Who Bears Flood Risk?
Evidence from Mortgage Markets

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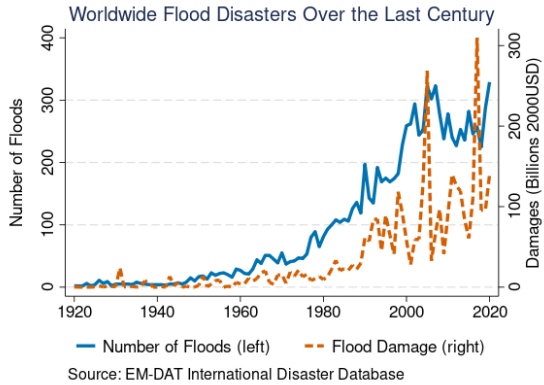
Motivations: Flood Risk and Climate Change

- Flood risk has been increasing dramatically over time
- Housing and mortgage markets have large exposures to floods
- Over $500 billion in damages over the last decade
- Over $1 trillion of U.S. coastal real estate exposed to sea-level rise (Gaul, 2019)



This Paper

Question: Who bears flood risk in residential mortgage markets?

Households	Lenders	Government
Live in flood zones	Lend in flood zones	Flood insurance

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   "It is vitally important to strengthen the U.S. financial system to meet the challenge of climate change" - Fed Governor Lael Brainard, Dec. 2020

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1. Financial stability:

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2. Moral hazard and efficiency:

   Subsidized insurance $\rightarrow$ over-development & migration into flood zones (Froot, 1999; Bagstad et al., 2007)

▸ PolicyMotivations

Overview

Novel Data: Merge digitized flood maps with loan-level mortgage data

Empirical Analysis: The effect of flood risk on mortgages

- Mortgage outcomes: Loan-to-value (LTVs), interest rates, delinquency
- Three sources of variation in flood risk:
  - Flood zone (descriptive)
  - Flood insurance coverage limits
  - Updated flood maps

Key findings

1. Banks offload flood risk to the government through flood insurance contracts
2. Banks require lower LTVs from underinsured borrowers
3. Rationing shifts mortgage composition towards richer people

Data

Mortgage Contract

(McDash, HMDA)

- Interest rate
- Loan-to-value ratio
- Maturity, etc
- Securitization status
- Performance

Borrower Characteristics

(McDash, HMDA)

- Credit score
- Income

House Characteristics

(McDash, Zillow, R.S. Means)

- Property value
- Building Size (Sq. Feet)
- Address
- Construction costs

Flood Risk

(FEMA, NOAA, GIS Libraries, ACS)

- Flood zone
- Flood map effective date
- Flood events and damages
- Flood insurance take-up

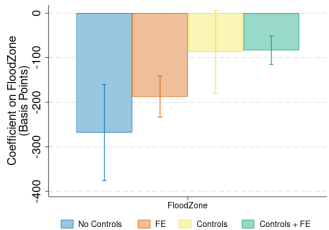
Final sample: Florida, purchase mortgages, single-family homes, 2010 - 2016

Descriptive Facts: The Effect of Flood Zone on Mortgages

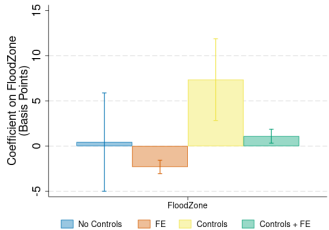
$$Y_{izt} = \beta FloodZone_{it} + \alpha_{zt} + \gamma' X_{it} + \varepsilon_{izt}$$

Controls X_{it} = income, credit score, property value

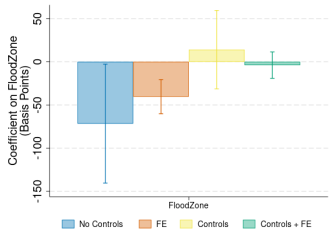
(a) Loan-to-Value Ratio



(b) Interest Rate



(c) Delinquency



Takeaways:

- Lenders bear less exposure to housing collateral in flood zones
- Lending in flood zones is not observably riskier

Identification

Why are LTVs lower in flood zones?

- Credit supply (flood risk) versus credit demand (unobserved wealth)

Two Identification Strategies

1. Flood Insurance Coverage Limit
   - Institutional Detail: Insurance only covers up to $250K in flood damages
   - Strategy: Cross-sectional difference-in-difference
   - Goal: Address unobserved wealth

2. Flood Zone Remappings
   - Institutional Detail: Updated flood maps change the boundaries of flood zones
   - Strategy: Staggered difference-in-differences
   - Goal: Address unobserved amenities & demonstrate real effects

Intuition for Cross-Sectional Difference-in-Differences

Consider LTV ratios of four borrowers: A, B, C, and D

	$100K house (Fully insured)	$300K house (Underinsured)	Reason for LTV difference
Flood zone	A	B	$\Delta wealth_{A,B} + floodrisk_B$
Outside flood zone	C	D	$\Delta wealth_{C,D}$
Diff-in-Diff			$floodrisk_B$

Key Identifying Assumptions

- Parallel Trends: $\Delta wealth_{A,B} = \Delta wealth_{C,D}$
- The effect of wealth on LTVs is the same in and out of flood zones

▸ idcap ▸ repcostdist ▸ claimbyasmt

The Effect of Flood Risk on Mortgages by Replacement Cost

$$Y_{izt} = \alpha_{zt} + \delta FloodZone_{it} + \sum_{k \neq 75{,}000} \theta_k RepCost_{k,it} + \sum_{k \neq 75{,}000} \phi_k (FloodZone_{it} \cdot RepCost_{k,it}) + \gamma' X_{it} + \varepsilon_{izt}$$

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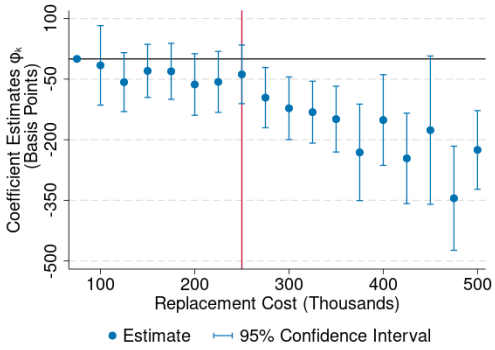

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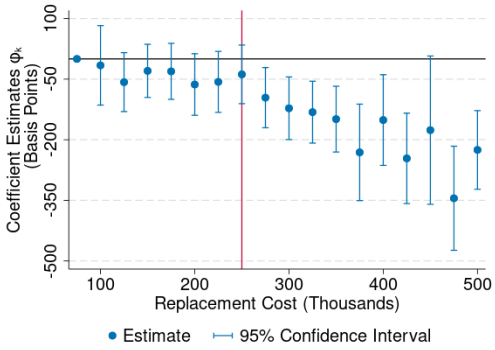

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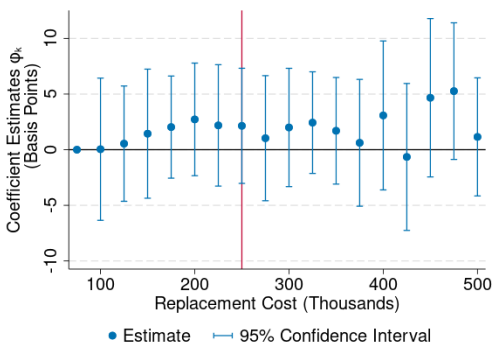

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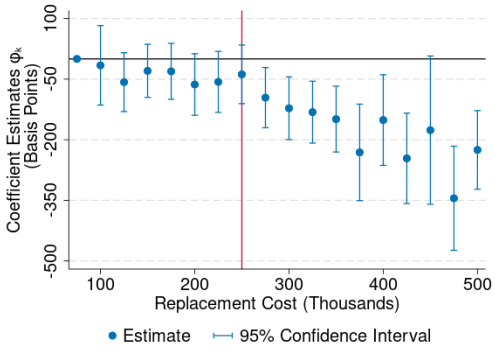
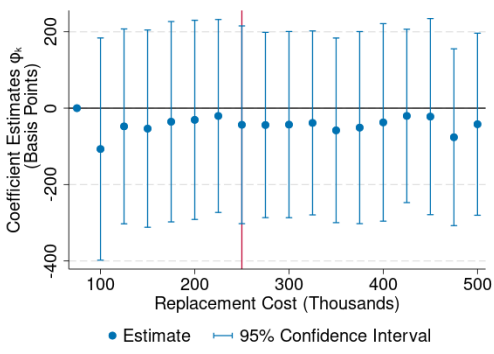


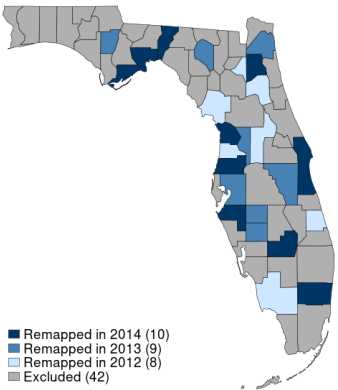
(c) Delinquency



Identification Strategy 2: Updated Flood Maps

$$Y_{i,c(z),t} = \alpha_{c(z)} + \delta_t + \sum_{h \neq -1} \beta_h \mathbb{I}\{E^{Expanded}_{c(z),t} = h\} + \varepsilon_{i,c(z),t}$$

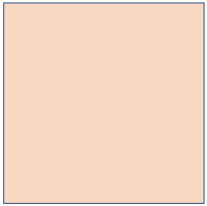
(a) Year of Map Update By County



▸ Diffindiff ▸ Intuition

- Staggered Timing: Counties receive updated maps in different years
- Control: Areas that are not not-yet-treated areas
- Intuition: Look at the same area before and after the updated map
- Treated: Mortgages in zips with expanded flood zone boundaries (164 zip codes)

Intuition for Event Study Design



Orange County

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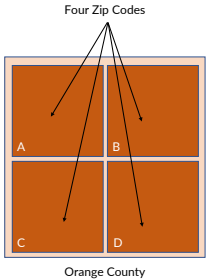

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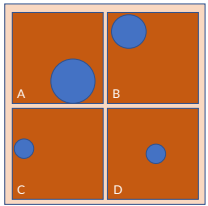
Flood Zones Under Old Map



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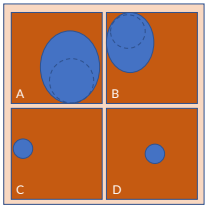

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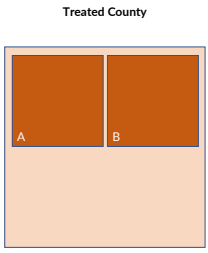

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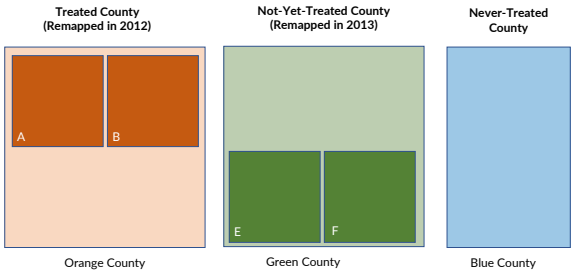
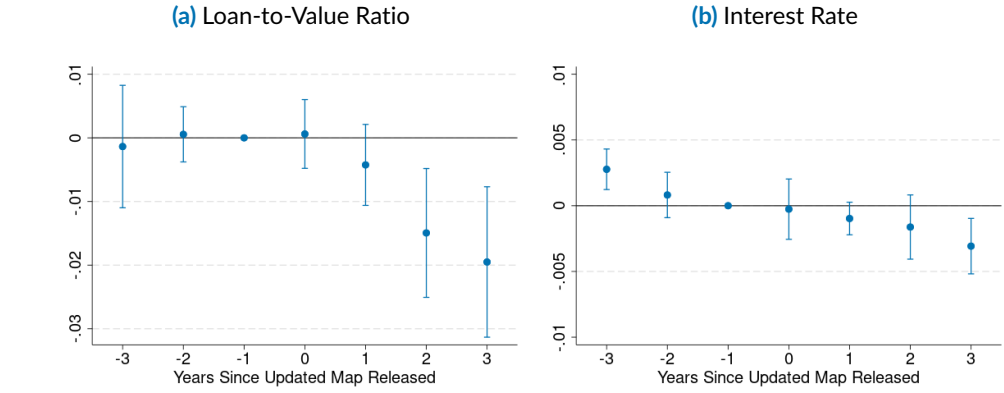


▸ Diffindiff

The mortgages in the sample will come from:

- Zips A and B in Orange
- Zips E and F in Green
- None of the mortgages in Blue (never-treated)
- Notation $c(z)$ denotes the fact that for a given county, I only include the relevant zip codes

Effect of Updated Maps on Mortgage Terms

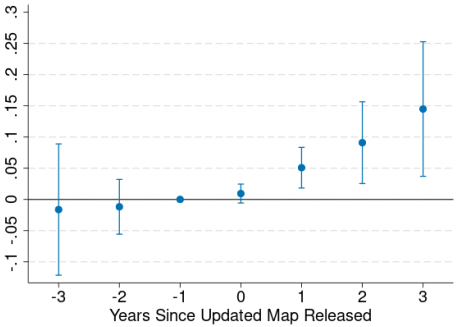


- LTV Ratios decline by 2pp after the new maps

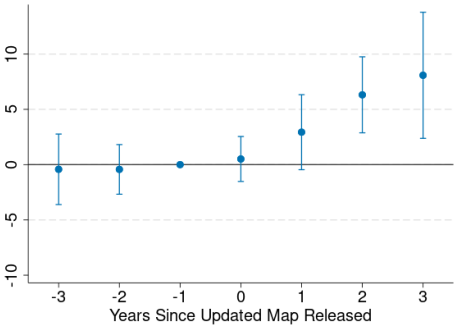
▸ Placebo ▸ House Prices ▸ eltvcontrols

Shift Towards Higher Income & Credit Quality Borrowers

(a) Log Income



(b) Credit Score



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LTV Reduction Driven By Lower Credit Quality Groups

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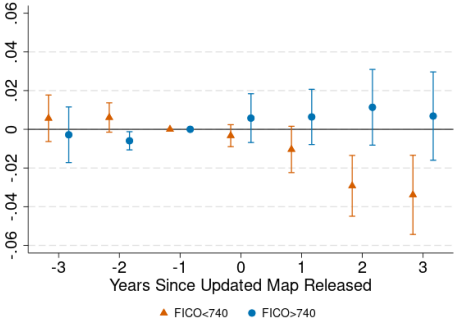

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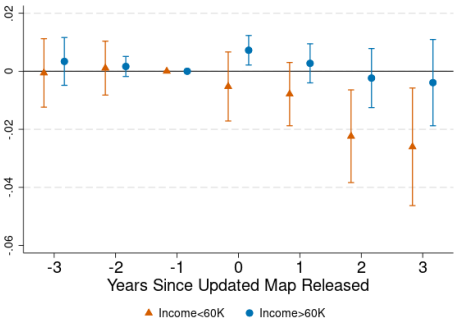

▸ Placebo ▸ House Prices ▸ eltvcontrols

Effect of Updated Maps on Other Outcomes

	(1) Delinquency	(2) DTI Ratio	(3) Maturity
Post	-0.0098***	-0.2720	-0.0548
	(0.0024)	(0.2529)	(0.3786)
Adjusted R-Squared	0.05	0.05	0.00
County FE	Y	Y	Y
Year FE	Y	Y	Y
Observations	55,819	19,505	55,819

▸ InsuranceTakeUp ▸ climatebeliefs ▸ GSEPlot ▸ eltvcontrols

Who bears the risk? Back-of-the-Envelope

- Q: Do lenders still bear flood risk after reducing LTVs by 1pp?

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Probability of uninsured losses over the mortgage $\approx$

[1% Annual Flood Probability]
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$= 50bp$

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- Assumption: Lender recovery in delinquency are similar by flood zone

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  - Flood insurance program provides about $1.3 trillion in coverage annually
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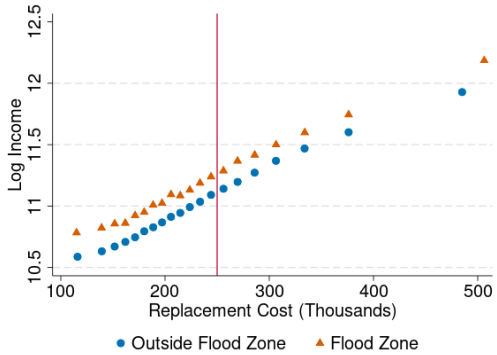
  - Flood insurance program provides about $1.3 trillion in coverage annually
    - In 2017, government guaranteed $5 trillion in Fannie/Freddie MBS
- Systemic risk
  - Combination of flood insurance + lower LTVs protects the banking system
  - Banks adapt to new information about flood risk
  - Lender rationing helps dampen the taxpayer's overall exposure to flood risk

APPENDIX

Evidence Supporting the Identifying Assumption

- Wealthier people live in flood zones (OK!)
- Wealthy people buy bigger homes (OK!)
- Parallel trends: no differential sorting of wealthy people into flood zones by home values



▸ PropertyValue ▸ Income ▸ idcapintuition

Policy Motivations

Federal Reserve (Lael Brainard, 2020): “It is vitally important to strengthen the U.S. financial system to meet the challenge of climate change... We are already seeing elevated financial losses associated with an increased frequency and intensity of extreme weather events... Mortgages in coastal areas are vulnerable to hurricanes and sea level rise... Recent research argues that lenders hit by hurricanes, particularly in areas not typically affected by natural disasters, tend subsequently to securitize more of their mortgage loans, which could have higher climate risks, higher borrower defaults, and lower collateral values.”

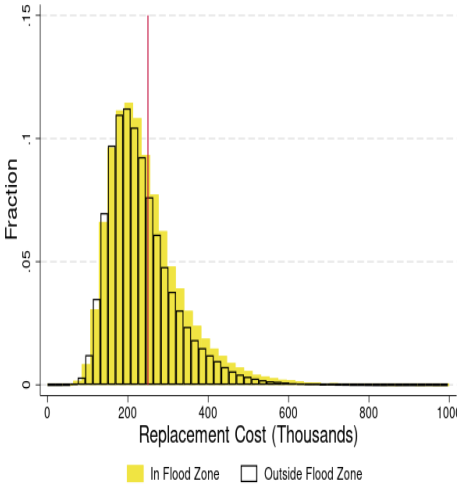
OCC (Michael Hsu, 2020): "Weaknesses in how banks identify, measure, monitor and control the potential physical and transition risks associated with a changing climate could adversely affect a bank’s safety and soundness, as well as the overall financial system"

Bank of England (Mark Carney, 2015) "Once climate change becomes a defining issue for financial stability, it may already be too late.”

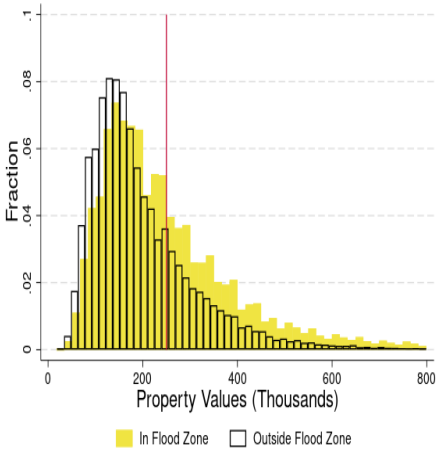
▸ thispaper

Distribution of House Values by Flood Zone

(a) Replacement Costs



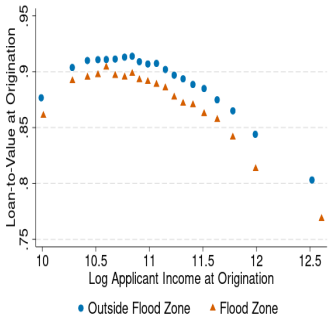
(b) Transaction Price



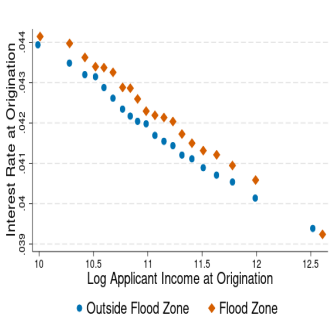
▸ EvidenceSupportingId ▸ repcostdist

The Effect of Flood Risk on Mortgages by Income

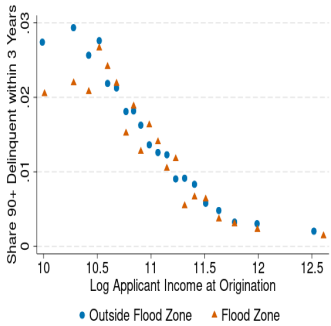
(a) LTV



(b) Interest Rate



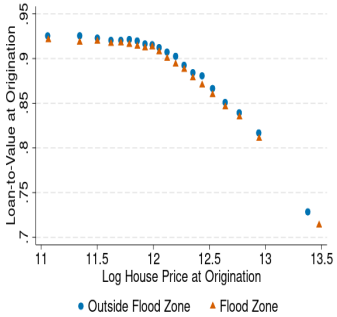
(c) Delinquency Rate



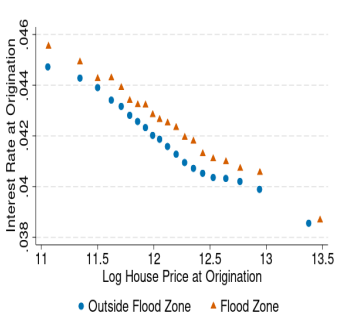
▸ DescriptiveAnimation ▸ DescriptiveFactsInterp

The Effect of Flood Zone on Mortgage Terms by Property Value

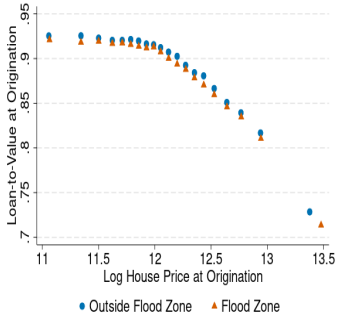
(a) LTV



(b) Interest Rate



(c) Property Value



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The Effect of Flood Zone on Mortgage Terms by Credit Score

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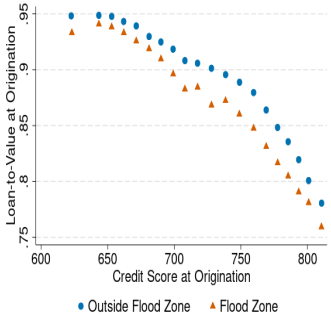
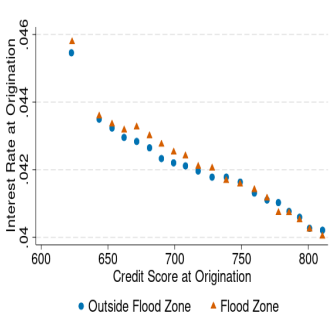
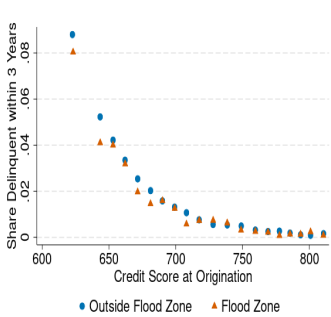


(b) Interest Rate



(c) Property Value



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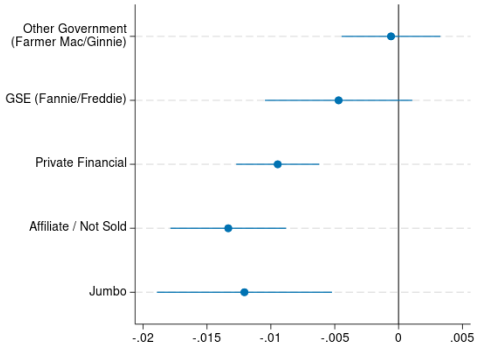
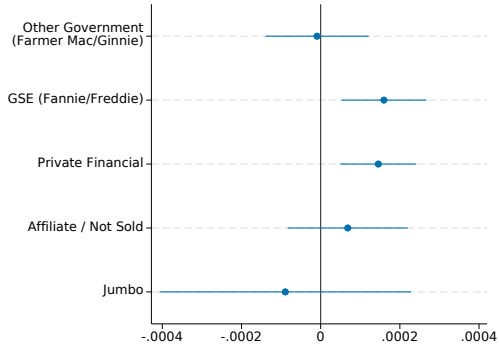
What about the GSEs?

$$Y_{ikzt} = \alpha_{zt} + \sum_k \delta_k Purchaser_{ikt} + \sum_k \beta_k (FloodZone_{it} \cdot Purchaser_{ikt}) + \gamma' X_{it} + \varepsilon_{ikzt}$$

(a) LTVs

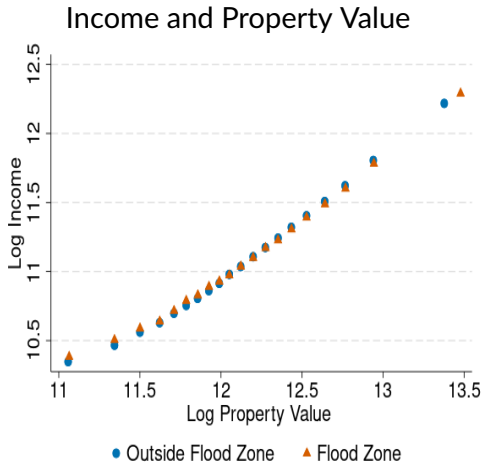


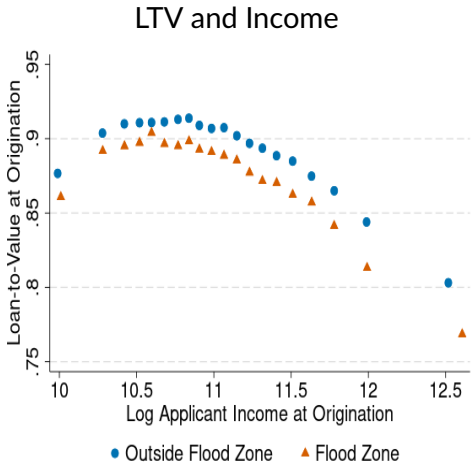
(b) Larger Bins



▸ DescriptiveFactsIntern ▸ SummStatsExtended ▸ captakeaways ▸ eventstudyother

Additional Evidence Supporting the Identifying Assumption





▸ EvidenceSupportingId

Identifying Assumptions: More Detail

Notation and Approach (Angrist and Pishke, 2009)

- f is an indicator for whether the house is in a flood zone
- r indicates whether the house has a replacement cost that exceeds the flood insurance coverage limit
- Y_{1irf} is LTV for borrower i in flood zone f with house type r if there is exposure to flood risk
- Y_{0irf} is LTV for borrower i in flood zone f with house type r if there is no exposure to flood risk

Assumptions:

- Additivity: $\mathbb{E}[Y_{0ifr}] = \gamma_f + \lambda_r$
- Constant Effects: $\mathbb{E}[Y_{1fr} - Y_{0fr}|f, r] = \delta$

The Effect of Uninsurable Flood Risk on LTVs Varies by Income

	(1) LTV	(2) LTV	(3) LTV	(4) LTV
CapBinds	-0.0136***	-0.0046***	0.0033**	0.0215***
	(0.0027)	(0.0017)	(0.0016)	(0.0023)
FloodZone	-0.0044	-0.0053*	-0.0010	0.0062*
	(0.0027)	(0.0028)	(0.0028)	(0.0037)
CapBinds	-0.0216***	-0.0034	-0.0019	-0.0146***
× FloodZone	(0.0062)	(0.0032)	(0.0026)	(0.0039)
Observations	70,587	77,180	74,674	75,987
Adjusted R^2	0.47	0.49	0.49	0.48
ZipYearFE	Y	Y	Y	Y
Controls	Y	Y	Y	Y
sample	$Income \leq 40K$	$Income \in (40K, 60K)$	$Income \in (60K, 93K)$	$Income > 93K$

Back

Compliance Rates

- FEMA estimates a nationwide compliance rate of 63%; FL is likely to be higher
- Evidence of full compliance at origination, but lapses after 3+ years (Michel-Kerjan et al., 2012)
- Lenders are now required to escrow flood insurance premiums
  - Requirement instituted in 2012; greatly improved compliance (Shabman, Kousky and Lingle, 2019)
- Banking regulators also monitor lender compliance and issue penalties
  - Penalty rates increased in 2012, and maximum cap on penalties was removed
- Limited evidence of selection on insurance take-up in flood zones (Wagner, 2021)

▸ institutional

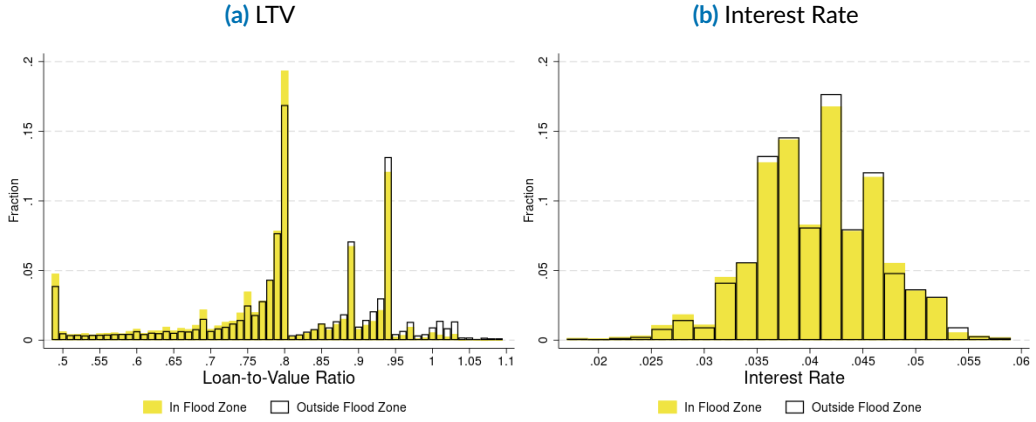
Increased Flood Insurance Takeup After Map Updates

	(1) $\Delta TakeupRates_z$	(2) $\Delta LapseRates_z$
$\Delta FloodZoneShare_z$	0.269***	-0.274***
	(0.0173)	(0.0176)
Constant	-0.0231**	-0.0155**
	(0.0093)	(0.0056)
Observations	382	382
Adjusted R^2	0.1965	0.2954

- For 10 new homes, 3 will take up a flood insurance policy
- 5 homes out of 10 will be associated with a mortgage (54% mortgage share)
- If all new policy holders have mortgages, compliance rate $\approx$ 60%
  - Note: About 80% of policy holders have mortgages (FEMA)

▸ Back

Mortgage Terms Distribution by Flood Zone



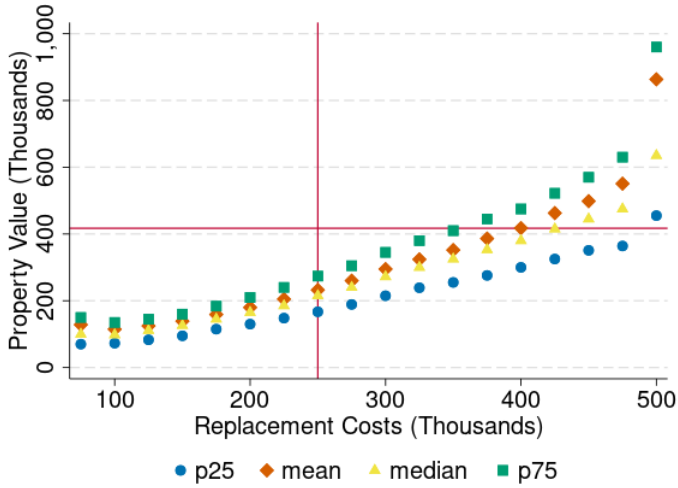
- Pull back from high LTV lending in flood zones

▸ DescriptiveAnimation ▸ DescriptiveFactsInterp

The Insurance Cap and the Conforming Loan Limit

- Between 2010-2016, the CLL for single-family homes in FL was $417,000

Figure: House Price by Replacement Cost



Evidence that Excess Flood Insurance is Limited

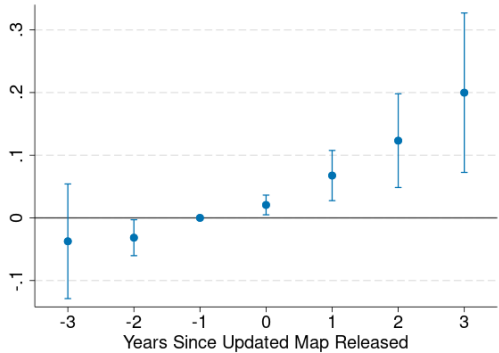
- Six excess flood underwriters (Florida Office of Insurance Regulation, 2021)
- As of 2018, only 5,983 excess flood policies (Lingle and Kousky, 2018)
- My data: at least 100,000 homes with replacement costs that exceed $250K; 22,000 in flood zones

▸ Institutional

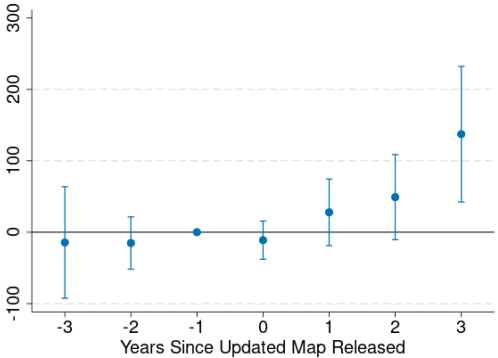
- "The following risks are ineligible for coverage in this [excess flood] program ... Buildings located in V zones unless located behind the natural dune line and the lowest floor elevation is equal to or above the base flood elevation level ... Risks with more than two losses in the past five years or any one loss in excess of $150,000" (Bankers Insurance XFLD Underwriting Manual)

Effect on House Prices

(a) Log Property Value



(b) Building Size (Square Feet)



▸ EventStudyLTV

Robustness: Alternate Proxies for Whether the Insurance Cap Binds

	OriginalLTV (1)	OriginalLTV (2)
HPriceGt250K	-0.0041	
	(0.0032)	
FloodZone	-0.0017	-0.0021
	(0.0019)	(0.0018)
HPriceGt250K	-0.0066***	
× FloodZone	(0.0018)	
StructValGt250K		-0.0086*
		(0.0033)
StructValGt250K		-0.0068***
× FloodZone		(0.0019)
Adjusted R^2	0.48	0.48
Zip-Year FE	Y	Y
Controls	Y	Y
Observations	300,530	300,530

▸ RobustnessCap

Robustness: Statistically Significant Change in Slope

Slope: LTV reduction in flood zones by share uninsured

$$Y_{it} = \alpha_{zt} + \beta_1 Ins_{it} + \beta_2 F_{it} + \beta_3 C_{it} + \beta_4 (C_{it} \cdot Ins_{it}) + \beta_5 (F_{it} \cdot C_{it}) + \beta_3 (Ins \cdot Fit) + \beta_6 (Ins_{it} \cdot F_{it} \cdot C_{it}) + \gamma' X_{it} + \varepsilon_{izt}$$

	LTV	LTV
FloodZone	-0.0001*	-0.0086**
× UninsuredShare	(0.0000)	(0.0035)
FloodZone × CapBinds	-0.0476***	-0.0408***
× UninsuredShare	(0.0077)	(0.0151)
Observations	300,530	234,768
Adjusted R^2	0.48	0.47
Zip-Year FE, Controls	Y	Y
sample	Full	Within100KOfCap

▸ RobustnessCap

Magnitudes: What is the Marginal Adjustment?

Slope: Downpayment-Repcost relationship by Flood Zone and Cap Binds

$$Y_{it} = \alpha_{zt} + \beta_1 Ins_{it} + \beta_2 F_{it} + \beta_3 C_{it} + \beta_4 (C_{it} \cdot Ins_{it}) + \beta_5 (F_{it} \cdot C_{it}) + \beta_3 (Ins \cdot Fit) + \beta_6 (Ins_{it} \cdot F_{it}) \cdot C_{it} + \gamma' X_{it} + \varepsilon_{izt}$$

Elasticity:

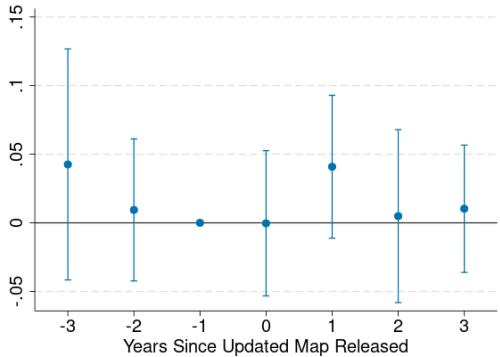
$$Y_{izt} = \alpha_{zt} + \beta_1 FloodZone_{it} + \beta_2 logInsGap_{it} + \beta_3 FloodZone_{it} \cdot \log InsGap_{it} + \gamma' X_{it} + \eta_{izt} \quad (1)$$

	DownPayments	log(LTV)
FloodZone · CapBinds · ExcessRepCost	0.0696**	
	(0.0275)	
FloodZone · log($UninsShare$)		-0.0055***
		(0.0013)
Observations	234,768	104,483
Adjusted R^2	0.52	0.43
FE, Controls	Y	Y
sample	Within100KofCap	AboveCap

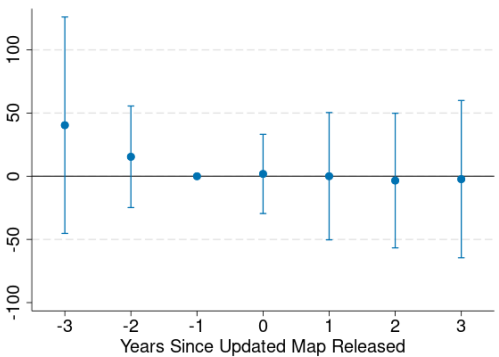
▸ slopechange

Alternate Channels

(a) Beliefs (Republican Share)



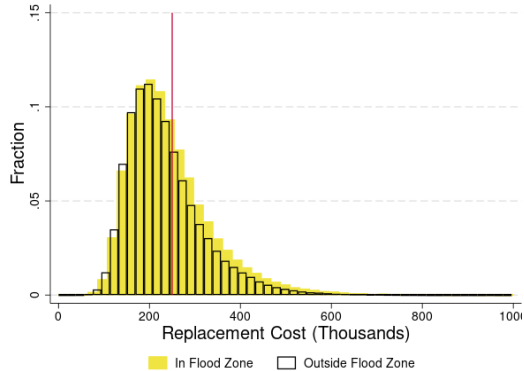
(b) Risk Aversion (Deductible Choices)



▸ eventstudyother

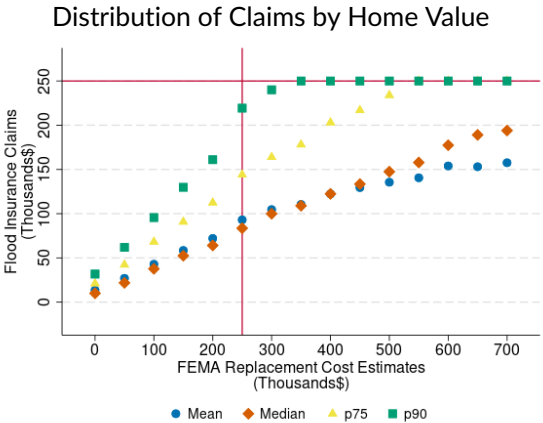
Replacement Cost: When Is the Home Underinsured?

- The home value will also include the value of the land
- But only the structure of the property is covered by insurance
- Replacement cost: the amount it would take to rebuild the home if totally damaged
- Proxy: RepCost = Building Size (sq. ft) $\times$ Construction Cost per sq. ft.



▸ PropertyValueDist ▸ idcapintuition

The Flood Insurance Cap Can Bind for Higher Value Homes



▸ EvidenceSupportingId ▸ backoftheenvelope ▸ idcapintuition

- Damages exceed flood insurance cap about 10% of the time
- Data spans 2008-2018 for the gulf states (FL, TX, LA, MS, AL)

Magnitudes and Robustness

What is the Marginal Adjustment?

- Fixing house prices, each uninsured dollar $\rightarrow$ 6 cent $\uparrow$ in downpayments
- Consider a home with price \$500K in a flood zone
- What is the effect of going from a \$300K $\rightarrow$ \$350K replacement cost?
  - Downpayment Increase: \$0.06 $\cdot$ 50K = \$3K
  - LTV change: -60bp

Magnitudes and Robustness

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  - Downpayment Increase: \$0.06 $\cdot$ 50K = \$3K
  - LTV change: -60bp

Robustness:

- Statistically significant change in slope ▸ slopechange ▸ magnitudes
- Alternate measures of whether the insurance cap binds
  - Structure value from tax assessments ▸ alternate
  - Property values ▸ alternate
- Excluding jumbo loans ▸ ConformingII

Empirical Specification

$$Y_{izt} = \alpha_{zt} + \beta_1 FloodZone_{it} + \beta_2 CapBinds_{it} + \beta_3 (FloodZone_{it} \cdot CapBinds_{it}) + \gamma' X_{it} + \varepsilon_{izt}$$

- Outcomes (Y_{it}): LTV, interest rate, delinquency
- FloodZone: Dummy for whether the borrower is in a flood zone
- CapBinds: Dummy for whether replacement costs exceeds coverage limit
- Controls (X_{it}): FICO, income, house price, DTI, maturity, mortgage type, etc.
- Fixed Effects (α_{zt}): Zip-year
- Standard errors clustered at the county level

Effect of Flood Risk on Mortgages

	(1) LTV	(2) InterestRate	(3) Delinquency
CapBinds	0.0053***	-0.0001**	-0.0018***
	(0.0012)	(0.0000)	(0.0006)
FloodZone	-0.0009	0.0001	-0.0006
	(0.0020)	(0.0001)	(0.0008)
CapBinds=1	-0.0081***	0.0000	-0.0005
× FloodZone	(0.0019)	(0.0000)	(0.0011)
Observations	300,530	300,530	300,530
Adjusted R^2	0.476	0.578	0.084
Zip-Year FE	Y	Y	Y
Controls	Y	Y	Y

▸ HeterogeneityByIncome ▸ Magnitudes

Institutional Setting: Flood Maps

- FEMA aims to update flood maps at least every decade
  - physical changes in topography caused by climate events
  - infrastructure construction
  - climate change
  - methodological advancements in modeling
  - data (new maps require new data on elevation)

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- Maps take up to 5 years to produce and are very costly (>$1bn investment)

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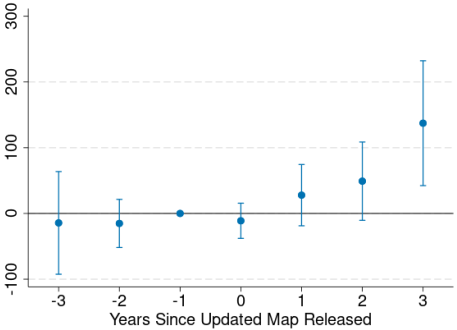
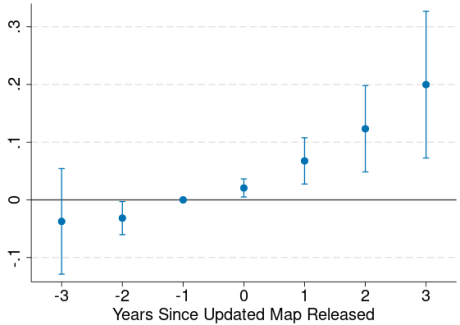
  - infrastructure construction
  - climate change
  - methodological advancements in modeling
  - data (new maps require new data on elevation)
- Maps take up to 5 years to produce and are very costly (>$1bn investment)
- What changes with the updated flood maps?
  - information about flood risk (Giglio, Kelly and Stroebel, 2021)
  - flood insurance requirements
  - lender compliance costs

Compositional Change in Transacted Properties

(a) Building Area (Square Feet)



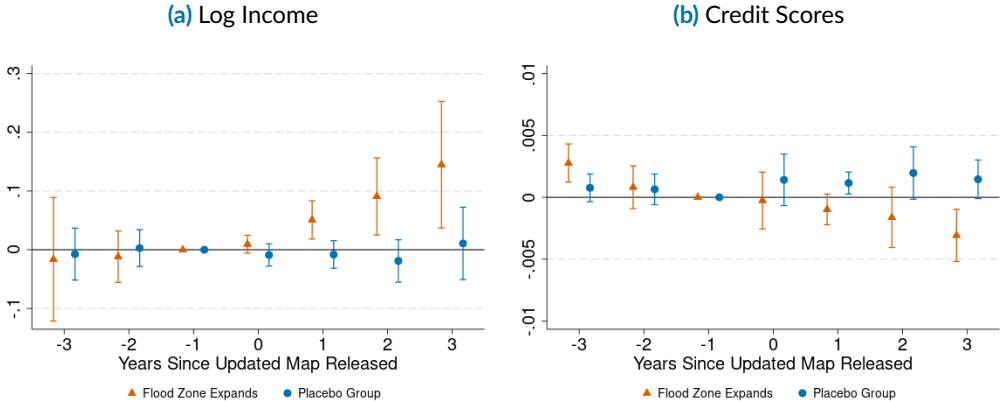
(b) Log Property Value (with controls)



- When controlling for property size, no significant change in house prices

▸ House Prices

Placebo: No Effect When Flood Zone Boundaries Do Not Change



▸ BorrowerComposition ▸ MortgageTermsComposition ▸ MortgageTerms ▸ House Prices

Research Agenda

How will financial markets support the economy's adaptation to climate change?

- Households: Does government insurance crowd out private insurers?
- Insurers: Do monopolistic reinsurers limit primary insurer diversification?
- Investors: What drives the portfolio allocation decisions of prosocial investors?
- Firms: Do corporate asset sales to private companies reduce overall emissions?

Identification Strategy 1: Flood Insurance Cap

Government Flood Insurance:

- Borrowers in flood zones are required to purchase flood insurance
  (Flood Disaster Protection Act & National Flood Insurance Reform Act)
- Government flood insurance coverage is capped at $250,000
- Limited top-up private flood insurance in Florida

Takeaway:

- Lower-value homes in flood zones will be fully insured against flood risk
- Only higher-value homes in flood zones remain exposed to flood risk

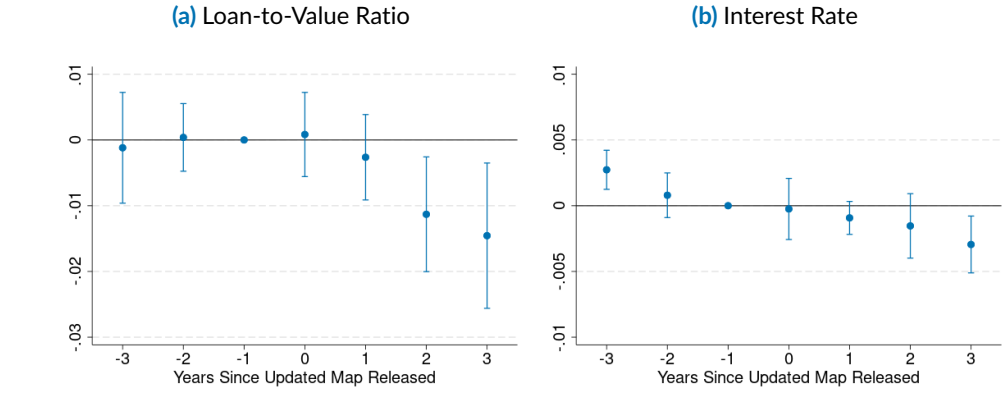
Approach: cross-sectional difference-in-differences design

▸ Compliance ▸ PrivateInsurance

Identification Strategy 2: Updated Flood Maps

- Results from insurance limits implies that lenders require lower LTVs
- This section: new variation in flood risk from updated flood maps
- Goal 1: Confirm that lower LTVs are not driven by unobserved amenities
  - Look at the same area before and after the remapping
- Goal 2: Explore the effect of lower LTVs on borrower composition
  - What is the risk-bearing capacity of people who move into flood zones?
  - The economy's exposure to floods depends on who lives in high risk areas

Change in Composition Does Not Drive the LTV Results



- When including borrower controls, LTV still declines by 1pp

eventltv | eventcomposition | eventstudyother

Empirical Specification

$$Y_{i,c(z),t} = \alpha_{c(z)} + \delta_t + \sum_{h \neq -1} \beta_h \mathbb{I}\{E^{Expanded}_{c(z),t} = h\} + \varepsilon_{i,c(z),t}$$

- Outcomes (Y): mortgage terms, borrower characteristics, etc.
- Event-Time: $E^{Expanded}_{i,c(z),t} = t - \tau_{c(z)}$
  - Origination year t relative to map update year $\tau_{c(z)}$
  - Defined for zipcodes z with expanded flood zone boundaries or never-treated
- Fixed Effects: county, year
- Standard Errors: clustered at the county level
- Identifying Assumptions: treatment timing exogeneity; parallel trends

▸ Spillovers ▸ floodiq ▸ Intuition ▸ diffindiffmap