# Leveraging the Disagreement on Climate Change

## Theory and Evidence

Laura Bakkensen (Arizona) Toan Phan (FRB-R) Russell Wong (FRB-R)

ABFER, May 2023

# Big picture

- How do climate risks affect financial system?
  - Topic of a rapidly growing climate finance literature.
  - Relevant for financial regulators.
- Particularly relevant: How do climate risks affect housing & mortgage market?
  - What do we know so far? Mostly on housing prices.
  - Much less is known about how climate risks affect mortgage market.

# This paper: 1. New stylized facts of the U.S. market

- Purchases of homes more exposed to sea level rise (SLR) are
  - More likely to be leveraged ← extensive margin
  - More likely to use mortgage contracts with longer maturity (more exposure to long-run climate risk) ← intensive margin
  - Despite exposed properties having lower prices.

- Results are driven by transactions with buyers coming from counties with more pessimistic beliefs about climate change.
  - And driven by transactions with conforming loans (that can be securitized and sold to GSEs).

# This paper: 2. Theory

- To understand these facts, need a new model of credit market with belief disagreement.
  - Standard models predict optimists (not pessimists) leverage more; silent on maturity.
- We propose one. Key additions: endogenous maturity choice & competitive search.
  - Intuition: Pessimists (buyers with strong climate beliefs) could transfer climate risk to lenders via leveraged investment – using defaultable debt contract at long maturity.
- Monetary & securitization policies can affect debt market's climate exposure.
  - Test this implication using our data.

# Related literature

- Empirical climate finance
  - Pricing of climate risk: Bernstein Gustafson Lewis JFE 2019, Baldauf Garlappi Yannelis RFS 2020, Murfin Spiegel RFS 2020, Bakkensen Barrage RFS 2021, Hino Burke PNAS 2021, Giglio Maggiori Rao Stroebel Weber RFS 2021...
  - Climate risk in mortgage market: Keys Mulder 2020, Issler et al 2020, Ouazad Kahn RFS 2021, Liao Mulder 2021, Panjwani 2022, Sastry 2022
  - Surveys: Hong Karolyi Scheinkman RFS 2020, Giglio Kelly Stroebel 2021, Furukawa Ichiue Shiraki 2021, 5th National Climate Assessment
  - First to study how climate risk $\times$ belief disagreement affects debt market
- Theory
  - Credit markets with heterogeneous beliefs: Geanakoplos NBERma 2010, Fostel Geanakoplos AER 2008, ECT 2015, Simsek ECTA 2013, Bailey Dávila Kuchler Stroebel Restud 2019...
    - First to apply and evaluate theory in climate context, adding search and maturity
  - Risk shifting: Allen Gale 2000, Barlevy 2014, Allen Allen Gale 2022, Bengui and Phan 2018.
  - House search: Moen JPE 1997, Ngai Tenreyro AER 2014; Head Lloyd-EllisSun AER 2014; Landvoigt Piazzesi Schneider AER 2015; Garriga Hedlund AER 2020...
  - Mortgage search: Allen Clark Houde AER 2014; JPE 2019

# Stylized model

# A model of long-term debt with long-run risk disagreement

- Continuous time. Risk neutral & deep-pocketed agents. Common discount rate $r$.
- A one-time disaster arriving at a random time $T_d$.
- Binomial: indivisible asset yields a payoff stream $H_t = 1$ before $T_d$ and $H_t = 1 - d$ after.
- Belief disagreement:
  - Asset buyers believe $T_d$ arrive at the Poisson rate $r\lambda$, where $\lambda$ follows $F(\lambda)$
  - Lenders: $r\bar{\lambda}$.
  - Asset price $P$ exogenous (for now).
- A long-term debt contract specifies $(L, M, \mu)$:
  - Lender loans $L$ to borrower
  - Borrower promises to pay $M$ until maturity $T_m$
  - Stochastic maturity: $T_m$ arrives at the rate $r\mu$, $\mu \in [0, \mu_0]$.

# A very stylized model...

for conception/ intuition pump/ testable implications. In particular,

- Price is exogenous (for this talk, endogenous in paper)
- Asset is indivisible (not crucial, following the asset-search literature)
- No reselling of assets (but no trade theorem applies before the disaster arrives)
- No refinancing (ditto)
- No insurance of disaster (can be relaxed)
- Belief disagreement is common knowledge (consider private info in paper)
- Disaster is not recurring (crucial to simplify results: no need to worrying about learning/ belief updating)

# One-page summary

**Credit search**

Asset buyer chooses optimal debt contract to search,

Competitive search determines approval rate $\alpha(L, M, \mu)$.

Borrower can default at any $t_{def} \leq T_m$:

- Pay the default cost $f$;
- Repay the lesser of loan balance and asset liquidation value.

**Disaster**

$t$

$T_d$

# Borrower

- Expected payoff from a debt contract $(L, M, \mu)$:

$$\underbrace{\alpha\left[-\underbrace{(P-L)}_{\text{down payment}}+V(M,\mu)\right]}_{\text{mortgage approved}}+\underbrace{(1-\alpha)\left[-P+V(0,\infty)\right]}_{\text{not approved}}$$

- where continuation value $V(M, \mu)$ is defined as:

$$V := \mathbb{E}_{\lambda}\left\{\underbrace{\int_0^{t_{def}} re^{-rt}(H_t - M_t)}_{\text{repaying debt}} + e^{-rt_{def}}(-\underbrace{f}_{\text{default cost}} + \max\{\underbrace{p_{t_{def}}}_{\text{liquidation value}} - \underbrace{B_{t_{def}}}_{\text{remaining balance}}, 0\})\right\}$$

$$B_{t_{def}} = \int_{t_{def}}^{T_m} re^{-r(t-t_{def})} M dt$$

# Proposition: Default strategy

Given a debt contract $(L, M, \mu)$, the optimal stopping time of default is

$$t_{def} = \begin{cases} 0, & \text{if } L > b^{\text{risky}}; \\ T_d, & \text{if } L \in (b^{\text{safe}}, b_\lambda^{\text{risky}}] \text{ and } T_d < T_m; \\ \infty, & \text{otherwise,} \end{cases}$$

where the safe and risky debt limits, $b^{\text{safe}} < b_\lambda^{\text{risky}}$ are given by:

$$b^{\text{safe}} \equiv 1 - d + f, \quad b_\lambda^{\text{risky}} \equiv 1 - \frac{\lambda}{1+\lambda}\frac{d}{1+\mu} + f. \tag{1}$$

Intuition:

- Risk-free debt contract: No default if debt is below $b^{\text{safe}}$ (i.e., max min contract in F-G).
- Risky debt contract: Default after disaster if debt is between $b^{\text{safe}}$ and $b_\lambda^{\text{risky}}$.
- Default immediately if the debt is greater than $b_\lambda^{\text{risky}}$.

# Competitive lenders

- Expected payoff from a contract:

$$\Pi(L, M, \mu) := -L + PV(M, \mu) - \underbrace{K(\mu)}_{\text{operation cost (to pin down optimal } \mu)}$$

$$PV(M, \mu) := \mathbb{E}_{\bar{\lambda}}\{\int_0^{\min(T, t_{def})} re^{-rt} M dt + 1_{t_{def} < T} e^{-rt_{def}} \min(p_{t_{def}}, B_{t_{def}})\}.$$

- Free-entry condition pins down loan approval rate $\alpha$:

$$0 = \underbrace{\eta(\alpha)}_{\text{prob. of finding a matching buyer}} \Pi(L, M, \mu) - \underbrace{\kappa}_{\text{cost of issuing debt contract}}.$$

# Competitive search

For each borrower type $\lambda$ and each contract $(L, M, \mu)$:

**Borrowers**: endogenous mass $n_b$

$\updownarrow$

Number of matches produced: $\mathcal{M}(n_b, n_l)$, e.g. $M_0 n_b^{\gamma} n_l^{1-\gamma}$

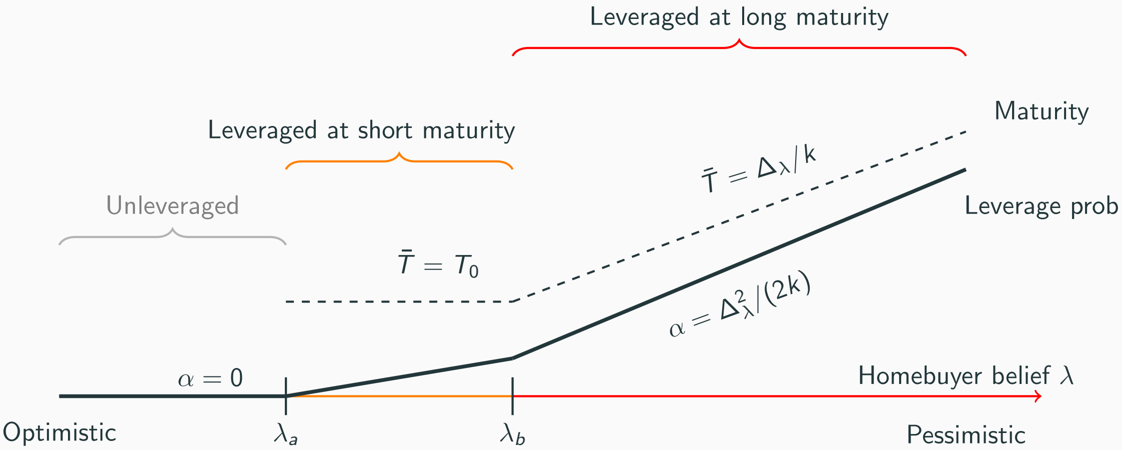
$\Rightarrow$ Prob a borrower finds a match: $\alpha := \frac{\mathcal{M}}{n_b}$

$\Rightarrow$ Prob a lender finds a match: $\eta := \frac{\mathcal{M}}{n_l}$

**Lenders**: endogenous mass $n_l$

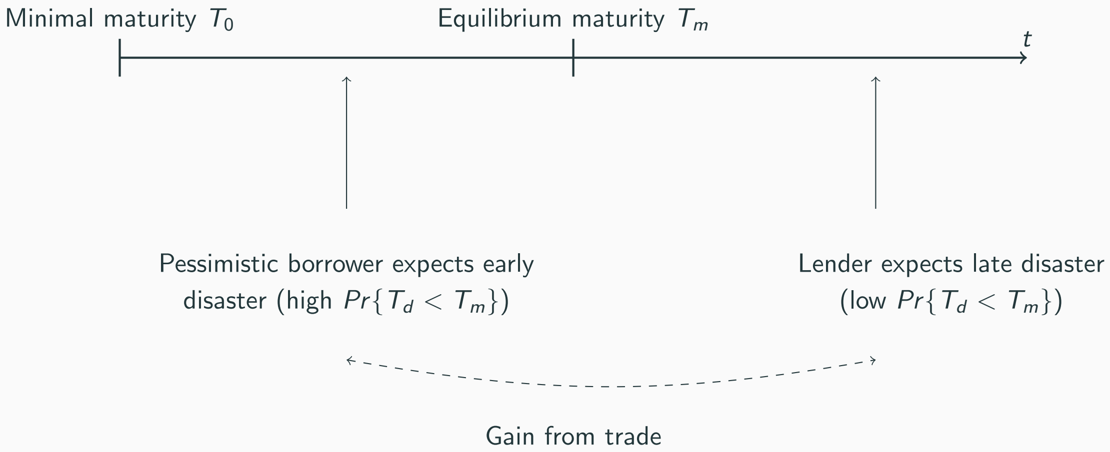
‣ Equilibrium definition

# Proposition: Equilibrium long-term debt contract (assuming $d > \bar{\lambda} f$)




▸ Detailed closed-form solutions

# Intuition


Minimal maturity $T_0$
Equilibrium maturity $T_m$
$t$
Pessimistic borrower expects early disaster (high $Pr\{T_d < T_m\}$)
Lender expects late disaster (low $Pr\{T_d < T_m\}$)
Gain from trade

# Taking Stock: Testable implications

| | Pessimistic buyer ($\lambda > \lambda_b$) & exposed to disaster ($d > \bar{\lambda} f$) | Otherwise |
|---|---|---|
| Leverage probability $\alpha$ | high | low |
| Maturity $\bar{T}$ | long | short |

# Extensions

1. Monetary policy: Banks' and borrowers' funding costs are $i$ and $\rho$, where $i \leq \rho$. A reduction in policy interest rate $i$ will
   - Increase leverage probability ($d\alpha/di < 0$) $\leftarrow$ intensive margin
   - Expand set of borrowers $[\lambda_a, \infty)$ choosing risky mortgage contracts $\leftarrow$ extensive margin
   - No effect on maturity ($dT/di = 0$).

   ▸ Details

2. Endogenize housing price via Nash bargaining ▸ Details
   - deceasing in pessimism ($dP/d\lambda < 0$)
   - decreasing in policy interest rate ($dP/di < 0$).

3. Insurance ▸ Details

## Further results

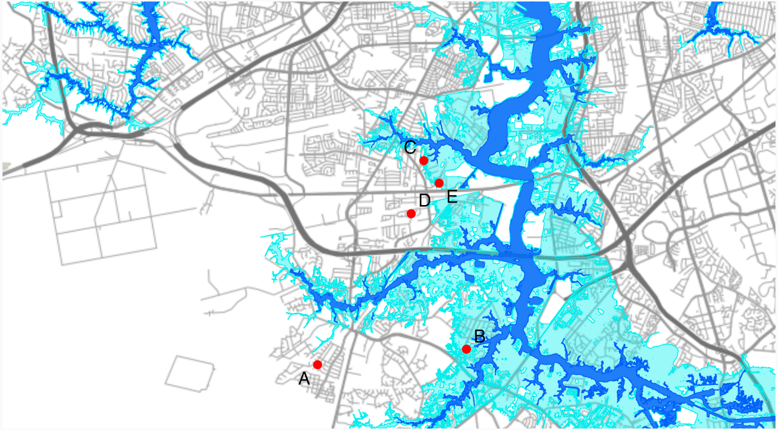
- Importance of endogenous maturity: Assume maturity is exogenously fixed ($\mu \to \mu_0$).
  - Then pessimists are less likely to leverage ($\alpha \downarrow \lambda$) and borrow less ($B \downarrow$ in $\lambda$).
  - In other words, similar to predictions in "standard" belief-disagreement models of Geanakoplos 2010, Simsek 2013.

# Data

# Data

- Extensive housing & mortgage transaction data from Corelogic (2001-2016).
  - Single-family homes within 1km from East Coast (>1m transactions).
- Property-level geophysical measures.
  - Whether inundated under various sea level rise scenarios (from ▸ NOAA SLR shapefiles).
  - Distance to coast (ArcGIS) & minimum bare-earth elevation (First Street).
- County-level climate belief proxy: % of adults saying whether global warming is happening (Yale climate opinion survey 2014).
  - Assumption: a buyer from a county with more pessimistic belief is more likely to be have a pessimistic belief herself.
  - Potential ▸ selection bias.
- ▸ Summary statistics

# Exploiting high resolution variation in SLR risk exposure




Chesapeake, VA under 6ft of SLR. Properties A-E lie in same ZIP, distance to coast bin ((0, .01], (.01–.02], (.02–.08], (.08–.16], (.16, $\infty$) miles), elevation bin (2m), and same bedroom number, transaction time.

# Results

# Result 0: Pricing of climate risk, revisited

| | Log Housing Price |
|---|---|
| Climate Risk | 0.234*** |
| | (0.0303) |
| | “Naive” regression |
| Property controls (age,$ft^2$) | Y |
| Z x D x E x B x T fe | |
| N | 1640345 |
| R2 | 0.196 |

Standard errors clustered at zip code. Z: ZIP, D: distance to coast bins, E: elevation bins, B: number of bedrooms, T: month-year of sale.

# Result 0: Pricing of climate risk, revisited

| | Log Housing Price | |
|---|---|---|
| Climate Risk | 0.234*** | -0.062*** |
| | (0.0303) | (0.022) |
| Property controls (age,$ft^2$) | Y | Y |
| Z x D x E x B x T fe | | Y |
| N | 1640345 | 419143 |
| R2 | 0.196 | 0.866 |

Pricing of SLR risk $\approx -6\%$ (consistent w Bernstein et al 2019)

Standard errors clustered at zip code. Z: ZIP, D: distance to coast bins, E: elevation bins, B: number of bedrooms, T: month-year of sale.

# Result 0: Pricing of climate risk, revisited

| | Log Housing Price | | |
|---|---|---|---|
| Climate Risk | 0.234*** | -0.062*** | -0.027** |
| | (0.0303) | (0.022) | (0.013) |
| Climate Risk x Pessi. Buyer | | | -0.064*** |
| | | | (0.021) |
| Property controls (age,$ft^2$) | Y | Y | Y |
| Z x D x E x B x T fe | | Y | Y |
| N | 1640345 | 419143 | 410560 |
| R2 | 0.196 | 0.866 | 0.866 |

Standard errors clustered at zip code. Z: ZIP, D: distance to coast bins, E: elevation bins, B: number of bedrooms, T: month-year of sale.

Most of SLR pricing is driven by transactions with more pessimistic buyers

# Result 1: Climate-Leverage relationship

| | Leveraged |
|---|---|
| Climate Risk | -0.093*** |
| | (0.008) |
| Controls (property, sale price, buyer cty) | Y |
| Z $\times$ D $\times$ E $\times$ B $\times$ T fe | |
| Buyer county controls $\times$ Climate Risk | |
| N | 1580756 |
| R2 | 0.019 |

# Result 1: Climate-Leverage relationship

| | Leveraged | |
|---|---|---|
| Climate Risk | -0.093*** | 0.021*** |
| | (0.008) | (0.007) |
| Controls (property, sale price, buyer cty) | Y | Y |
| Z $\times$ D $\times$ E $\times$ B $\times$ T fe | | Y |
| Buyer county controls $\times$ Climate Risk | | |
| N | 1580756 | 405893 |
| R2 | 0.019 | 0.473 |

# Result 1: Climate-Leverage relationship

| | Leveraged | |
|---|---|---|
| Climate Risk | -0.093*** | 0.021*** |
| | (0.008) | (0.007) |

Purchases of exposed homes are 2% more likely to be leveraged (extensive margin)

Comparison: Share of leveraged transactions increase by ∼4% bt 2001-2007 in our sample

| | | |
|---|---|---|
| Controls (property, sale price, buyer cty) | Y | Y |
| Z × D × E × B × T fe | | Y |
| Buyer county controls × Climate Risk | | |
| N | 1580756 | 405893 |
| R2 | 0.019 | 0.473 |

# Result 1: Climate-Leverage relationship

| | Leveraged | | |
|---|---|---|---|
| Climate Risk | -0.093*** | 0.021*** | -0.004 |
| | (0.008) | (0.007) | (0.007) |
| Climate Risk × Pessi. Buyer | | | 0.047*** |
| | | | (0.009) |
| Controls (property, sale price, buyer cty) | Y | Y | Y |
| Z × D × E × B × T fe | | Y | Y |
| Buyer county controls × Climate Risk | | | |
| N | 1580756 | 405893 | 405893 |
| R2 | 0.019 | 0.473 | 0.473 |

Relationship is driven by transactions with buyers from counties with more pessimistic climate beliefs

# Result 1: Climate-Leverage relationship

| | Leveraged | | | |
|---|---|---|---|---|
| Climate Risk | -0.093*** | 0.021*** | -0.004 | -0.003 |
| | (0.008) | (0.007) | (0.007) | (0.014) |
| Climate Risk × Pessi. Buyer | | | 0.047*** | 0.034*** |
| | | | (0.009) | (0.011) |
| Controls (property, sale price, buyer cty) | Y | Y | Y | Y |
| Z × D × E × B × T fe | | Y | Y | Y |
| Buyer county controls × Climate Risk | | | | Y |
| N | 1580756 | 405893 | 405893 | 405893 |
| R2 | 0.019 | 0.473 | 0.473 | 0.473 |

Relationship is driven by transactions with buyers from counties with more pessimistic climate beliefs

# Result 1: Climate-Leverage relationship

| | Leveraged | | | | |
|---|---|---|---|---|---|
| Climate Risk | -0.093*** | 0.021*** | -0.004 | -0.003 | |
| | (0.008) | (0.007) | (0.007) | (0.014) | |
| Climate Risk × Pessi. Buyer | | | 0.047*** | 0.034*** | |
| | | | (0.009) | (0.011) | |
| Moderate Climate Risk | | | | | 0.003 |
| | | | | | (0.014) |
| High Climate Risk | | | | | -0.035 |
| | | | | | (0.031) |
| Moderate Climate Risk × Pessi. Buyer | | | | | 0.026** |
| (inundated at $(3, 6]$ft SLR) | | | | | (0.011) |
| High Climate Risk × Pessi. Buyer | | | | | 0.083*** |
| (inundated at $\leq$ 3ft SLR) | | | | | (0.023) |
| Controls (property, sale price, buyer cty) | Y | Y | Y | Y | Y |
| Z × D × E × B × T fe | | Y | Y | Y | Y |
| Buyer county controls × Climate Risk | | | | Y | Y |
| N | 1580756 | 405893 | 405893 | 405893 | 405893 |
| R2 | 0.019 | 0.473 | 0.473 | 0.473 | 0.473 |

Note monotonicity

# Result 2: Climate-Maturity relationship

| | Long Maturity | | | | |
|---|---|---|---|---|---|
| Climate Risk | -0.019*** | 0.005 | -0.004 | 0.002 | |
| | (0.002) | (0.005) | (0.007) | (0.014) | |
| Climate Risk × Pessi. Buyer | | | 0.018*** | 0.024*** | |
| | | | (0.007) | (0.007) | |
| Controls (property, sale price, buyer cty) | Y | Y | Y | Y | Y |
| Z × D × E × B × T fe | | Y | Y | Y | Y |
| Lender fe | | Y | Y | Y | Y |
| Buyer county controls × Climate Risk | | | | Y | Y |
| N | 822890 | 150746 | 150746 | 150746 | 150746 |
| R2 | 0.002 | 0.441 | 0.441 | 0.441 | 0.441 |

# Result 2: Climate-Maturity relationship

| | Long Maturity | | | | |
|---|---|---|---|---|---|
| Climate Risk | -0.019*** | 0.005 | -0.004 | 0.002 | |
| | (0.002) | (0.005) | (0.007) | (0.014) | |
| Climate Risk × Pessi. Buyer | | | 0.018*** | 0.024*** | |
| | | | (0.007) | (0.007) | |
| Controls (property, sale price, buyer cty) | Y | Y | Y | Y | Y |
| Z × D × E × B × T fe | | Y | Y | Y | Y |
| Lender fe | | Y | Y | Y | Y |
| Buyer county controls × Climate Risk | | | | Y | Y |
| N | 822890 | 150746 | 150746 | 150746 | 150746 |
| R2 | 0.002 | 0.441 | 0.441 | 0.441 | 0.441 |

Purchases of exposed home by more pessimistic buyers
tend to have longer maturity (intensive margin)

# Result 2: Climate-Maturity relationship

| | Long Maturity | | | | |
|---|---|---|---|---|---|
| Climate Risk | -0.019*** | 0.005 | -0.004 | 0.002 | |
| | (0.002) | (0.005) | (0.007) | (0.014) | |
| Climate Risk × Pessi. Buyer | | | 0.018*** | 0.024*** | |
| | | | (0.007) | (0.007) | |
| Moderate Climate Risk | | | | | 0.006 |
| | | | | | (0.014) |
| High Climate Risk | | | | | -0.028 |
| | | | | | (0.024) |
| Moderate Climate Risk × Pessi. Buyer | | | | | 0.023*** |
| | | | | | (0.008) |
| High Climate Risk × Pessi. Buyer | | | | | 0.031* |
| | | | | | (0.019) |
| Controls (property, sale price, buyer cty) | Y | Y | Y | Y | Y |
| Z × D × E × B × T fe | | Y | Y | Y | Y |
| Lender fe | | Y | Y | Y | Y |
| Buyer county controls × Climate Risk | | | | Y | Y |
| N | 822890 | 150746 | 150746 | 150746 | 150746 |
| R2 | 0.002 | 0.441 | 0.441 | 0.441 | 0.441 |

# Robustness checks

- Other belief specifications:
  - Finer bins of climate beliefs + Other survey questions (stated worry; belief about timing of damage). ▸ Details
  - Alternative data source: impute county-level & time-varying climate beliefs from individual-level environmental survey by Gallup. ▸ Details
- Other fixed effect specifications. ▸ Details
  - Including investment-property (i.e., non-owner-occupied) fixed effect.
- Finer bins of SLR exposure. ▸ Details
- Potential confounders: More buyer county controls (income, pop, edu, age, race, unemp rate, housing starts, crime). ▸ Details
- FEMA flood map, past flood events ▸ Details

# Diving Deeper

# Selection bias

- Concern: our sample of coastal homebuyers is biased. Reason: optimists more likely to select/sort towards coastal properties. Thus, county-level belief is a biased proxy for individual-level buyer belief.
- One approach: Impute buyer belief from each transaction. ▸ Details
- Other approaches:
  1. Very significant and negative effect of SLR $\times$ buyer county belief on house price (bias not strong enough to cancel out this negative correlation).
  2. Bakkensen Barrage (RFS 2021): county-level Yale belief ▸ strongly correlated with individual-level belief in door-to-door survey in coastal RI (caution: small sample, n=187).
  3. If sorting is dominant, we should see strong *negative* correlation between frequency of coastal buyers in a county and the county's belief (i.e., fewer buyers of coastal homes coming from pessimistic counties). This ▸ does not seem to be the case in our data.

# Role of securitization?

- Securitization could reduce banks' incentive to screen climate risk: banks could shift climate risks to Government Sponsored Enterprises, by securitizing and selling off exposed mortgages that are below conforming loan limits (Ouazad Kahn 2021).
- Suppose this is true, then we should expect effects of SLR exposure on leverage and maturity to strengthen for conforming loan segment & weaken for nonconforming segment.
- This turns out to be the case in our data.

# Results driven by conforming loan segment

| | Leveraged & | | Long Maturity & | |
|---|---|---|---|---|
| | Conforming | Nonconform | Conforming | Nonconform |
| Climate Risk | -0.016 | 0.013* | -0.009 | 0.007 |
| | (0.015) | (0.007) | (0.021) | (0.013) |
| Climate Risk × Pessi. Buyer | 0.033*** | -0.001 | 0.033*** | -0.015** |
| | (0.012) | (0.004) | (0.012) | (0.007) |
| Property & buyer county controls | Y | Y | Y | Y |
| Buyer county controls × Climate Risk | Y | Y | Y | Y |
| Z × D × E × B × M fe | Y | Y | Y | Y |
| Lender fe | | | Y | Y |
| N | 406601 | 406601 | 182771 | 182771 |
| R2 | 0.478 | 0.566 | 0.569 | 0.669 |

# Monetary policy

- Model predicts that policy rate $i$ affects leveraged probability, but not maturity.
- Both predictions find support in our data. ▸ Details

# Other results

- Mortgage rates: do not seem to reflect climate risk or climate beliefs. ▸ Details
- Loan amount: Model predicts ambiguous effects on loan amount (B; intensive margin). Prediction supported. ▸ Details

# Conclusion

- What makes climate risks special?
  - Possibility of large damage in the future.
  - Pronounced belief disagreement (esp. in U.S.).
- We found: risk of *future* damage $\times$ belief disagreement is an important determinant of how climate risks affect debt market.
- How financial markets adapt to climate change under belief disagreement: nontrivial patterns and policy implications. **Exciting research agenda!**

# Appendix: Model

# Competitive search equilibrium

- Competitive search equilibrium consists of a menu $\Omega$ of available contracts, with quantities $(n_b, n_l)$ associated with each borrower type $\lambda$ and contract $a \in \Omega$, s.t.:
  1. Matching probabilities for a borrower is $\alpha = M/n_b$ and for a lender is $\eta = M/n_l$;
  2. $n_b$ is the measure of borrowers for which $a$ solves their optimization problem;
  3. $n_l$, the measure of lenders who enter the associated submarket, is so that free-entry condition is satisfied;
  4. the market clears: for each borrower type $\lambda$, the sum total of all the measures of borrowers in each submarket must satisfy

$$\int_{a\in\Omega} n_b(a)da = f(\lambda)$$

     where $f$ is the density function of the borrower type distribution.

◂ Back

# Closed-form solutions

- Leverage probability:

$$\alpha^{(1+\xi)/\xi} = \frac{1+\xi}{(1-\theta)\kappa}\left[P - \frac{1+\theta\rho}{1+\rho} v(\lambda) + \theta\xi\right]. \tag{2}$$

- Maturity:

$$\bar{T} = \begin{cases} \frac{\overbrace{(1+\bar{\lambda})[v(\bar{\lambda}) - v(\lambda)] - \bar{\lambda}}^{\text{“disagreement value”}}}{k} & \text{if } \lambda > \lambda_b, \\ T_0 & \text{otw.} \end{cases} \tag{3}$$

- Mortgage payment:

$$m = \underbrace{\Delta\left(\lambda, \bar{\lambda}\right)}_{\text{disagreement}} - \underbrace{\bar{\lambda}\left(1-D\right)}_{\text{foreclosing the damaged house}} + \underbrace{\frac{1}{\bar{T}}\left[v\left(\lambda\right) + F\right]}_{\text{amortizing the subjective value}} \tag{4}$$

Back

# Extension: Monetary policy

- Assume borrowers face funding cost $\rho$:

$$\underbrace{\alpha\left[-(1+\underbrace{\rho}_{\text{funding cost}})\underbrace{(P-B)}_{\text{down payment}}+V(m,\mu)\right]}_{\text{mortgage approved}}+\underbrace{(1-\alpha)\left[-(1+\rho)P+V(0,\infty)\right]}_{\text{not approved}}$$

- And banks face funding cost $i \leq \rho$, where $i$ depends on monetary policy. Free-entry condition:

$$0=\underbrace{\eta(\alpha)}_{\text{prob. of finding a matching buyer}}\Big[\underbrace{-(1+i)B}_{\text{funding cost}}+\underbrace{\Pi(m,\mu)}_{\text{expected payoff from mortgage}}-\underbrace{K(\mu)}_{\text{operation cost}}\Big]-\underbrace{\kappa}_{\text{fixed cost}}$$

Back

# Extension: Nash bargaining

- Assume for simplicity, seller has same belief as buyer (e.g., both buyer and seller are from the same county and inherit the same county-level belief).
- Borrower's bargaining power $\theta$.
- To motivate trade, assume seller faces a higher house maintenance cost $\xi$ relative to buyer.
- House price $P$ determines by

$$\max_P U^\theta [P - v(\lambda) + \xi]^{1-\theta}.$$

- Solution:

$$P = \underbrace{\frac{1+\theta\rho}{1+\rho} v(\lambda) - \theta\xi}_{\text{standard ``hedonic'' term}} + \underbrace{(1-\theta)\alpha \left[ \frac{\overbrace{S(m,\mu)}^{\text{joint surplus}}}{1+\rho} - \overbrace{\frac{\kappa}{\eta(\alpha)}}^{\text{mortgage cost}} \right]}_{\text{mortgage term}}, \tag{5}$$

Back

# Extension: Insurance (and why few buy it)

Assume an insurance that charges $rq$ continuously and pays $\delta$ when climate shock hits.

- Homebuyers can choose any coverage $\delta \in [0, \bar{\delta}]$, where $D - \bar{\delta} > \bar{\lambda} F$.
- If insurance is mandatory, then isomorphic to lowering $D$ by $\delta \rightarrow$ same qualitative results.
- If insurance is not mandatory:
  - Assume premium is priced at the bank's belief: $q = \bar{\lambda}\delta$.
  - If $\bar{\lambda} \geq \lambda_a$, then no homebuyer will buy any insurance.
    - Intuition: Optimists find the premium too high as priced at a higher belief. Pessimists will surrender the house when the climate shock hits so insurance is no use.
  - If $\bar{\lambda} < \lambda_a$, then
    - Homebuyers with $\lambda \in [\bar{\lambda}, \lambda_a]$ will buy max insurance ($\delta = \bar{\delta}$). Continue to choose risk-free mortgage.
    - Homebuyers with $\lambda \notin [\bar{\lambda}, \lambda_a]$ will not buy insurance and behave as before.
  - Hence, similar qualitative results again.
  - Intuition: default is implicit insurance against climate shock, hence crowds out insurance uptake (related empirical evidence for this mechanism: Liao Mulder 2021)

◂ Back

# Appendix: Data

# NOAA Sea Level Rise Data

- Maps sea level rise inundation.
  - Bathtub-style model.
  - Relative to Mean Higher High Water levels.
  - 0 to 10ft SLR scenarios mapped.
  - Variation in local SLR driven by small differences in elevation, topography, bathymetry, etc.
  - Publicly free at `https://coast.noaa.gov/slr/`
- Does not include potentially endogenous local factors, e.g.:
  - Erosion, subsidence/accretion, human mitigation.

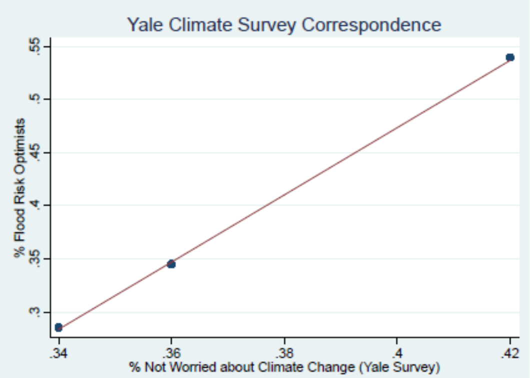
Back

# Summary statistics

| | Mean | Std |
|---|---|---|
| Sale price ($) | 370,819.40 | 523,768.00 |
| Leveraged (mortgage dummy) | 0.63 | 0.48 |
| Mortgage amount ($) | 178,732.50 | 262,627.20 |
| Mortgage maturity (y) | 17.20 | 14.44 |
| Distance to coast (m) | 402.74 | 296.83 |
| Elevation (m) | 6.84 | 11.69 |
| Climate belief (county level,%) | 64.97 | 4.06 |
| Inundated with 1ft SLR | 0.00 | 0.06 |
| Inundated with 2ft SLR | 0.01 | 0.10 |
| Inundated with 3ft SLR | 0.03 | 0.17 |
| Inundated with 4ft SLR | 0.07 | 0.26 |
| Inundated with 5ft SLR | 0.14 | 0.34 |
| Inundated with 6ft SLR | 0.21 | 0.41 |
| N | 876,729 | |

◂ Back

# Yale data vs. Bakkensen-Barrage 2021 data




Back to data

Back to selection

# Appendix: Robustness checks

# Other belief specifications

| | Leveraged | | | Long Maturity | | |
|---|---|---|---|---|---|---|
| | Happening | Worried | Timing | Happening | Worried | Timing |
| SLR Risk × Pess. Buyer (above median) | 0.034*** | 0.049*** | 0.031** | 0.024*** | 0.026*** | 0.023*** |
| | (0.011) | (0.012) | (0.013) | (0.007) | (0.007) | (0.007) |
| SLR × 2nd Quartile Belief | 0.023** | 0.006 | 0.001 | 0.030*** | 0.008 | 0.025** |
| | (0.011) | (0.012) | (0.011) | (0.008) | (0.010) | (0.010) |
| SLR × 3rd Quartile Belief | 0.011 | 0.058*** | 0.022 | 0.034*** | 0.033*** | 0.017 |
| | (0.017) | (0.013) | (0.015) | (0.011) | (0.009) | (0.010) |
| SLR × 4th Quartile (highest) Belief | 0.045** | 0.047* | 0.051*** | 0.034*** | 0.023 | 0.038*** |
| | (0.018) | (0.027) | (0.015) | (0.010) | (0.017) | (0.010) |
| SLR Risk × Belief (continuous) | 0.002 | 0.003*** | 0.002* | 0.002* | 0.002** | 0.000 |
| | (0.001) | (0.001) | (0.001) | (0.001) | (0.001) | (0.000) |
| Z × D × E × B × M fe | Y | Y | Y | Y | Y | Y |
| Property & buyer county controls | Y | Y | Y | Y | Y | Y |
| Buyer county controls × Climate Risk | Y | Y | Y | Y | Y | Y |
| Lender fe | | | | Y | Y | Y |

◂ Back

# Imputed county-level belief from individual-level Gallup survey

| | Leveraged | Long Maturity |
|---|---|---|
| SLR Risk | -0.031 | 0.006 |
| | (0.021) | (0.021) |
| SLR Risk x Pess. Buyer | 0.032** | 0.028* |
| | (0.015) | (0.015) |
| Property & buyer county controls | Y | Y |
| Z x D x E x B x T fe | Y | Y |
| Buyer county controls x SLR | Y | Y |
| Lender f.e. | | Y |
| N | 210774 | 62928 |
| R2 | 0.439 | 0.442 |

◂ Back

# Other fixed-effect specifications: Leveraged result

| | Leveraged | | | |
|---|---|---|---|---|
| SLR Risk | 0.007 | -0.005 | 0.010 | 0.012 |
| | (0.016) | (0.012) | (0.010) | (0.013) |
| SLR Risk × Pess. Buyer | 0.032*** | 0.031*** | 0.019** | 0.021** |
| | (0.010) | (0.011) | (0.008) | (0.010) |
| F.e. | Z×D×E×B | Z×D×E×B×Q | Z×D×E×B×Q×O | Z×D×E×B×M×O |
| Property & buyer county controls | Y | Y | Y | Y |
| Buyer county controls × Climate Risk | Y | Y | Y | Y |
| N | 852817 | 568636 | 490546 | 322484 |
| R2 | 0.188 | 0.404 | 0.461 | 0.526 |

Z – zip code, D – distance to coast bin, E – elevation bin, B – number of bedrooms, Q – quarter and year of transaction, M – month and year of transaction, O – owner-occupied status.

# Other fixed-effect specifications: Long maturity result

| | Long Maturity | | | |
|---|---|---|---|---|
| SLR Risk | -0.011* | -0.003 | -0.005 | -0.010 |
| | (0.006) | (0.011) | (0.012) | (0.019) |
| SLR Risk × Pess. Buyer | 0.007 | 0.017*** | 0.012* | 0.022** |
| | (0.005) | (0.006) | (0.007) | (0.009) |
| F.e. | Z×D×E×B | Z×D×E×B×Q | Z×D×E×B×Q×O | Z×D×E×B×M×O |
| Property & buyer county controls | Y | Y | Y | Y |
| Buyer county controls × Climate Risk | Y | Y | Y | Y |
| Lender fe | Y | Y | Y | Y |
| N | 852817 | 568636 | 490546 | 322484 |
| R2 | 0.188 | 0.404 | 0.461 | 0.526 |

Z – zip code, D – distance to coast bin, E – elevation bin, B – number of bedrooms, Q – quarter and year of transaction, M – month and year of transaction, O – owner-occupied status

Back

# Finer SLR exposure bins

| | Leveraged | Long Maturity |
|---|---|---|
| 1.SLR (6ft) | 0.0180 | 0.0169 |
| | (0.014) | (0.017) |
| 2.SLR (5ft) | 0.0140 | -0.0042 |
| | (0.020) | (0.026) |
| 3.SLR (4ft) | -0.0343 | -0.0038 |
| | (0.027) | (0.020) |
| 4.SLR ($\leq$3ft) | -0.0362 | -0.0305 |
| | (0.031) | (0.024) |
| 1.SLR x Pess. Buyer | 0.0154 | 0.0140 |
| | (0.012) | (0.009) |
| 2.SLR x Pess. Buyer | 0.0246* | 0.0321** |
| | (0.015) | (0.014) |
| 3.SLR x Pess. Buyer | 0.0455** | 0.0323** |
| | (0.018) | (0.014) |
| 4.SLR x Pess. Buyer | 0.0856*** | 0.0322* |
| | (0.023) | (0.018) |
| Property & buyer county controls | Y | Y |
| Buyer county controls x SLR | Y | Y |
| Z $\times$ D $\times$ E $\times$ B $\times$ M fe | Y | Y |
| Lender fe | | Y |
| N | 405893 | 150746 |
| R2 | 0.473 | 0.441 |

Back

# Including more buyer county controls (2010-2016 sample)

| | Leveraged | Long Maturity |
|---|---|---|
| SLR Risk | -0.019 | 0.070* |
| | (0.031) | (0.040) |
| SLR Risk x Pess. Buyer | 0.038** | 0.039*** |
| | (0.014) | (0.015) |
| Property & buyer county controls | Y | Y |
| Z x D x E x B x T fe | Y | Y |
| Buyer county controls x SLR | Y | Y |
| Lender f.e. | | Y |
| N | 210774 | 62928 |
| R2 | 0.440 | 0.443 |

Buyer county controls: income, population, education (share of bachelors), age (18-29 share), race (black share).

Back

# Controlling for FEMA flood map

| | Leveraged | Long Maturity |
|---|---|---|
| SLR | 0.007 | 0.001 |
| | (0.014) | (0.014) |
| SLR x Pess. Buyer | 0.027** | 0.023*** |
| | (0.011) | (0.008) |
| FEMA Zone | -0.024*** | -0.002 |
| | (0.008) | (0.004) |
| FEMA Zone x Pess. Buyer | 0.015 | 0.001 |
| | (0.011) | (0.007) |
| Z x D x E x B x T FE | Y | Y |
| Buyer County x SLR Controls | Y | Y |
| Lender FE | | Y |
| N | 405908 | 150746 |
| R2 | 0.473 | 0.441 |

◂ Back

# Appendix: Further results

# Effects of monetary policy

| | Leveraged | Long Maturity |
|---|---|---|
| SLR Risk | -0.022 | 0.001 |
| | (0.017) | (0.016) |
| SLR Risk x High Belief | 0.051*** | 0.035*** |
| | (0.015) | (0.012) |
| SLR Risk x High Belief x $i$ | -0.010** | -0.005 |
| | (0.005) | (0.004) |
| Z x D x E x B x M fe | Y | Y |
| Property & buyer county controls | Y | Y |
| Buyer county controls x SLR | Y | Y |
| Lender fe | | Y |
| N | 405,908 | 150,746 |
| $R^2$ | 0.473 | 0.441 |

$i$: Market Yield on Treasury Securities at 2-Year Maturity

Back

# Insignificant effects on borrowing amount (as model predicts)

| | log(Mortgage amount) | |
|---|---|---|
| Climate Risk | -0.003 | |
| | (0.011) | |
| Climate Risk x Pess. Buyer | 0.004 | |
| | (0.010) | |
| Moderate Climate Risk | | -0.001 |
| | | (0.012) |
| High Climate Risk | | -0.018 |
| | | (0.030) |
| Moderate Climate Risk x Pess. Buyer | | 0.005 |
| | | (0.010) |
| High Climate Risk x Pess. Buyer | | -0.006 |
| | | (0.020) |
| Property & buyer county controls | Y | Y |
| Z x D x E x B x M fe | Y | Y |
| Lender fe | Y | Y |
| Buyer county controls x SLR | Y | Y |
| N | 167402 | 167402 |
| R2 | 0.919 | 0.919 |

Back

# Insignificant effects on interest rates

| | Interest rate | |
|---|---|---|
| Climate Risk | -0.095 | |
| | (0.160) | |
| Climate Risk x Pess. Buyer | 0.037 | |
| | (0.088) | |
| Moderate Climate Risk | | -0.074 |
| | | (0.162) |
| High Climate Risk | | -0.348 |
| | | (0.365) |
| Moderate Climate Risk x Pess. Buyer | | 0.035 |
| | | (0.098) |
| High Climate Risk x Pess. Buyer | | 0.102 |
| | | (0.206) |
| Property & buyer county controls | Y | Y |
| Z x D x E x B x M fe | Y | Y |
| Lender fe | Y | Y |
| Buyer county controls x SLR | Y | Y |
| 30 year f.e. | Y | Y |
| N | 28873 | 28873 |
| R2 | 0.725 | 0.725 |

Back

# Appendix: Selection

# Sorting

| | Fraction of buyers from county choosing a coastal home |
|---|---|
| Buyer county belief | 0.001* |
| | (0.001) |
| Buyer county income | 0.003*** |
| | (0.000) |
| Buyer county population | -0.000*** |
| | (0.000) |
| Buyer county share with Bachelor degree | -0.006 |
| | (0.072) |
| Buyer county share 18-29 age | -0.089 |
| | (0.056) |
| Buyer county share of white | -0.067*** |
| | (0.019) |
| Time F.E. | Y |
| State F.E. | Y |
| N | 14921 |
| R2 | 0.174 |

Back

# Using transaction-specific belief imputed from house prices

- Idea: higher capitalization of SLR in housing price implies likely more pessimistic buyer.
- Assume housing price follows true data generating process:

$$\log P^i = (\beta + \gamma\lambda^i)SLR^i + \text{controls} + \text{constant} + \epsilon^i \tag{6}$$

- Regress and predict error term $\hat{\zeta}^i$ in

$$\log P^i = \beta_1 SLR^i + \text{controls} + \text{constant} + \zeta^i \tag{7}$$

  - (6) and (7) implies $\zeta^i = \gamma SLR^i \lambda^i + \epsilon^i$ and therefore the predicted $\hat{\zeta}^i := E[\zeta^i] = \gamma SLR^i \lambda^i$
- Define our proxy for property-level climate belief as (the negative sign is because we expect $\gamma$ to be negative)

$$\hat{\lambda}^i := -\hat{\zeta}^i. \tag{8}$$

  $\hat{\lambda}^i$ should be positively correlated with the true unobserved $\lambda^i$.
- For the subsample where $SLR^i = 1$, define $\widehat{PessiBuyer}^i$ as 1 if $\hat{\lambda}^i$ is above median.

| | Leveraged | Long maturity |
|---|---|---|
| SLR | -0.030 | 0.131** |
| | (0.044) | (0.059) |
| SLR x $\widehat{PessiBuyer}$ | 0.039*** | 0.012 |
| | (0.009) | (0.008) |
| Z x D x E x B x T fe | Y | Y |
| Property & buyer county controls | Y | Y |
| Buyer county controls x SLR | Y | Y |
| Lender fe | | Y |
| N | 210774 | 62928 |
| R2 | 0.440 | 0.443 |

$\widehat{PessiBuyer}$ is transaction-specific and imputed from housing price regression.

◂ Back