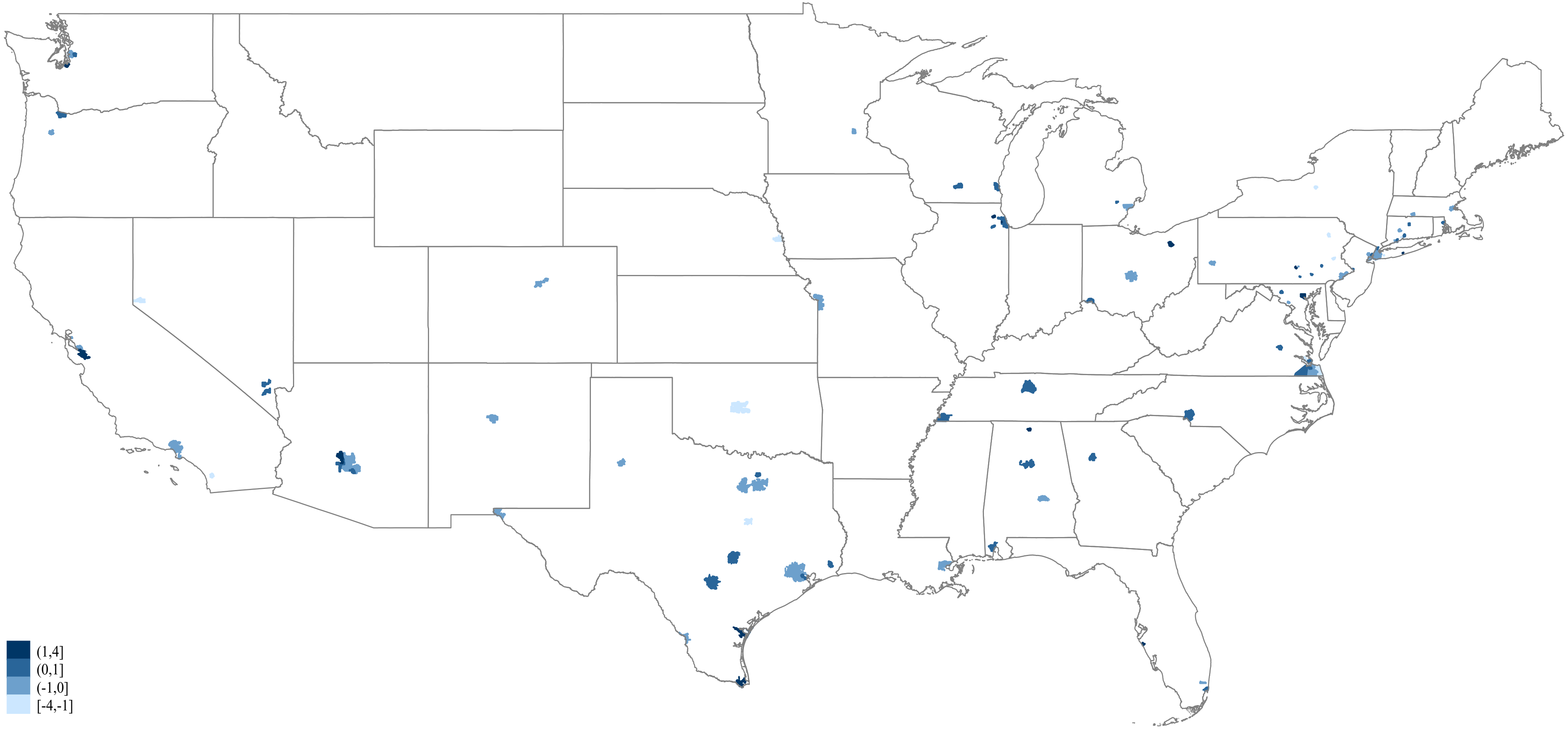
Some statistics about the cities in our sample: Physical climate exposure

Variables	Unit	N	Mean	Median	SD
Flood Instances	Number	79	21.16	14.00	21.55
Coastal Flood Instances	Number	79	1.30	0.00	3.06
Carbon Intensity of the Economy	Number	104	290.40	275.47	119.36
Sea Level Rise Exposure	Percent	14	0.20	0.09	0.38
Climate Damages	Percent	104	9.92	8.63	6.76

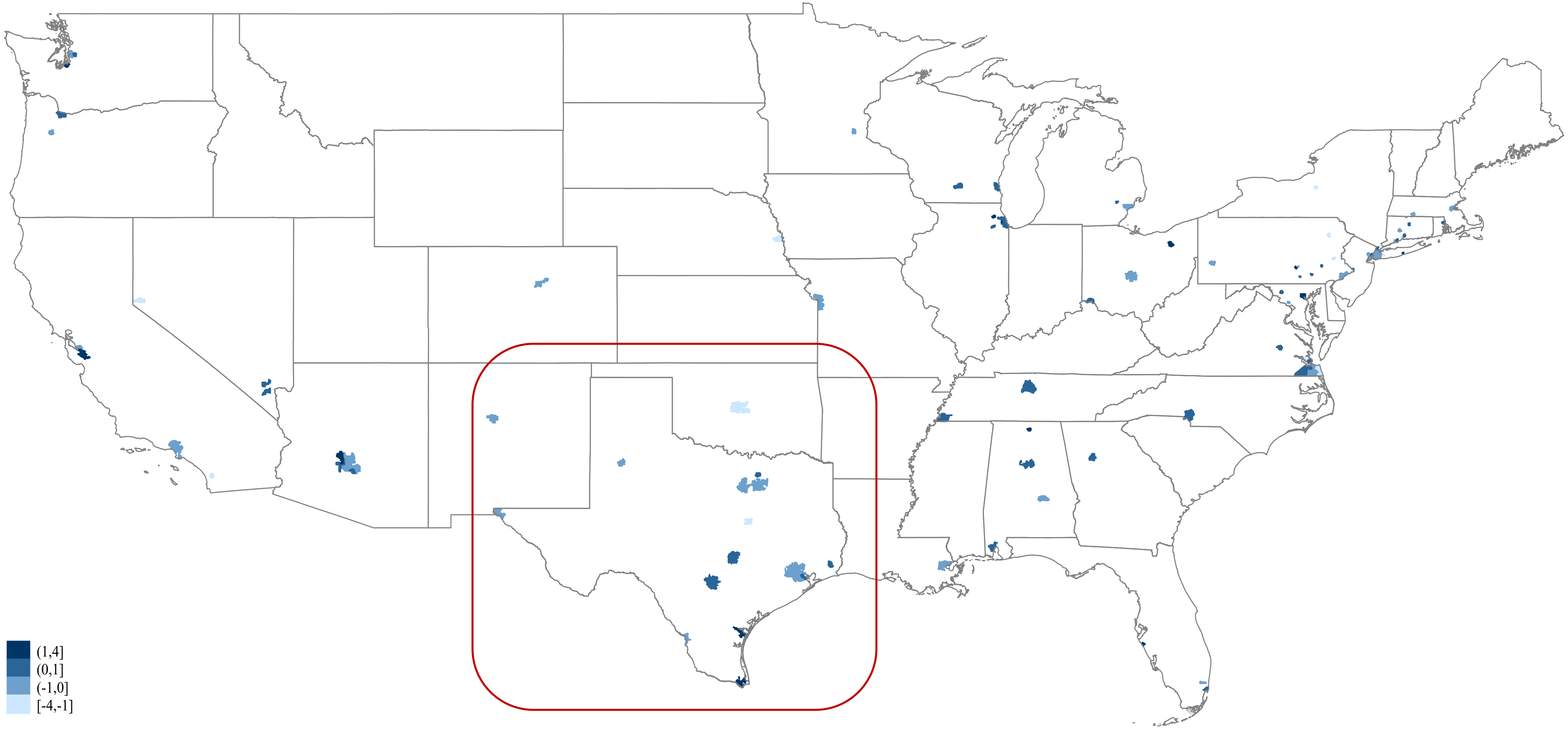
Not tabulated in the paper. Computing means at the bond level instead of city level shows more flood and coastal flood instances.

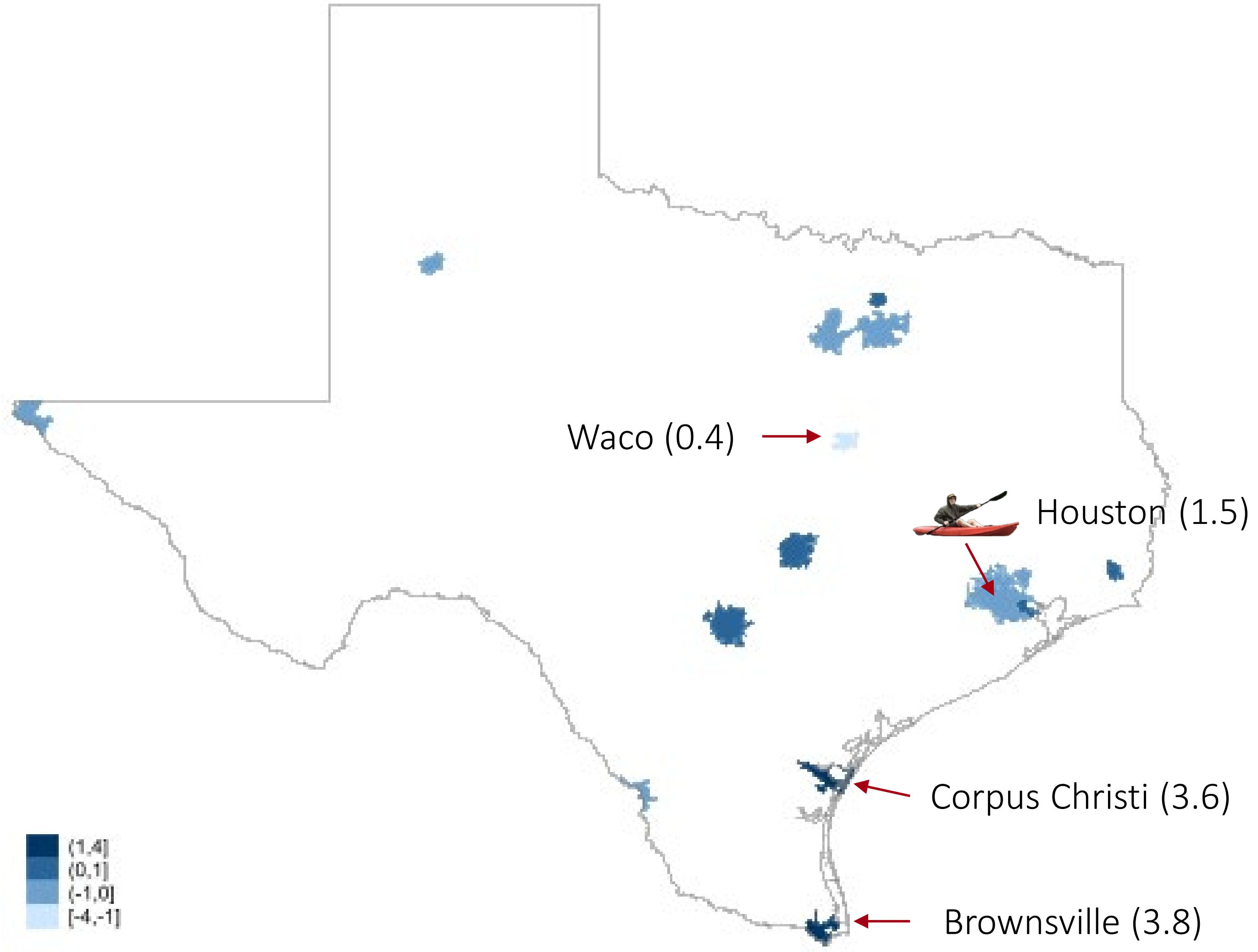
Small N for physical measures of climate risk like sea level rise underscores the importance of having a market-based measure of cities’ climate exposure.

Climate News Sensitivity can vary within a short distance.



Climate News Sensitivity can vary within a short distance.



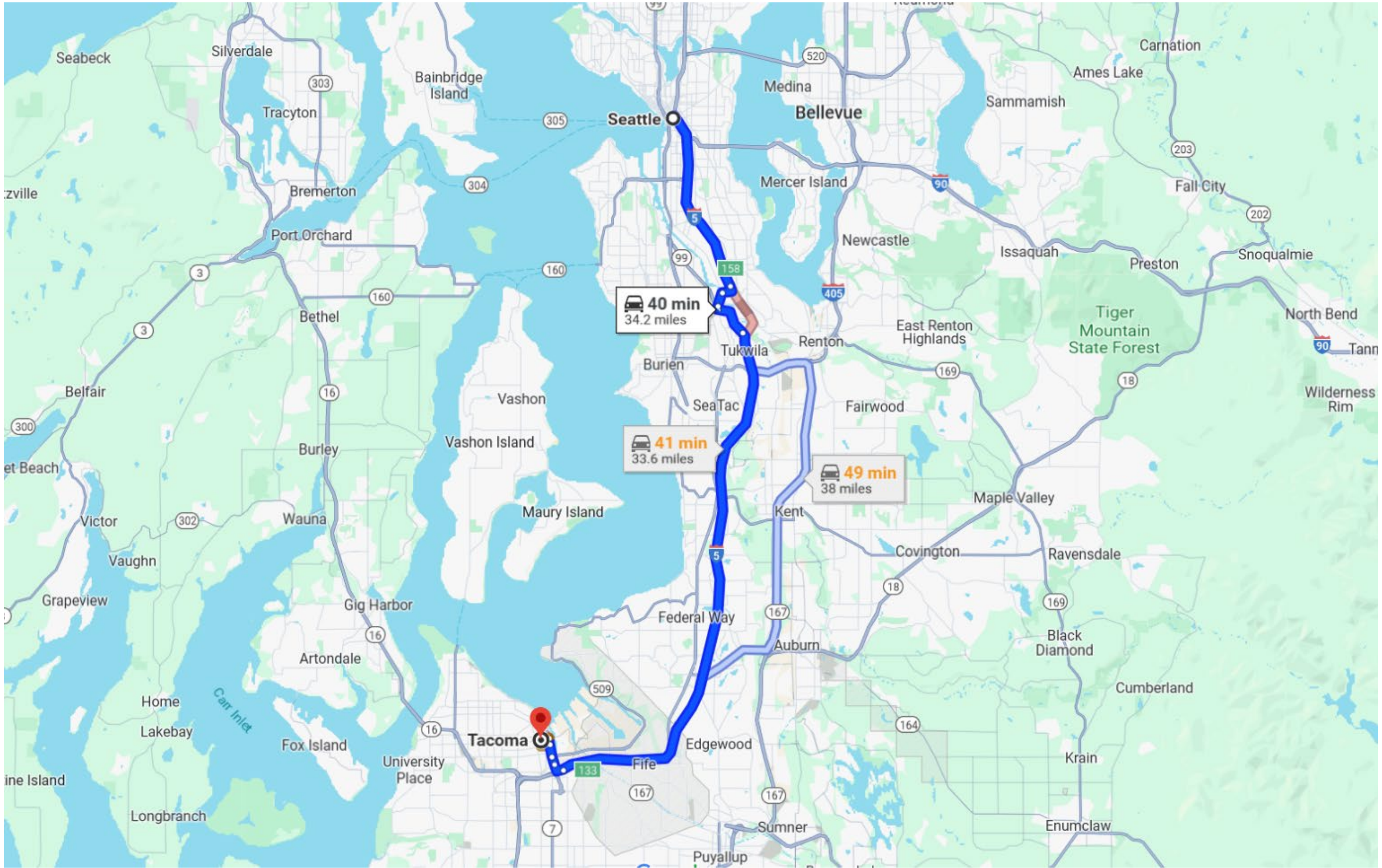


For instance, in Texas, Corpus Christi and Brownsville have the highest *Climate News Sensitivity* controlling for bond characteristics; Waco has the lowest.

Some selected cities and their climate sensitivity. Full list and unconditional estimates in Appendix C.

City, State	Conditional Climate Beta	City, State	Conditional Climate Beta
Atlanta, GA	2.7	New Haven, CT	0.3
Austin, TX	2.6	New Orleans, LA	1.2
Boston, MA	1.7	New York, NY	1.4
Brownsville, TX	3.8	Pasadena, TX	2.6
Chicago, IL	1.9	Philadelphia, PA	1.5
Dallas, TX	0.9	Phoenix, AZ	1.6
Denver, CO	0.7	Richmond, VA	1.9
Houston, TX	1.5	San Jose, CA	5.7
Los Angeles, CA	1.5	Seattle, WA	1.4
Madison, WI	2.5	Tacoma, WA	5.5
Miami, FL	1.8	Virginia Beach, VA	-0.1
Minneapolis, MN	1.4	Waco, TX	0.4

Seattle vs Tacoma: How can cities that are adjacent (<50 km) have wildly different Climate News Betas?



Seattle vs Tacoma: How can two cities that are literally adjacent have wildly different Climate News Betas?

Answer: Very different economies, despite very similar geographies.

- Tacoma [Seattle] has 38% [17%] of buildings at risk of wildfires.
- Tacoma [Seattle] has a median household income of $41k [$66k].
- Tacoma [Seattle] has a 12.2% [6.7%] poverty rate.
- Tacoma [Seattle] has 2017 NI/Revenues of -0.08% [3.74%].

Climate News Sensitivity is positively correlated with cities' physical climate risk measures. TABLE 6

Variables	(1)	(2)	(3)	(4)
Standardized Sea Level Rise Exposure	1.16	.	.	.
	(1.57)	.	.	.
Standardized Climate Damages	.	0.04**	.	.
	.	(2.04)	.	.
Log(1+Standardized # of Flood Instances)	.	.	0.20***	.
	.	.	(5.31)	.
Log(1+Standardized # of Coastal Flood Instances)	.	.	.	0.27***
	.	.	.	(3.28)
Intercept	Yes	Yes	Yes	Yes
Bond Characteristics	Yes	Yes	Yes	Yes
Beta Estimates	Yes	Yes	Yes	Yes
City Financials	Yes	Yes	Yes	Yes
Number of Observations	26,434	43,521	40,678	40,678
R-Squared (%)	14.96	15.02	14.74	14.80

Climate News Sensitivity is also positively correlated with climate change-related transition risks. TABLE 6

Variables	(9)
Standardized Carbon Intensity of the Economy	0.08***
	(2.87)
Intercept	Yes
Bond Characteristics	Yes
Beta Estimates	Yes
City Financials	Yes
Number of Observations	40,678
R-Squared (%)	15.04

Climate News Beta is higher for cities located in states with greater economic dependence (carbon emissions/GDP) on high carbon emission industries. We orthogonalize emissions to % adults believing in climate change ($\rho = -0.73$).

Climate News Sensitivity is higher where people believe climate change is harmful. TABLE 6

Variables	(7)	(8)
Standardized % of Adults Believing in Global Warming	0.15***	.
	(2.81)	.
Standardized Percent Voted Democrat	.	0.13**
	.	(2.63)
Intercept	Yes	Yes
Bond Characteristics	Yes	Yes
Beta Estimates	Yes	Yes
City Financials	Yes	Yes
Number of Observations	40,678	43,521
R-Squared (%)	15.05	15.37

Climate News Sensitivity is higher in cities with higher levels of poverty. TABLE 6

Variables	(6)
Standardized Percent of Population in Poverty	0.09***
	(3.45)
Intercept	Yes
Bond Characteristics	Yes
Beta Estimates	Yes
City Financials	Yes
Number of Observations	40,678
R-Squared (%)	15.10

For an avg size bond issue ($33.6 million), a one stdev increase in poverty is associated with a climate-related increase in annual interest expenses up to $2,722. This per-bond estimate can aggregate to economically significant values, as the total municipal bonds outstanding in the U.S. exceeded $4 trillion in 2021.

Climate News Sensitivity increases weakly with population density. TABLE 6

Variables	(5)
Log(Standardized Population Density)	0.06
	(1.65)
Intercept	Yes
Bond Characteristics	Yes
Beta Estimates	Yes
City Financials	Yes
Number of Observations	40,678
R-Squared (%)	14.73

Alternative approach: At-issuance yield spreads and climate exposure

Rather than using secondary market prices, we could relate primary market yield spreads to issuers' climate exposure.

Climate exposure = average of a city's *Climate News Sensitivity* of existing bonds.

Using at-issuance pricing confirms our results: Climate exposure is priced in muni bond spreads.

$$Offering\ Yield\ Spread_i = \alpha + \alpha_{Issue\ Year-Month} + \beta Average\ Climate\ News\ Sensitivity_j + X'_{i,t}\gamma + \varepsilon_i$$

Bond-level controls: Log(Issue Amount), Log(Time to Maturity), Competitive Offering Dummy, Federal Tax Exemption Dummy, State Tax Exemption Dummy, Callable Dummy, Sinking Fund Dummy, Credit Enhancement Dummy, rating dummies

Other controls: Average Stock Market Beta, Average Term Spread Beta, Avg Credit Spread Beta

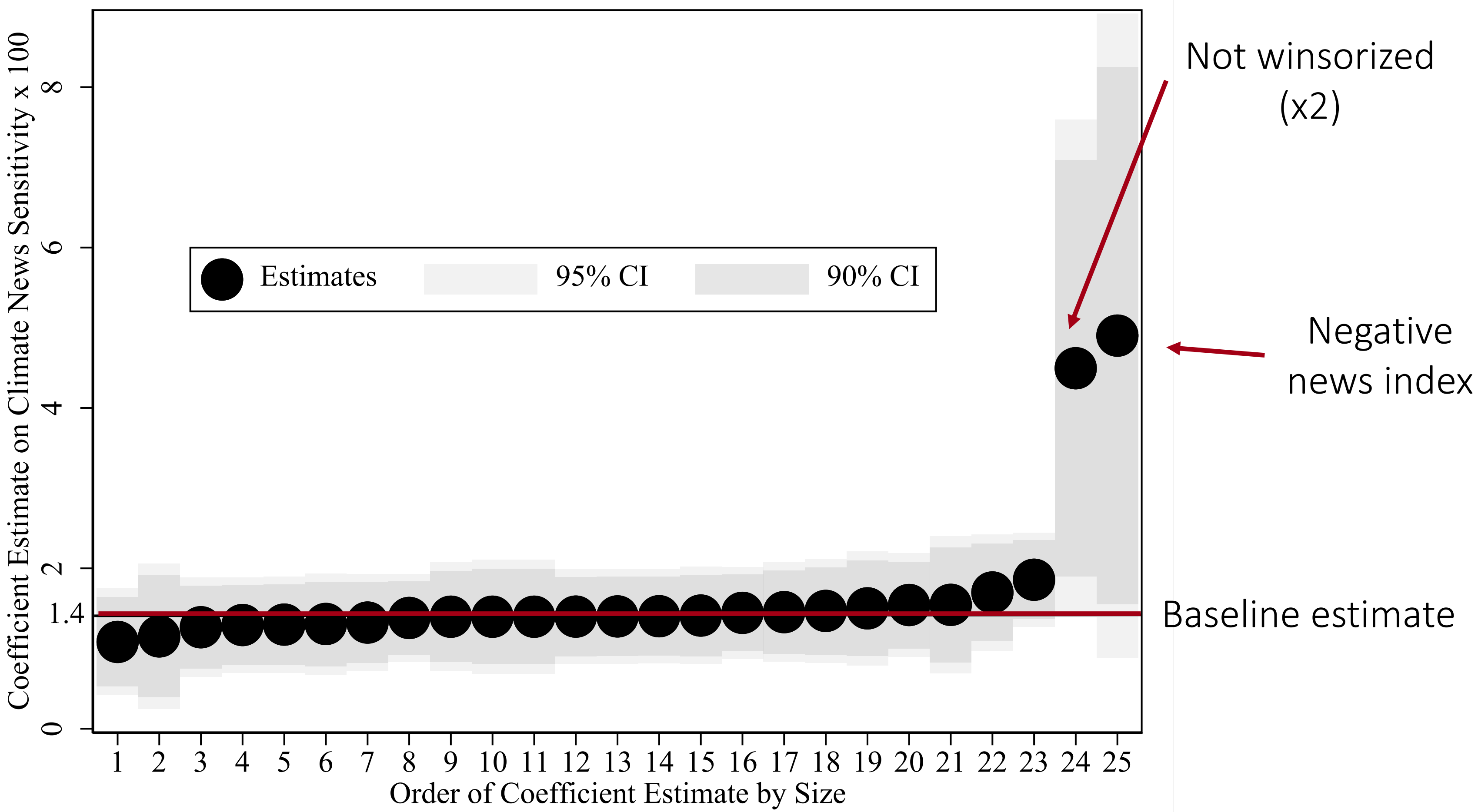
City Financials: include Log(Assets), Net Income/Assets, Cash/Assets, and Liabilities/Assets

Using at-issuance pricing confirms our results: Climate exposure is priced in muni bond spreads. TABLE 7

$$Offering\ Yield\ Spread_i = \alpha + \alpha_{Issue\ Year-Month} + \beta Average\ Climate\ News\ Sensitivity_j + X'_{i,t}\gamma + \varepsilon_i$$

Variables	(1)	(2)	(3)	(4)
Climate News Sensitivity × 100	7.64***	2.55**	2.79*	2.40*
	(3.11)	(2.03)	(1.89)	(1.73)
Intercept	Yes	Yes	Yes	Yes
Year-month Fixed Effects	Yes	Yes	Yes	Yes
Bond Characteristics	No	Yes	Yes	Yes
Beta Estimates	No	No	Yes	Yes
City Financials	No	No	No	Yes
Number of Observations	18,973	18,973	18,973	18,642
R-Squared (%)	19.22	71.51	71.68	72.16

Robustness: A visual representation of differences in our estimates across a variety of varieties.



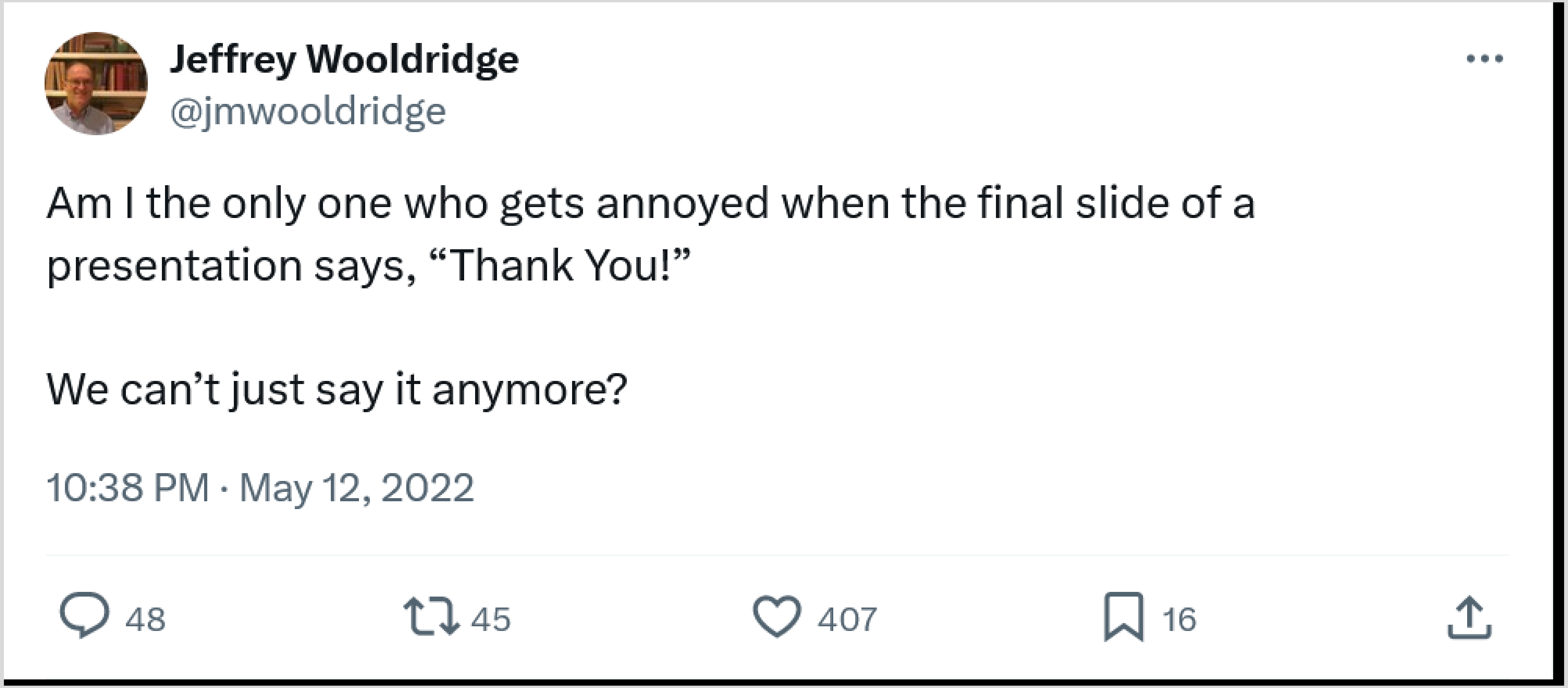
Full details in Appendix E.

Conclusion: Physical climate risk measures mis-measure the climate risk exposures of municipalities.

We construct a new market-based measure of climate risk that incorporates both physical and transition risks of climate change.

A one stdev increase in our measure of climate risk relates to up to an 11.2% increase in yield spreads, whereas existing studies report a 1.2% to 8.8% increase based on physical climate risk measures.

Policy implications: Cities with higher poverty rates are disproportionally affected by climate change.


Jeffrey Wooldridge
@jmwooldridge

Am I the only one who gets annoyed when the final slide of a presentation says, “Thank You!”

We can’t just say it anymore?

10:38 PM · May 12, 2022

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