Virtual Seminar on Climate Economics

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Leveraging the Disagreement on Climate Change

Evidence and Theory

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Virtual Seminar on Climate Economics - 10 Feb 2022

Big picture

- How do climate risks affect financial system?
  - Topic of a rapidly growing climate finance literature.
  - Relevant for financial regulators. E.g. of a concern: "investors may underestimate the likelihood of large shocks related to climate, particularly physical risks. Such pervasive underestimation could lead to excessive levels of effective leverage" (Brunetti et al FEDS Notes 2021).

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  - Relevant for financial regulators. E.g. of a concern: "investors may underestimate the likelihood of large shocks related to climate, particularly physical risks. Such pervasive underestimation could lead to excessive levels of effective leverage" (Brunetti et al FEDS Notes 2021).
- Particularly relevant: How do climate risks affect housing & mortgage market?
  - What do we know so far? Mostly on housing prices.
    - Climate risks (e.g., sea level rise, increased flood risk) tend to negatively affect housing prices (e.g., Bernstein et al 2019, Bakkensen Barrage 2021, Hino Burke 2021).
    - Belief heterogeneity is a moderating factor: extent of pricing increases with climate belief (e.g., Baldauf et al 2020, Bakkensen Barrage 2021).
  - But relatively less is known about mortgage market.

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3. Does exposure to future climate risk reduce debt maturity?
    - All else equal, SLR risk is positively correlated with maturity length, when buyers come from counties with stronger climate beliefs.
4. Findings consistent with implications of a competitive search model for defaultable mortgage contracts with heterogeneous beliefs.
    - Potential policy implication: expansionary monetary policies may incentivize leveraged exposure to climate risks.

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, Sastry 2022
- Surveys: Hong Karolyi Scheinkman RFS 2020, Giglio Kelly Stroebel 2021, Furukawa Ichiue Shiraki 2021

Theoretical literature

- Models of asset and credit markets with heterogeneous beliefs: Fostel Geanakoplos AER 2008, ECT 2015, Geanakoplos NBERma 2010, Simsek ECTA 2013, Bailey Dávila Kuchler Stroebel Restud 2019...
- Search model in housing market: Ngai and Tenreyro AER 2014; Head Lloyd-EllisSun AER 2014; Landvoigt Piazzesi Schneider AER 2015; Garriga Hedlund AER 2020...

Agenda

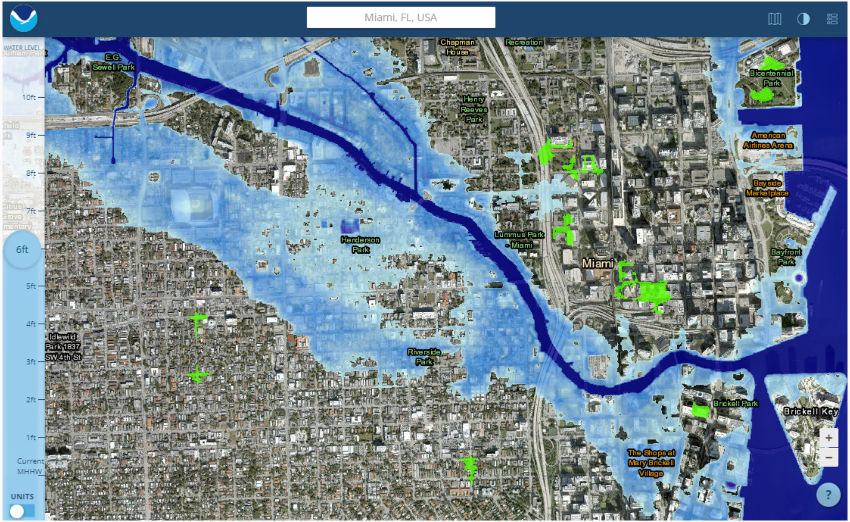
1. Empirical analysis
2. Theoretical model

Data

Data constrution

- Extensive housing & mortgage transaction data from Corelogic (2001-2016).
    - Single-family homes within 1km from East Coast (>1m transactions).
    - Key variables: Sale price, mortgage amount & term.
    - Property controls: age, square footage, number of bedrooms.
- Property-level geophysical measures.
    - Whether inundated under various SLR scenarios (from NOAA shapefiles).
    - Distance to coast (computed in ArcGIS using property coordinates).
    - Minimum bare-earth elevation (First Street).
- County-level climate belief proxy: % of adults saying whether global warming is happening (Yale climate opinion survey 2014).
    - Data limitation: we cannot directly observe transaction-specific belief (nor can we observe other buyer's characteristics – education, credit score, etc. – to impute buyer-specific belief).
    - Assumption: avg belief in buyer's ZIP code is a plausible proxy for buyer's belief.
    - Cross check with Bakkensen Barrage individual belief data for Rhodes Island. Plot

Exploiting high resolution variation in SLR risk exposure



Example of Miami's exposure to SLR inundation risk under 6ft scenario. Source: NOAA SLR Viewer

Summary statistics

	Mean	Std
Sale price ($)	419,358.90	631,877.10
Mortgage amount ($)	181,407.00	290,976.90
Mortgage term (y)	27.90	6.19
Distance to coast (m)	386.42	294.66
Elevation (m)	7.03	12.43
Climate belief (county level,%)	66.01	4.80
Inundated with 1ft SLR	0.01	0.07
Inundated with 2ft SLR	0.01	0.11
Inundated with 3ft SLR	0.04	0.19
Inundated with 4ft SLR	0.09	0.29
Inundated with 5ft SLR	0.16	0.37
Inundated with 6ft SLR	0.24	0.43

Setting the Stage: SLR Pricing

Step 0: SLR pricing revisited

1. Does a property exposed to future SLR risk trade at a lower price (compared to an equivalent unexposed property)? Regression (based on Bernstein et al JFE 2019):

$$\ln Price_{it} = \beta SLR_i + \lambda_{zdebm} + \phi' X_{it} + \epsilon_{it} \tag{P1}$$

   - SLR_i: whether property i would be inundated with 6 feet of SLR,
   - X_{it}: property's controls (age & square footage),
   - λ_{zdebm}: rich set of fixed effects. Effectively, comparing transaction within same ZIP & Distance to coast & Elevation & number of Bedrooms & Month-year of sale.

2. Is SLR pricing moderated by (proxy for) buyer's climate belief?

$$\ln Price_{it} = \beta SLR_i + \gamma SLR_i \times HighBelief_c + HighBelief_c + \lambda_{zdebm} + \phi' X_{it} + \epsilon_{it} \tag{P2}$$

   - $HighBelief_c$: whether avg climate belief in buyer's county is above median ($\geq 66\%$).

Result 0: SLR pricing replicated

	Log Price		
SLR	0.234***	-0.062***	-0.027**
	(0.0303)	(0.022)	(0.013)
SLR x High Buyer Belief			-0.064***
			(0.021)
Property controls	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.

- Results consistent with previous findings:
    - SLR pricing $\approx -6\%$.
    - Most of SLR pricing is driven by transactions with "more pessimistic buyers."

Main Results

SLR-Leverage relationship?

- Does SLR exposure affect leverage ratio or probability?

$$Y_{it} = \beta SLR_i + \alpha lnPrice_{it} + \lambda_{zdebm} + \phi' X_{it} + \epsilon_{it} \tag{L1}$$

where Y is either

- Leverage ratio,
- Leveraged dummy: whether transaction has a mortgage contract (extensive margin); Note: OLS regression,
- Leverage ratio conditional on leveraged (intensive margin).

Result 1: SLR-Leverage relationship

	Lev Ratio	Lev Ratio if leveraged	Leveraged
SLR	0.016***		
	(0.005)		
Property controls	Y		
Z x D x E x B x T fe	Y		
N	418428		
R2	0.477		

- Transactions of exposed properties tend to have higher leverage ratios (compared to transactions of equivalent unexposed properties).

Result 1: SLR-Leverage relationship

	Lev Ratio	Lev Ratio if leveraged	Leveraged
SLR	0.016***	0.000	
	(0.005)	(0.002)	
Property controls	Y	Y	
Z x D x E x B x T fe	Y	Y	
N	418428	207689	
R2	0.477	0.501	

- Relationship does not seem to come from the intensive margin.

Result 1: SLR-Leverage relationship

	Lev Ratio	Lev Ratio if leveraged	Leveraged
SLR	0.016***	0.000	0.021***
	(0.005)	(0.002)	(0.007)
Property controls	Y	Y	Y
Z x D x E x B x T fe	Y	Y	Y
N	418428	207689	418428
R2	0.477	0.501	0.474

- Extensive margin: Transactions of exposed properties are 2% more likely to be leveraged.
    - Comparison: Share of leveraged transactions increase by ∼4% between 2001 and 2007 (peak of housing boom) in our sample.

Role of belief?

- Does SLR-leverage relationship depend on buyer's climate belief?

$$Leveraged_{it} = \beta SLR_i + \gamma SLR_i \times HighBelief_c + HighBelief_c + \alpha \ln Price_{it} + \lambda_{zdebm} + \phi' X_{it} + \epsilon_{it} \tag{L2}$$

Result 2: "Leverage of the Pessimists"

	Leveraged		
SLR	0.021***	-0.004	-0.197***
	(0.007)	(0.007)	(0.072)
SLR x High Buyer Belief		0.048***	
		(0.009)	
SLR x c.Buyer Belief			0.003***
			(0.001)
Property controls	Y	Y	Y
Z x D x E x B x T fe	Y	Y	Y
N	418428	409850	409850
R2	0.474	0.472	0.472

- SLR-leverage relationship is driven by transactions with more pessimistic buyers (i.e., buyers from counties with stronger climate beliefs).

SLR-Maturity relationship?

- Does SLR exposure affect maturity choice?
    - Longer maturity implies more exposure to future SLR risk.
    - So maybe exposure should shorten maturity?
- Rerun regressions (L1) and (L2), with new dependent variable $LongMaturity_{it}$: whether mortgage maturity is ≥ 30 years.
    - Restrict to leveraged sub-sample (otherwise *LongMaturity* is not defined).
    - Include lender fixed effects (to control for possibility that different lenders may have varying tendencies to issue different types of mortgage contracts).
    - Use dummy instead of continuous maturity as most mortgages have either 15 or 30-year maturity (results similar for continuous maturity).
    - OLS regression.

Result 3: Pessimists and long-term debt

	Long Maturity		
SLR	0.005	-0.009	-0.099**
	(0.004)	(0.007)	(0.047)
SLR x High Buyer Belief		0.025***	
		(0.007)	
SLR x c.Buyer Belief			0.002**
			(0.001)
Property controls	Y	Y	Y
Z x D x E x B x T fe	Y	Y	Y
Lender fe	Y	Y	Y
N	163554	162627	162627
R2	0.508	0.508	0.508

- Purchases of exposed properties by more pessimistic buyers tend to have longer maturity.

Taking stock

Climate risk exposure $\times$ heterogeneous belief: significant predictor of mortgage outcomes:

1. Purchases of exposed properties have higher leverage probability.
2. This relationship is mainly driven by transactions involving pessimistic buyers (from counties with strong climate beliefs).
3. Mortgage contracts of exposed properties by pessimistic buyers tend to have longer maturity.

Further results

Finer measures of climate risk exposure

- A concern: our exposure measure is too coarse (e.g., very unlikely that sea level will rise by 6ft in next 30 years[1]).
- We use finer exposure measures:
  - Check 1: Define *Moderate (High) SLR risk* as whether a property will be inundated with 3-6ft (less than 3ft) of sea level rise.
  - Check 2: Monotonically increasing exposure measure, from 0 to 6 (depending on the lowest SLR threshold that will inundate the property).
- Main results hold.
  - Result 1 (Leverage) Details
  - Result 2 (Heterogeneous beliefs) Details
  - Result 3 (Maturity) Details
  - Effects of SLR×belief generally tend to increase with SLR exposure & climate belief.

[1] Though it's possible that negative climate *news shocks*, which reduce exposed property prices, could arrive in next 30 years. If so, then exposed properties are still at a higher risk of devaluation in this time horizon.

Other robustness checks

Our results are robust to

- Other belief specifications (belief quartiles, stated worry about climate change, beliefs of property's county).
- Other fixed effect specifications.
- Excluding specifications with more than one associated mortgage (about 11% of sample).
- Omit housing price as a control.

Role of securitization?

- Ouazad Kahn (2021): banks could shift climate risks to GSEs, by securitizing and selling off exposed mortgages that are below conforming loan limits.
- 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.

Conforming loan limits

	Leveraged &		Long Maturity &	
	Conforming	Nonconforming	Conforming	Nonconforming
SLR	-0.024**	0.006	-0.015	0.003
	(0.010)	(0.004)	(0.010)	(0.006)
SLR x High Buyer Belief	0.067***	0.004	0.036***	-0.016
	(0.014)	(0.005)	(0.014)	(0.010)
Property controls	Y	Y	Y	Y
Z x D x E x B x T fe	Y	Y	Y	Y
Lender fe			Y	Y
N	204922	204922	86550	86550
R2	0.481	0.555	0.512	0.633

Stylized model

Model primitives

- A one-time climate shock: causes permanent damage to houses, arriving at a random time.
- Belief disagreement:
    - Home buyers believe arrival rate of climate shock is $r\lambda$, where $\lambda > 0$ varies across buyers.
    - Lenders: $\bar{\lambda}$.
- Asset: houses that yield utility stream $H_t = 1$ before climate shock and $H_t = 1 - D$ after (damage D can vary across houses).
- Mortgage contract: specifying loan amount B, reaches maturity period T at Poisson rate $r\mu$ (where $\mu \in [0, \mu_0]$), mortgage payment stream $m_t = m$ for $t \leq T$.

Optimizations

- Borrowers: A risk-neutral home buyer can
  - purchase a house at (endogenous) price P; facing funding cost $\rho \geq 0$ per unit of down payment,
  - choose a mortgage contract, subject to (endogenous) approval rate α,
  - choose to default at any $t_{def} < T$, suffering default cost F_{def},

  to maximize expected payoff. Details

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- Lenders:
  - Risk-neutral and competitive,
  - Funding cost $i < \rho$ (i depends on monetary policy),
  - Operation cost $K(\mu)$ of servicing debt of maturity μ (K helps pin down equilibrium μ)
  - Fixed operation cost κ (κ helps pin down equilibrium approval rate). ▸ Details

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- Housing price P is determined via Nash bargaining between home buyer and a seller.
  ▸ Details

Mortgage market: competitive search

- Borrowers and lenders have potential gains from trade, due to belief heterogeneity and different funding costs ($i < \rho$).
- There is a menu of mortgage contracts available for each borrower. Probability a borrower can find an approving bank for contract (B, m, μ) is $\alpha(B, mu, \mu)$.
- Banks' probability of finding a matching buyer is $\eta(\alpha)$.
- Free-entry condition of banks pins down equilibrium approval rate α. ▸ Details

Theorem

Analytical characterization of equilibrium mortgage contract

- For a property sufficiently exposed to climate shock ($D > \bar{\lambda} F_{def}$) & a relatively pessimistic buyer (climate belief $\lambda > \lambda_a$),
  - Mortgage contract is risky – borrower will default when climate shock hits;
  - ✓ Leverage prob α strictly increases in belief λ and exposure D.
  - ✓ Maturity $\bar{T}$ increases in λ & D (strictly if $\lambda > \lambda_b$, where $\lambda_b > \lambda_a$).
  - ✓ Borrowing amount B: ambiguous effect of λ & D.
- ▸ Closed-form solutions for α, $\bar{T}$, P

Theorem (continued)

Monetary policy implications

A reduction in policy interest rate i will

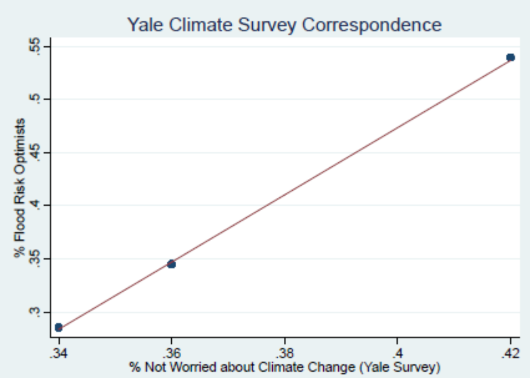
- Increase leverage probability and borrowing amount of pessimists.
- Expand the set of borrowers $[\lambda_a, \infty)$ that will choose risky mortgage contracts.

Conclusion

- What makes climate risks special?
  - Possibility of large damage in the future.
  - Pronounced belief disagreement (esp. in U.S.).
- Our paper documents that exposure to future SLR risk $\times$ belief disagreement is an important predictor of leverage and maturity in mortgage market.
- Potential policy implication: expansionary monetary policies may incentivize leveraged exposure to climate risks.

Appendix

Yale data vs. Bakkensen-Barrage 2021 data



Back

	Leveraged	
Moderate SLR Risk	0.0188**	
	(0.00733)	
High SLR Risk	0.0490***	
	(0.0129)	
1.SLR (6ft)		0.012**
		(0.006)
2.SLR (5ft)		0.023**
		(0.010)
3.SLR (4ft)		0.036***
		(0.013)
4.SLR (3ft)		0.058***
		(0.014)
5.SLR (2ft)		0.062**
		(0.029)
6.SLR (1ft)		-0.007
		(0.028)

- SLR-Leverage relationship seems to increase with exposure to SLR risk. Back

	Leveraged		Long Maturity	
Moderate SLR Risk	-0.00174		-0.00202	
	(0.00652)		(0.00571)	
High SLR Risk	-0.00978		-0.00169	
	(0.0135)		(0.0104)	
Moderate SLR x Believer Buyer	0.0411***		0.0141**	
	(0.00925)		(0.00600)	
High SLR x Believer Buyer	0.0969***		0.0156	
	(0.0201)		(0.0122)	
1.SLR (6ft)		-0.001		-0.005
		(0.006)		(0.006)
2.SLR (5ft)		-0.002		-0.007
		(0.010)		(0.012)
3.SLR (4ft)		-0.001		-0.019
		(0.013)		(0.014)
4.SLR (3ft)		-0.012		-0.031
		(0.016)		(0.021)
5.SLR (2ft)		-0.006		0.032
		(0.027)		(0.042)
6.SLR (1ft)		0.011		-0.063
		(0.030)		(0.043)
1.SLR x High Buyer Belief		-0.010		0.020**
		(0.009)		(0.008)
2.SLR x High Buyer Belief		0.027***		0.024**
		(0.009)		(0.012)
3.SLR x High Buyer Belief		0.044***		0.037***
		(0.013)		(0.014)
4.SLR x High Buyer Belief		0.065***		0.056***
		(0.015)		(0.021)
5.SLR x High Buyer Belief		0.112***		-0.053
		(0.023)		(0.042)
6.SLR x High Buyer Belief		0.110***		0.104
		(0.041)		(0.065)

- Coefficients of $SLR \times Belief$ tend to increase with exposure. Back

Borrower's problem: Details

- A buyer with belief λ chooses a mortgage contract in contract space Ω_λ to maximize

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

- Continuation value:

$$V(m,\mu)=\mathbb{E}\{\underbrace{\int_0^{t_{def}} re^{-rt}(H_t-m_t)}_{\text{repaying debt}}+\underbrace{e^{-rt_{def}}[-F_{def}+\max\{p_{def}-b_{def},0\}]}_{\text{default value}}\}$$

Back

Lender's payoff

- Risk-neutral competitive lenders' expected present value of mortgage payments:

$$\Pi(m,\mu) = \mathbb{E}\{\int_0^{\min(T,t_{def})} re^{-rt}mdt + 1_{t_{def}<T}e^{-rt_{def}}\min(p_{def}, b_{def})\}.$$

- Free-entry condition:

$$\kappa = \eta(\alpha)[-(1+i)B + \Pi(m,\mu) - K(\mu)].$$

Back

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 θ.
- To motivate trade, assume seller faces a higher house maintenance cost ξ relative to buyer.
- House price P determines by

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

Back

Closed-form solutions

- Leverage probability:

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

- Maturity:

$$\bar{T} = \begin{cases} \dfrac{\overbrace{(1+\bar{\lambda})[v(\bar{\lambda}) - v(\lambda)] - \bar{\lambda}}^{\text{"disagreement value"}}}{k} & \text{if } \lambda > \lambda_b, \\ T_0 & \text{otw.} \end{cases} \tag{2}$$

- House price:

$$P = \underbrace{\frac{1+\theta\rho}{1+\rho}v(\lambda) - \theta\xi}_{\text{standard "hedonic" term}} + \underbrace{(1-\theta)\,\alpha\left[\frac{\overbrace{S(m,\mu)}^{\text{joint surplus}}}{1+\rho} - \frac{\overbrace{\kappa}^{\text{mortgage cost}}}{\eta(\alpha)}\right]}_{\text{mortgage term}}, \tag{3}$$

◂ Back