

Private Benefits from Public Investment in Climate Adaptation and Resilience

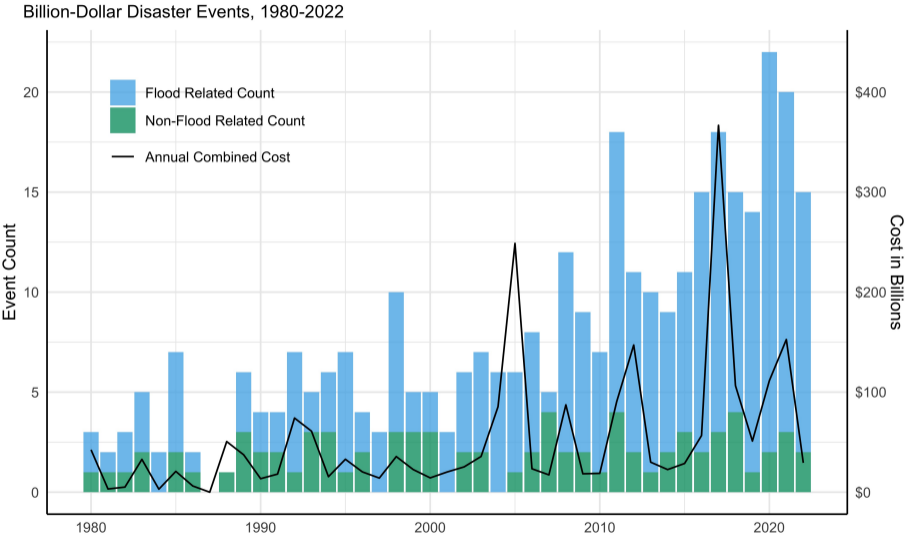
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NBER Summer Institute EEE

July 24, 2023

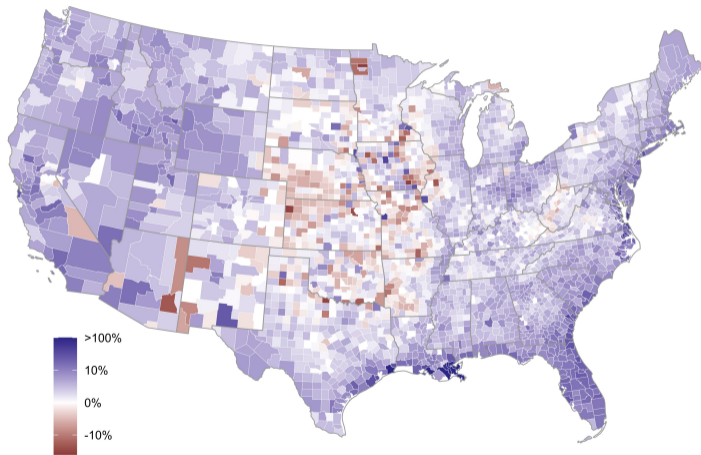
Flood events are the most costly disasters in US



Source: NOAA National Centers for Environmental Information; CPI-Adjusted

Climate change will exacerbate flood risk in the US

Estimated Change in Properties with Flooding (2021-2051)



- Share of US properties at risk of regular flooding \uparrow 8.2% over next 30 years (FSF)

Source: First Street Foundation and Authors' calculations

Research questions

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- These public investments provide private benefits, raising questions of **who gains (or loses) and by how much?**

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- These public investments provide private benefits, raising questions of **who gains (or loses) and by how much?**
- Motivating questions:
 - What is the magnitude of private impacts from public investments in adaptation?
 - What are the equity implications of these large transfers?
 - How do these investments impact aggregate welfare?

Summary of results

- We use novel data on areas protected by US Army Corps of Engineers (USACE) levees to estimate the housing market impacts of this large, public adaptation investment
 - One of the single largest public investments in flood risk reduction in US

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- Findings:
 1. Estimate subsidized flood protection benefits amount to 2.8% of a home's value
 2. Spillover effects to surrounding, unprotected properties in the form of increased flood risk can reduce home value by as much as 1.1%
 3. Flood protection benefits are progressive, but spillovers are regressive
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 3. Flood protection benefits are progressive, but spillovers are regressive
 4. Ex post, USACE-constructed levee costs appear to exceed benefits
- Presence of spillover introduces local strategic incentives that drive policy outcomes
 - Highlights difficulties for policymakers in using existing institutions for adaptation investments

Related literature

- Individual adaptation and adaptation policy
 - Auffhammer, 2022; Barreca et al., 2016; Baylis and Boomhower, 2021; Burke and Emerick, 2016; Kahn, 2016; Wagner, 2021

- Capitalization of flood risk and adaptive investments
 - Beltrán et al., 2019; Bernstein et al., 2019; Bin et al., 2008; Bin and Landry, 2013; Dundas, 2017; Dundas and Lewis, 2020; Fell and Kousky, 2015; Gopalakrishnan et al., 2018; Graff Zivin et al., 2022; Hallstrom and Smith, 2005; Kelly and Molina, 2022; Murfin and Spiegel, 2020; Ortega and Taşpınar, 2018; Walsh et al., 2019; Wang, 2021

- Public finance implications of climate change and impacts of place-based policies
 - Barrage, 2020; Busso et al., 2013; Fried, 2021; Goldsmith-Pinkham et al., 2021; Greenstone et al., 2010; Liao and Kousky, 2022; Mast, 2020

Related literature

- Individual adaptation and adaptation policy
 - Auffhammer, 2022; Barreca et al., 2016; Baylis and Boomhower, 2021; Burke and Emerick, 2016; Kahn, 2016; Wagner, 2021
 - We evaluate economic questions around large-scale, public adaptation investments
- Capitalization of flood risk and adaptive investments
 - Beltrán et al., 2019; Bernstein et al., 2019; Bin et al., 2008; Bin and Landry, 2013; Dundas, 2017; Dundas and Lewis, 2020; Fell and Kousky, 2015; Gopalakrishnan et al., 2018; Graff Zivin et al., 2022; Hallstrom and Smith, 2005; Kelly and Molina, 2022; Murfin and Spiegel, 2020; Ortega and Taşpınar, 2018; Walsh et al., 2019; Wang, 2021
 - We emphasize the importance of spillover effects and explore incidence
- Public finance implications of climate change and impacts of place-based policies
 - Barrage, 2020; Busso et al., 2013; Fried, 2021; Goldsmith-Pinkham et al., 2021; Greenstone et al., 2010; Liao and Kousky, 2022; Mast, 2020
 - We examine how strategic interactions drive adaptation investments and their outcomes

Outline

Institutional Background

Data and Empirical Design

Capitalization and Incidence Results

Mechanisms, Benefits/Costs, and Political Economy Considerations

Conclusion

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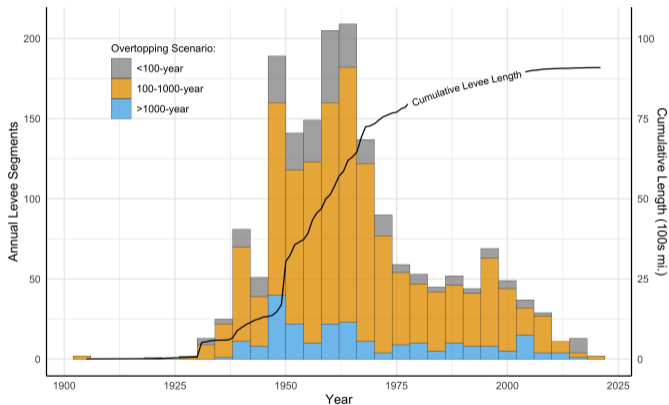
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What is a levee?



- Man-made structure that diverts water flow during flood stages
- Provides flood protection to defined area, up to a certain flood severity
- Imposes flood risk spillovers to downstream/upstream areas (Heine and Pinter, 2012; Remo et al., 2018)

Federal levee construction peaked in the 1950's and 1960's



- USACE primary federal entity responsible for flood control
- USACE project delivery:
 - Project-level Congressional authorization & funding
 - Require local cost share (45% construction, 100% O&M)
- Recent shift from flood control to policies managing consequences (e.g., NFIP)

Why do we study levees?

- Unclear if US shift away from flood control to managing flood consequences is sustainable (e.g., fiscal solvency issues)
- Adaptation to evolving future flood risks likely requires policies that address vulnerabilities *and* policies that manage consequences
 - Historically, USACE levees are the single largest federal investment in flood control
- Levees have key similarities to other forms of public adaptation investments, particularly those with geographically-differentiated benefits and costs
 - E.g., federally-constructed sea walls follow same institutional process as levees
 - USACE currently studying sea walls in New York, NY; Miami, FL; Galveston, TX

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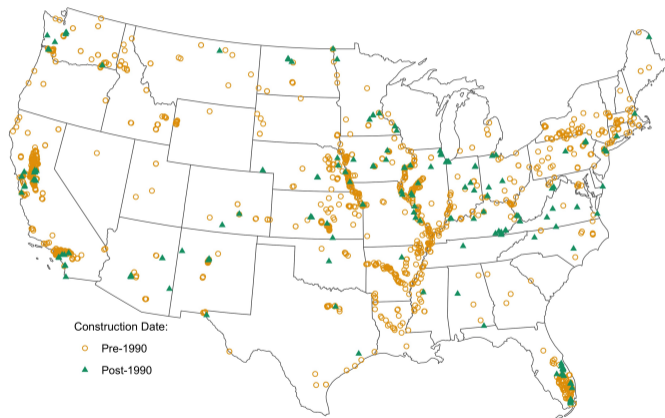
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Primary data



- Data on flood risk adaptation projects from First Street Foundation
 - Merge data from USACE National Levee Database
- Focus on USACE levees
 1. Construction date available
 2. Similar set of projects
- Combine levees with home sale data from Zillow (1990-2020) using ZTRAX coordinates
- Final estimation sample: 80 levee systems

Additional data

- **Home Mortgage Disclosure Act (HMDA)** → demographic data (1990-2020)
 - Fuzzy match HMDA and ZTRAX data on census tract, loan year, loan amount, and lender
 - Match rates: 42% (unconditional); 68% (conditional) ▶ **HMDA match**
- **USGS National Hydrography Dataset** → distance to water
 - Use ZTRAX coordinates and all relevant surface waters (e.g., estuaries, lakes/ponds, marsh, permanent and ephemeral rivers/streams) from NHD

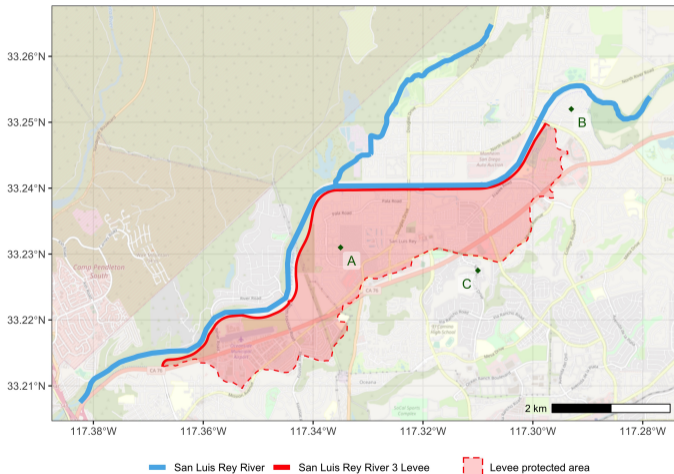
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- **FEMA Presidential Disaster Declarations** → county-level major floods (1990-2020)
- **National Flood Insurance Program (NFIP) Claims & Policies** → tract-/county-level NFIP outcomes (2009-2020)

▶ **Summary stats.**

Effects of levee construction

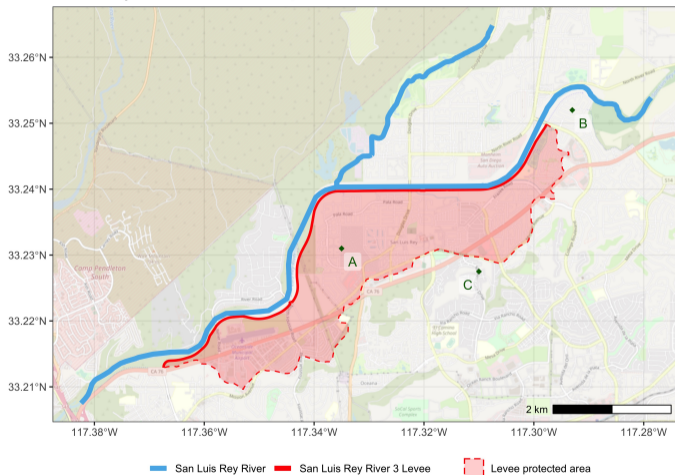
San Luis Rey River 3 Levee - Oceanside, CA



- Identification challenges:
 - Siting endogeneity
 - Heterogeneous effects
- Potential effects of levee construction:
 1. *Protection effects (A)*
 2. *Spillover effects (B)*
 3. *Macro effects (A, B, C)*

Effects of levee construction: Identification

San Luis Rey River 3 Levee - Oceanside, CA



- $\Delta_t P =$ pre-/post-levee construction diff. in sale price

- Then for each property:

$$\Delta_t P_A = \text{Macro} + \text{Protect}$$

$$\Delta_t P_B = \text{Macro} + \text{Spillover}$$

$$\Delta_t P_C = \text{Macro}$$

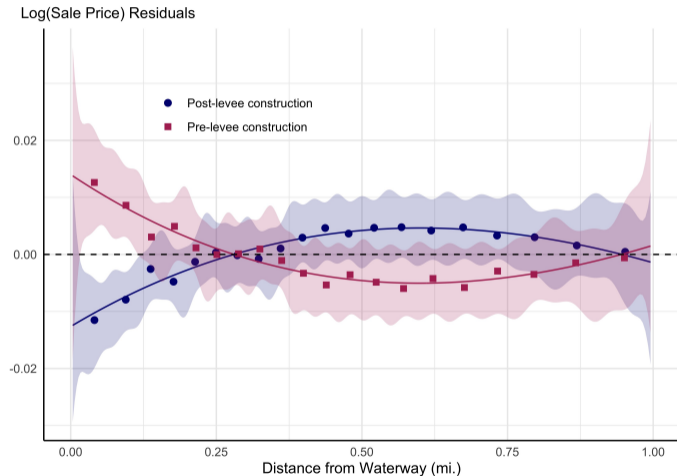
- ID effects w/ double differences:

$$(\text{Protect})_{DD} = \Delta_t P_A - \Delta_t P_C$$

$$(\text{Spillover})_{DD} = \Delta_t P_B - \Delta_t P_C$$

⇒ || trends assumption: absent levee, A, B, and C on same trend

Defining property exposure



- Treatment of parcel i transacting at time t defined using:

$$T_{it} = \mathbb{1}\{\text{Sale occurs post levee construction}\}$$

$$L_i = \mathbb{1}\{\text{Parcel is within a leveed area}\}$$

$$W_i = \mathbb{1}\{\text{Parcel is spillover exposed}\}$$

- Note that $L_i = 1 \Leftrightarrow W_i = 0$

- Data-driven definition of W_i
 - Will allow for flexible W_i
 - Also explore using floodplain delineations to define W_i

Research design: Difference-in-Differences (DD)

- Use repeat sales data from properties inside leveed areas and within 5 mi of leveed area boundaries, excluding those within 0.1 mi around leveed area boundaries (“donut” design)

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- Separately identify flood protection and flood risk spillover effects by specifying property i 's transaction price at time t , P_{it} , as:

$$\log(P_{it}) = \alpha_1 (T_{it} \times L_i) + \alpha_2 (T_{it} \times W_i) + \zeta_i + \mu_{l(i)t} + \delta_t + \varepsilon_{it}$$

↑ spillover effects

↓ protection effect

- ζ_i , $\mu_{l(i)t}$, δ_t are parcel, year-by-levee, and month-of-sample FE

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- ζ_i , $\mu_{l(i)t}$, δ_t are parcel, year-by-levee, and month-of-sample FE
- $\mu_{l(i)t}$ fixed effect shuts down inadmissible comparisons (de Chaisemartin and D'Haultfœuille, 2020; Goodman-Bacon, 2021) ▶ Staggered treatment timing

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Main capitalization estimates

	$k \leq 0.1$ mi.		$k \leq 0.2$ mi.	$k \leq 0.3$ mi.
	(1)	(2)		
Post \times Intersects (α_1)	0.098*** (0.015)	0.029*** (0.009)		
Post \times k mi. of Water (α_2)	-0.062*** (0.012)	-0.013* (0.007)		
Parcel FE	Yes	Yes		
Sale Year-Sale Month FE	Yes	Yes		
Sale Year-Levee Segment FE		Yes		
Observations	1,244,323	1,244,323		
R ²	0.924	0.948		

Clustered (Tract FE) standard-errors in parentheses

*Signif. Codes: ***: 0.01, **: 0.05, *: 0.1*

Main capitalization estimates

	$k \leq 0.1$ mi.		$k \leq 0.2$ mi.		$k \leq 0.3$ mi.
	(1)	(2)	(3)	(4)	
Post \times Intersects (α_1)	0.098*** (0.015)	0.029*** (0.009)	0.095*** (0.015)	0.028*** (0.009)	
Post \times k mi. of Water (α_2)	-0.062*** (0.012)	-0.013* (0.007)	-0.062*** (0.009)	-0.011** (0.005)	
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Main capitalization estimates

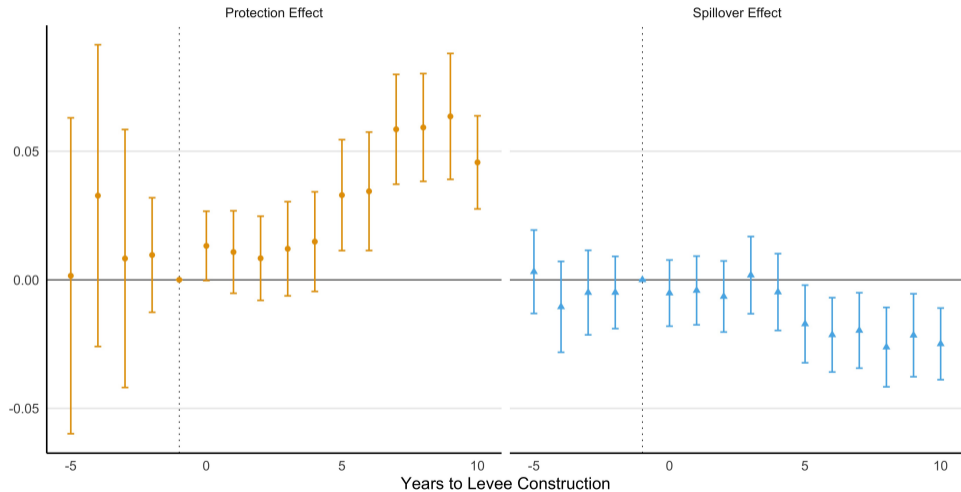
- Differences between specifications w/ and w/o level-year FE driven by negative weights
 - Large literature on issues w/ TWFE and staggered adoption (e.g., de Chaisemartin and D'Haultfœuille, 2020; Goodman-Bacon, 2021) ▶ Staggered treatment timing
- Estimate weight for each transaction under TWFE specification and find correlations which plausibly explain bias away from zero (e.g., income and weights pos. correlated) ▶ TWFE weights

Main capitalization estimates

- Differences between specifications w/ and w/o levee-year FE driven by negative weights
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 - Estimate weight for each transaction under TWFE specification and find correlations which plausibly explain bias away from zero (e.g., income and weights pos. correlated) ▶ TWFE weights
- Robustness checks:
 - Spillover exposure definition: ▶ Flexible fxn. of waterway distance ▶ Floodplain boundary
 - Richer set of capitalized impacts: ▶ Additional effects
 - Nearest-neighbor matching estimator to account for potential sorting ▶ Matching results
 - Alternative sample restrictions ▶ Alt. sample results
 - Alternative fixed-effect specifications ▶ Alt. fe results
 - Income-weighted results ▶ WLS results

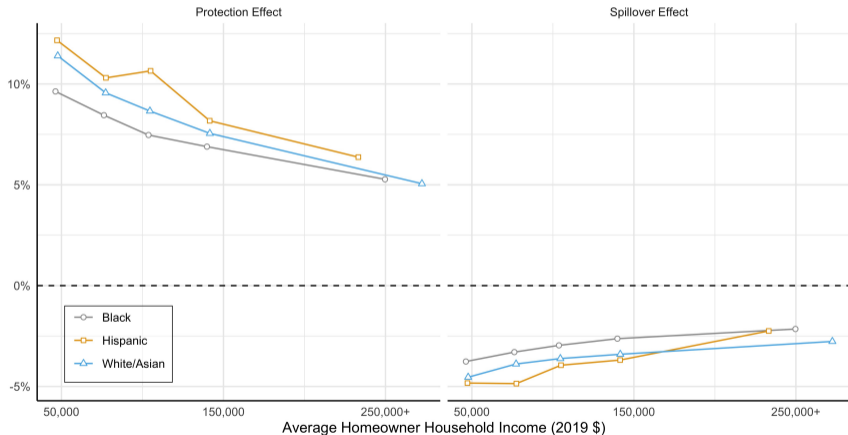
Dynamic effects of levee construction

Log(Sale Price)



Incidence of levee construction: Treated households

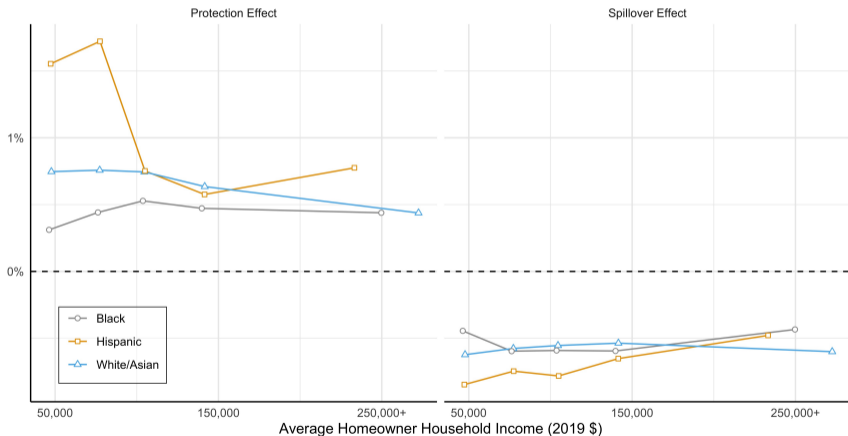
Average Household Effect: Treated Households (% of Income)



- Avg. transfers by race/ethnicity and income for treated HH/all HH
- Also find evidence of sorting ex-post by race/ethnicity
 - ▶ Differential sorting

Incidence of levee construction: All households

Average Household Effect: All Households (% of Income)



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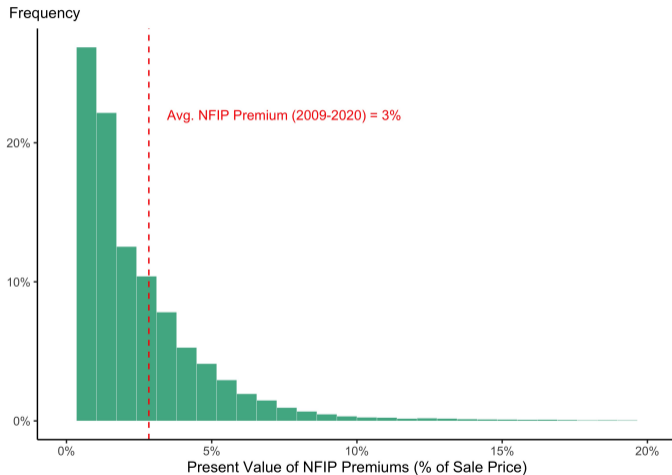
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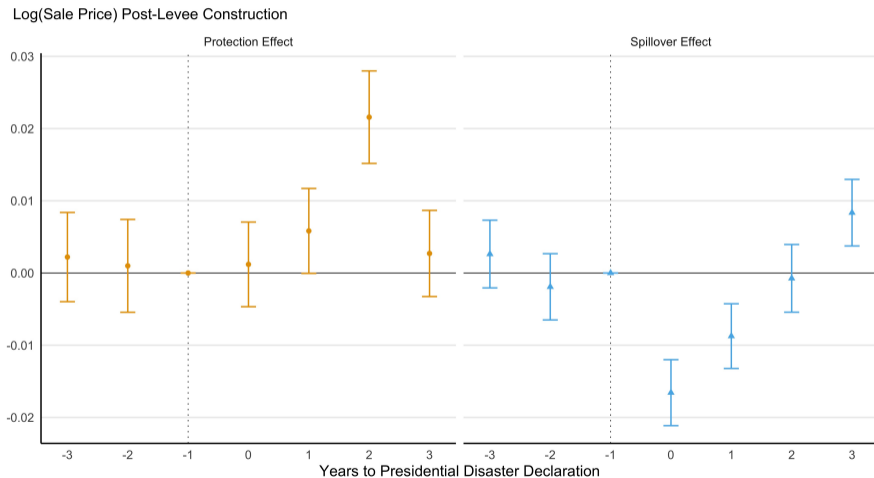
Mechanism: NFIP premium discounts



- Assume levee-protected HH take-up maximum NFIP coverage in perpetuity
 - Average PDV of NFIP cost: 3% of home value
- While NFIP discount plays a role, other factors likely:
 - SFHA take-up 48% nationally
 - 25% of segments in sample are not FEMA-accredited

Mechanism: Learning from flood exposure

- Households learn from experience (Bakkensen and Barrage, 2021; Gallagher, 2014)

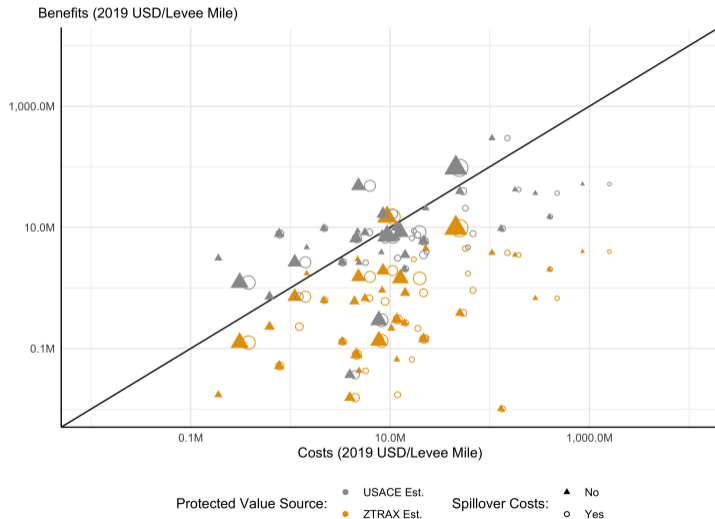


Aggregating benefits and costs of levees

- Capture three types of benefits/costs
 1. Capitalized protection benefits and spillover costs
 2. Local public finance externalities (property tax revenue impacts)
 3. Upfront construction costs
- Total capitalized protection benefits and spillover costs calculated using: (1) assessed values from Zillow or (2) USACE's National Structure Inventory (+ preferred estimates)
- Calculate fiscal externality of, e.g., protection benefits, as:

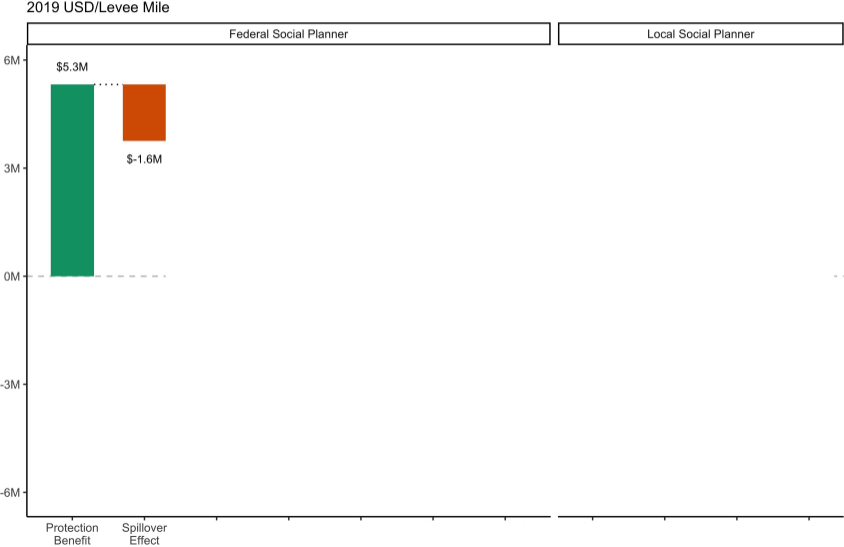
$$FE_I^{protection} = \frac{\text{Total Protection Benefits}_I \times \text{Effective Tax Rate}_I}{\text{Long-term Interest Rate}}$$

Estimated project-level benefits and costs

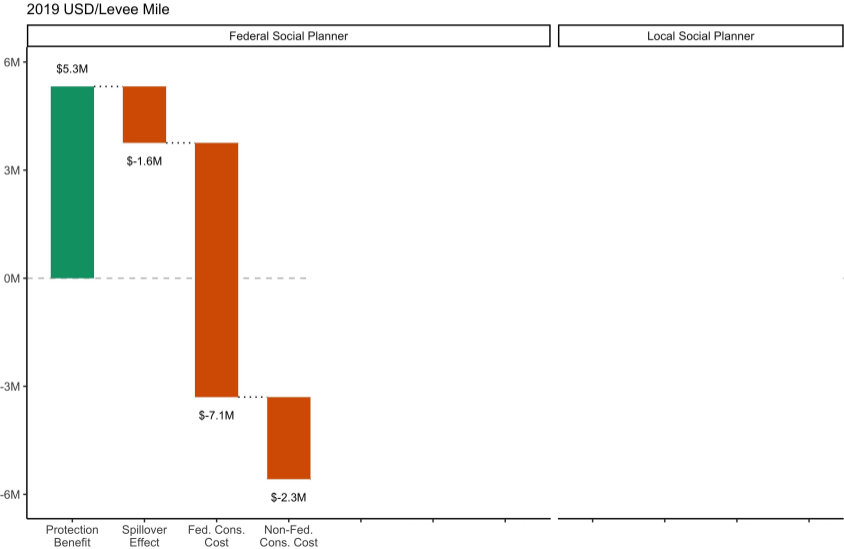


- Collect construction cost data for 37 projects
 - Covers 53 of 80 levee systems in sample
- Normalize benefits and costs by levee size
 - Points proportional to levee size

External costs and local political economy

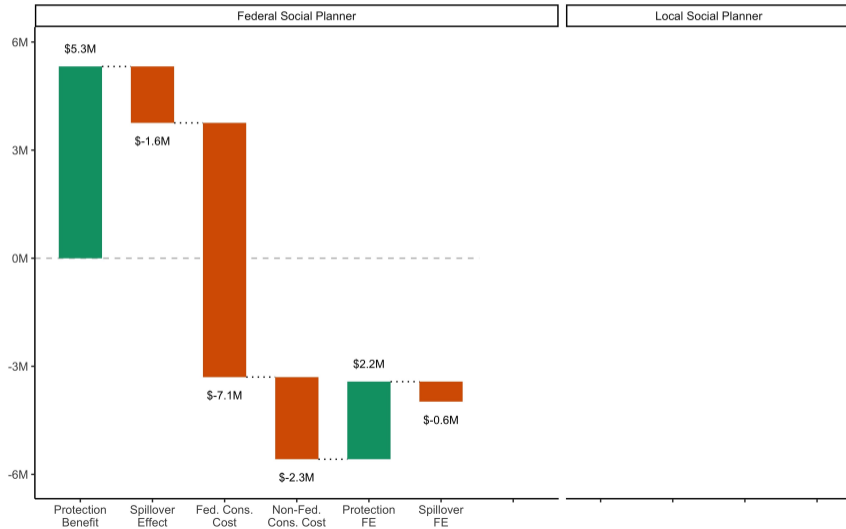


External costs and local political economy



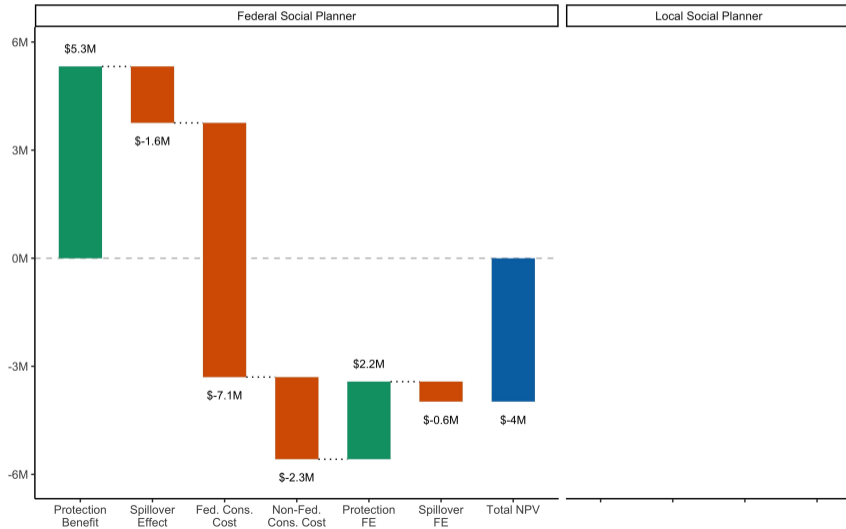
External costs and local political economy

2019 USD/Levee Mile



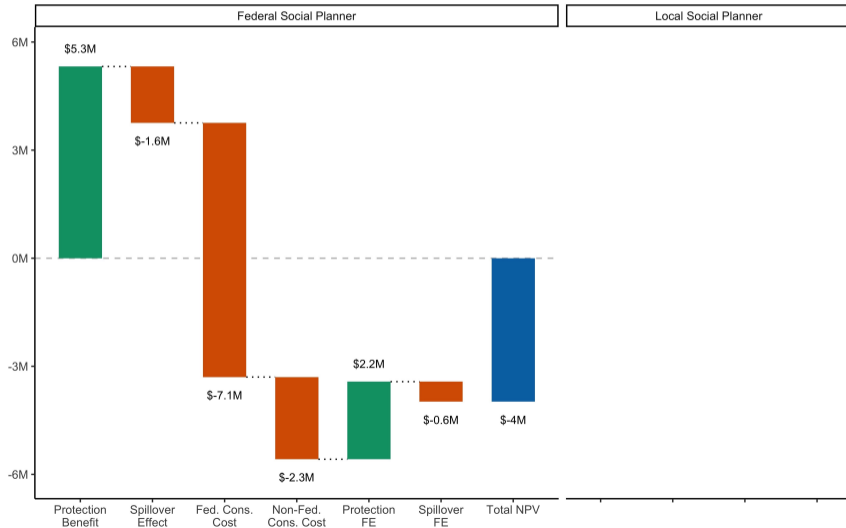
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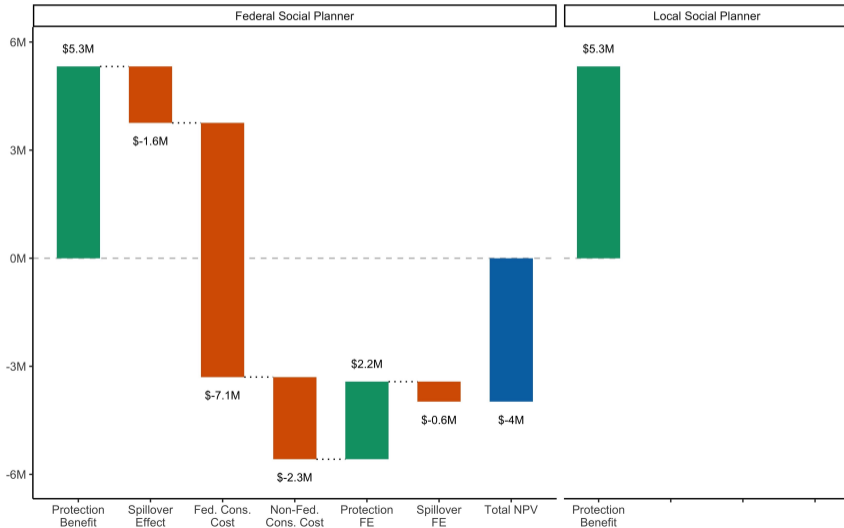
2019 USD/Levee Mile



- 30% of projects impose spillovers on other counties

External costs and local political economy

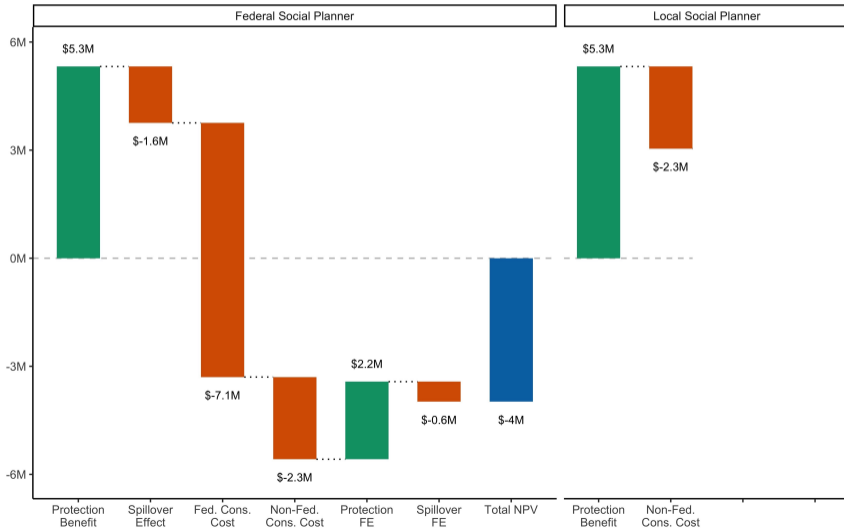
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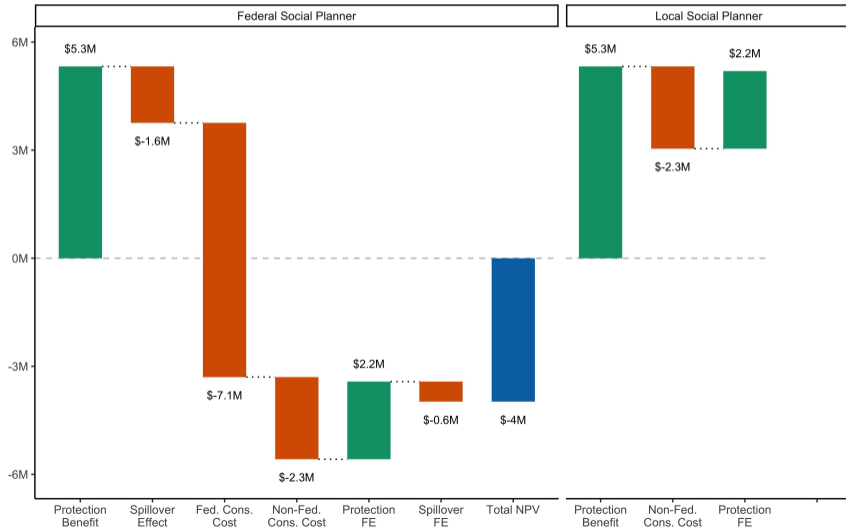
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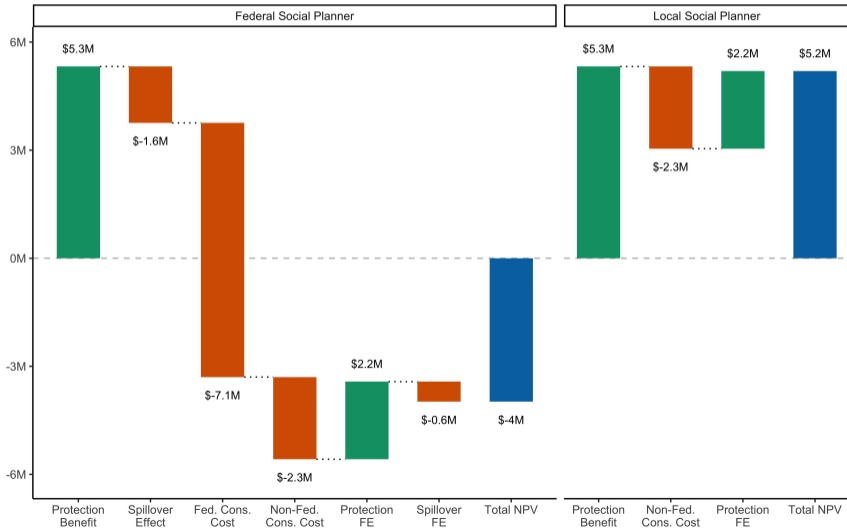
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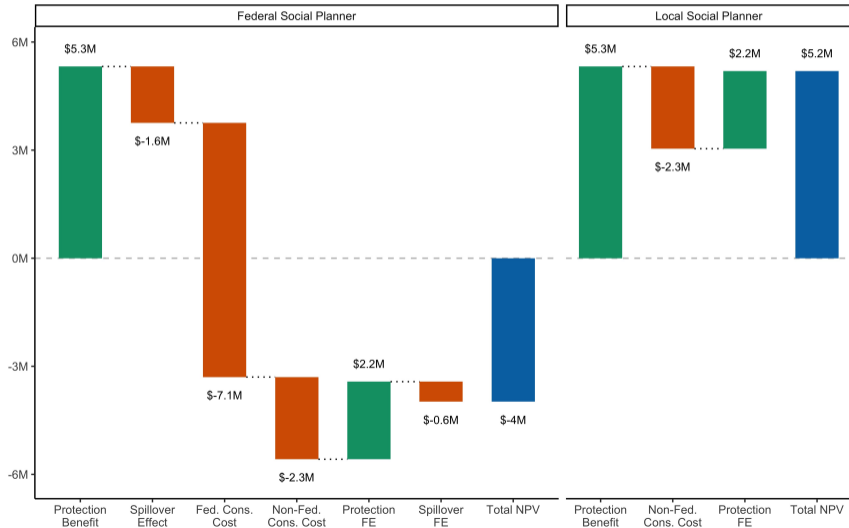
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External costs and local political economy

2019 USD/Levee Mile



- 30% of projects impose spillovers on other counties
 - Correlation: levee construction and representation
- ▶ [Committee membership](#)

BCA results and aggregate welfare

- Important to note that BCA results are informative, but should not be viewed as complete measures of welfare impacts
 - Capitalized effects \neq true costs and benefits of changes in flood risk [▶ Incomplete capitalization](#)
- Missing important benefit/cost categories (e.g., O&M costs, extensive/intensive effects, crowding out)
 - Evidence of crowding out of private adaptation [▶ NFIP impacts](#)
 - Evidence of extensive margin effects [▶ New construction results](#)
- With these caveats, working on presenting BCA results in line with Biden Admin's proposed revisions to Circular A-94
 - Aggregate benefits and costs translated into welfare equivalents, introduce equity-weights

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Summary

- We examine the case of USACE-constructed levees to better understand key economic questions around public adaptation investments
- Findings:
 1. Levee flood protection subsidies amount to 2.8% of a home's value
 2. Substantial flood risk spillovers: reduce home value by 1.1%
 3. Redistribution to lower income households partially offset by the regressivity of spillovers
 4. Ex post, USACE-constructed levee costs appear to exceed benefits

Takeaways

- USACE levees highlight the difficulties that policymakers face in using existing institutions for climate adaptation
- Presence of spillover costs and accounting of aggregate benefits and costs illuminate local strategic incentives that determine policy outcomes
 - Policymakers should carefully consider strategic incentives in the design of adaptation policy
- More broadly, economists' insights can be valuable in studying public investments in climate adaptation

Thank you!



Figure: Construction of old Galveston, TX sea wall

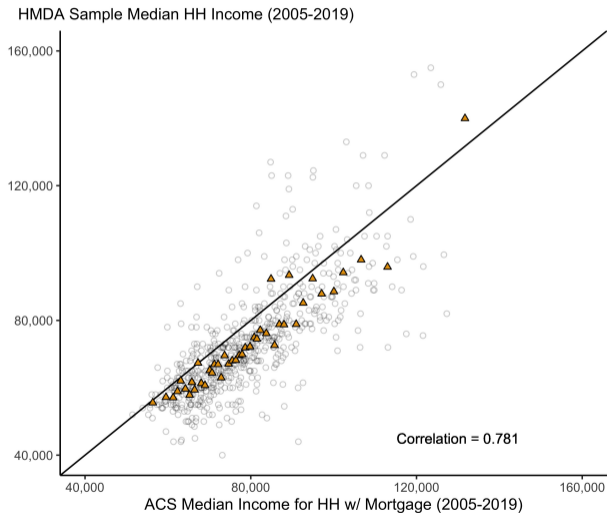


Figure: Rendering of new Galveston, TX sea wall

Please reach out with comments/questions
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Backup Slides

Transaction-level demographic data



- Match ZTRAX transaction-level data with demographic data from Home Mortgage Disclosure Act
- Match rates: 42% (unconditional); 68% (conditional)
- Match rates from literature: 54% (Bayer et al., 2016), 47% (Bakkensen and Ma, 2020)

[▶ Go back \(data desc\)](#)

[▶ Go back \(incidence\)](#)

Summary statistics

	Unmatched Sample		HMDA Sample		Diff. in Means	Std. Error
	Mean	Std. Dev.	Mean	Std. Dev.		
Price (1000s 2019\$)	390.465	286.726	406.597	262.969	16.133	0.410
Bathrooms	2.077	0.770	2.104	0.722	0.027	0.001
Bedrooms	3.235	0.837	3.275	0.807	0.040	0.001
Interior Area (ft. ²)	1.781	0.739	1.793	0.714	0.012	0.001
Age (years)	40.022	28.494	34.803	25.508	-5.219	0.040
Levee Protected	0.121	0.326	0.132	0.339	0.012	0.000
Distance from Leveed Area (mi.)	-2.292	1.815	-2.213	1.821	0.079	0.003
Distance from Levee (mi.)	3.659	2.560	3.622	2.524	-0.037	0.004
Distance from Water (mi.)	0.631	0.480	0.643	0.484	0.012	0.001
Loan Amount (1000s 2019 \$)	—	—	247.260	160.701	—	—
Income (1000s 2019 \$)	—	—	128.298	732.087	—	—
Black	—	—	0.046	0.210	—	—
White	—	—	0.637	0.481	—	—
Hispanic	—	—	0.087	0.283	—	—
Asian	—	—	0.144	0.351	—	—
N	867,490		944,366			

Identification details

- Define $\Delta_t P =$ pre-/post-levee construction change in a property's price
- Given the definition of the 3 example parcels and our primary specification, note that

$$\Delta_t P_A = \text{Macro} + \text{Protect} = \alpha_1 + \Delta_t \mu_{I(i)t} + \Delta_t \delta_t$$

$$\Delta_t P_B = \text{Macro} + \text{Spillover} = \alpha_2 + \Delta_t \mu_{I(i)t} + \Delta_t \delta_t$$

$$\Delta_t P_C = \text{Macro} = \Delta_t \mu_{I(i)t} + \Delta_t \delta_t$$

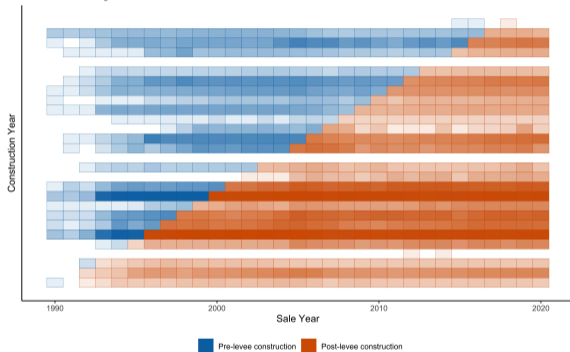
- We can therefore identify the protection and spillover effects with the following double differences (DD):

$$(\text{Protect})_{DD} = \Delta_t P_A - \Delta_t P_C = \alpha_1$$

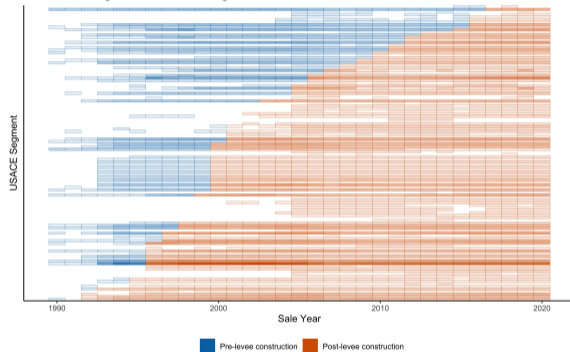
$$(\text{Spillover})_{DD} = \Delta_t P_B - \Delta_t P_C = \alpha_2$$

Staggered treatment

Construction Timing across Cohorts



Construction Timing across USACE Levee Segments



[▶ Go back](#)

TWFE weights

- Large literature on issues w/ TWFE and staggered adoption (e.g., de Chaisemartin and D'Haultfœuille, 2020; Goodman-Bacon, 2021) [▶ Staggered treatment timing](#)
- By the Frisch-Waugh-Lovell theorem, each observation's weight for each treatment in the TWFE specification given by:

$$\omega_{it}^L = \frac{\hat{\epsilon}_{it}^L}{\sum_{it} \hat{\epsilon}_{it}^L} \qquad \omega_{it}^W = \frac{\hat{\epsilon}_{it}^W}{\sum_{it} \hat{\epsilon}_{it}^W}$$

where

$$\hat{\epsilon}_{it}^L = (T_{it} \times L_i) - \hat{\beta}_1(T_{it} \times W_i) - \hat{\xi}_i - \hat{\delta}_t \qquad \hat{\epsilon}_{it}^W = (T_{it} \times W_i) - \hat{\beta}_1(T_{it} \times L_i) - \hat{\xi}_i - \hat{\delta}_t$$

- Relationship between TWFE weights and observables may be informative
 - Positive correlation between TWFE weights and borrower income
 - Negative correlation between TWFE weights and levee overtopping scenario

Spillover exposure definition: Flexible function of waterway proximity

	(1)	(2)
Post × Intersects	0.113*** (0.016)	0.030*** (0.009)
Post × Distance to Water Bins		
[0.0, 0.1 mi]	-0.072*** (0.012)	-0.017** (0.007)
(0.1, 0.2 mi]	-0.062*** (0.009)	-0.010* (0.005)
(0.2, 0.3 mi]	-0.060*** (0.008)	-0.003 (0.005)
(0.3, 0.4 mi]	-0.054*** (0.008)	-0.003 (0.005)
Parcel FE	Yes	Yes
Sale Year-Sale Month FE	Yes	Yes
Sale Year-Levee Segment FE		Yes
Observations	1,244,323	1,244,323
R ²	0.924	0.948

Clustered (Tract FE) standard-errors in parentheses
*Signif. Codes: ***: 0.01, **: 0.05, *: 0.1*

Spillover exposure definition: Floodplain boundaries

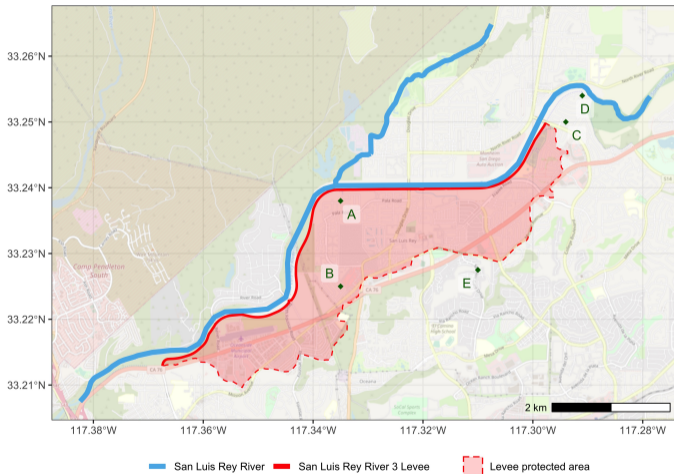
Spillover Exposure Defined by:	Proximity to Water			Floodplain
	(1)	(2)	(3)	(4)
Post × Intersects	0.029*** (0.009)	0.028*** (0.009)	0.027*** (0.009)	0.028*** (0.009)
Post × k mi. of Water	-0.013* (0.007)	-0.011** (0.005)	-0.008* (0.005)	
Post × Floodplain				-0.013* (0.009)
$k \leq$	0.1 mi.	0.2 mi.	0.3 mi.	—
Parcel FE	Yes	Yes	Yes	Yes
Sale Year-Levee Segment FE	Yes	Yes	Yes	Yes
Sale Year-Sale Month FE	Yes	Yes	Yes	Yes
Observations	1,244,323	1,244,323	1,244,323	1,244,308
R ²	0.948	0.948	0.948	0.948

Clustered (Tract FE) standard-errors in parentheses

*Signif. Codes: ***: 0.01, **: 0.05, *: 0.1*

Broader set of effects of levee construction

San Luis Rey River 3 Levee - Oceanside, CA



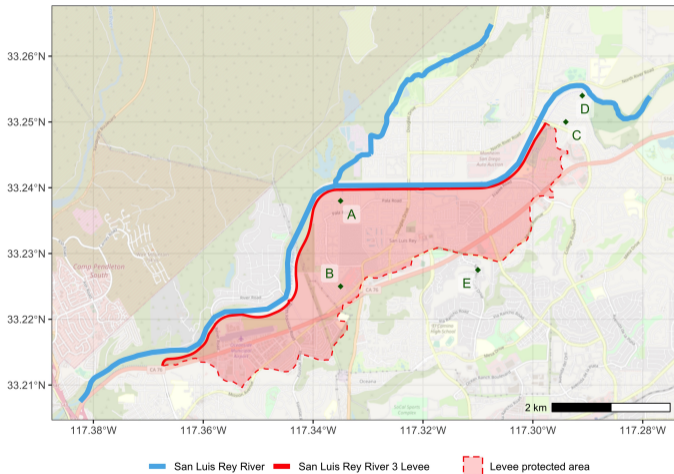
Potential effects of levee construction:

1. *Protection effects* (A, B)
2. *Adjacency effects* (A, C)
3. *Salience effects* (A)
4. *Spillover effects* (C, D)
5. *Macro effects* (A, B, C, D, E)

[▶ Go back](#)

Broader set of effects of levee construction

San Luis Rey River 3 Levee - Oceanside, CA



- Define $\Delta_t P =$ pre-/post-levee construction change in a property's price

- Then for each property:

$$\Delta_t P_A = \text{Macro} + \text{Protect} + \text{Adjacency} + \text{Salience}$$

$$\Delta_t P_B = \text{Macro} + \text{Protect}$$

$$\Delta_t P_C = \text{Macro} + \text{Adjacency} + \text{Spillover}$$

$$\Delta_t P_D = \text{Macro} + \text{Spillover}$$

$$\Delta_t P_E = \text{Macro}$$

⇒ Can use changes in prices across property types to identify effects

▶ Go back

Expanded capitalization estimates

	$k \leq 0.1$ mi.		$k \leq 0.2$ mi.		$k \leq 0.3$ mi.	
	(1)	(2)	(3)	(4)	(5)	(6)
Post \times Intersects (α_1)	0.098*** (0.015)	0.026*** (0.008)	0.097*** (0.015)	0.027*** (0.009)	0.095*** (0.015)	0.027*** (0.009)
Post \times k mi. of Levee (α_2)	-0.0005 (0.043)	-0.019 (0.029)	0.054* (0.029)	0.014 (0.015)	0.070*** (0.024)	0.018 (0.011)
Post \times k mi. of Water (α_3)	-0.062*** (0.012)	-0.014** (0.007)	-0.063*** (0.009)	-0.012*** (0.005)	-0.066*** (0.008)	-0.009* (0.005)
Post \times Intersects \times k mi. of Levee (α_4)	-0.068 (0.050)	-0.021 (0.035)	-0.101*** (0.037)	-0.043** (0.019)	-0.110*** (0.032)	-0.037** (0.016)
Parcel FE	Yes	Yes	Yes	Yes	Yes	Yes
Sale Year-Sale Month FE	Yes	Yes	Yes	Yes	Yes	Yes
Sale Year-Levee Segment FE		Yes		Yes		Yes
Observations	1,279,984	1,279,984	1,279,984	1,279,984	1,279,984	1,279,984
R ²	0.924	0.948	0.924	0.948	0.924	0.948

Clustered (Tract FE) standard-errors in parentheses

*Signif. Codes: ***: 0.01, **: 0.05, *: 0.1*

Robustness: Nearest-neighbor DD estimator

	$k \leq 0.1$ mi.	$k \leq 0.2$ mi.	$k \leq 0.3$ mi.
Post x Intersects	0.075*** (0.005)	0.064*** (0.005)	0.059*** (0.005)
Observations	422,265	422,265	422,265
R ²	0.713	0.720	0.727
Post x k mi. of Water	0.016** (0.007)	-0.0006 (0.004)	-0.014*** (0.003)
Observations	183,036	488,325	840,123
R ²	0.574	0.574	0.575

Cluster-robust standard-errors in parentheses

*Signif. Codes: ***: 0.01, **: 0.05, *: 0.1*

- Kuminoff and Pope, 2014 and Banzhaf, 2021 demonstrate bias from panel variation in settings with shifting price gradients (i.e., sorting)
- Follow Muehlenbachs et al., 2015 and match treated parcels to controls within years

Robustness: Sample restrictions

	Preferred Spec.	Alternative Sample Restrictions			
	(1)	(2)	(3)	(4)	(5)
Post x Intersects (α_1)	0.028*** (0.009)	0.023*** (0.008)	0.033*** (0.011)	0.022** (0.010)	0.024** (0.010)
Post x k mi. of Water (α_2)	-0.011** (0.005)	-0.012** (0.005)	-0.012** (0.005)	-0.003 (0.007)	0.0009 (0.010)
Donut BW (mi)	0.1	0.0	0.2	0.1	0.1
Control/Spillover BW (mi)	5.0	5.0	5.0	2.0	1.0
Parcel FE	Yes	Yes	Yes	Yes	Yes
Sale Year-Levee Segment FE	Yes	Yes	Yes	Yes	Yes
Sale Year-Sale Month	Yes	Yes	Yes	Yes	Yes
Observations	1,244,323	1,279,984	1,208,892	521,695	310,298
R ²	0.948	0.948	0.948	0.950	0.950

Clustered (Tract FE) standard-errors in parentheses

*Signif. Codes: ***: 0.01, **: 0.05, *: 0.1*

Robustness: Fixed effects

	$k \leq 0.1$ mi.		$k \leq 0.2$ mi.		$k \leq 0.3$ mi.	
	(1)	(2)	(3)	(4)	(5)	(6)
Post x Intersects (α_1)	0.054*** (0.011)	0.029*** (0.009)	0.053*** (0.011)	0.028*** (0.009)	0.053*** (0.011)	0.027*** (0.009)
Post x k mi. of Water (α_2)	-0.012 (0.007)	-0.013* (0.007)	-0.009* (0.005)	-0.011** (0.005)	-0.006 (0.005)	-0.008* (0.005)
Parcel, Month-of-sample FE	Yes	Yes	Yes	Yes	Yes	Yes
Sale Year-Levee System FE	Yes		Yes		Yes	
Sale Year-Levee Segment FE		Yes		Yes		Yes
Observations	1,244,323	1,244,323	1,244,323	1,244,323	1,244,323	1,244,323
R ²	0.948	0.948	0.948	0.948	0.948	0.948

Clustered (Tract FE) standard-errors in parentheses

*Signif. Codes: ***: 0.01, **: 0.05, *: 0.1*

Robustness: Weighted-least squares

	$k \leq 0.1$ mi.		$k \leq 0.2$ mi.		$k \leq 0.3$ mi.	
	(1)	(2)	(3)	(4)	(5)	(6)
Post x Intersects (α_1)	0.029*** (0.009)	0.039*** (0.007)	0.028*** (0.009)	0.038*** (0.007)	0.027*** (0.009)	0.038*** (0.007)
Post x k mi. of Water (α_2)	-0.013* (0.007)	-0.016** (0.007)	-0.011** (0.005)	-0.011** (0.005)	-0.008* (0.005)	-0.009** (0.004)
Weights	None	Income	None	Income	None	Income
Parcel FE	Yes	Yes	Yes	Yes	Yes	Yes
Sale Year-Levee Segment FE	Yes	Yes	Yes	Yes	Yes	Yes
Month-of-sample FE	Yes	Yes	Yes	Yes	Yes	Yes
Observations	1,244,323	646,825	1,244,323	646,825	1,244,323	646,825
R ²	0.948	0.987	0.948	0.987	0.948	0.987

Clustered (Tract FE) standard-errors in parentheses

*Signif. Codes: ***: 0.01, **: 0.05, *: 0.1*

Event study specification

- Separately estimate the following specifications on the relevant subset of treatment and control parcels

$$\log P_{it} = \sum_{\tau=-5}^{10} \alpha_1^\tau \left(L_i \times \mathbb{1}\{t = (\text{LeveeYear}_i + \tau)\} \right) + \zeta_i + \mu_{l(i)t} + \delta_t + \varepsilon_{it}$$

$$\log P_{it} = \sum_{\tau=-5}^{10} \alpha_2^\tau \left(W_i \times \mathbb{1}\{t = (\text{LeveeYear}_i + \tau)\} \right) + \zeta_i + \mu_{l(i)t} + \delta_t + \varepsilon_{it}$$

where

- LeveeYear_i indicates the year parcel i 's nearest levee segment is constructed
- $\mathbb{1}\{t = (\text{LeveeYear}_i + \tau)\}$ is an indicator variable that equals 1 if a parcel's transaction year t occurs in event times τ relative to the levee construction year and zero otherwise
- Normalize treatment effects relative to $\tau = -1$

Post-construction sorting

	log(Income) (1)	White/Asian (2)	Black (3)	Hispanic (4)
Post × Intersects	0.001 (0.013)	0.043*** (0.012)	-0.006 (0.004)	-0.041** (0.020)
Post × Distance to Water Bins				
[0.0, 0.1 mi]	-0.017 (0.011)	-0.043*** (0.010)	0.019*** (0.005)	-0.033** (0.015)
(0.1, 0.2 mi]	0.0006 (0.009)	-0.028*** (0.008)	0.010* (0.005)	-0.010 (0.012)
(0.2, 0.3 mi]	-0.009 (0.008)	-0.028*** (0.008)	0.014*** (0.004)	0.007 (0.012)
(0.3, 0.4 mi]	-0.004 (0.008)	-0.013* (0.007)	0.005 (0.003)	0.0003 (0.012)
Parcel FE	Yes	Yes	Yes	Yes
Sale Year-Sale Month FE	Yes	Yes	Yes	Yes
Sale Year-Levee Segment FE	Yes	Yes	Yes	Yes
Dependent variable mean	138,319	0.787	0.043	0.174
Observations	646,825	646,837	646,837	387,507
R ²	0.817	0.668	0.690	0.816

Clustered (Tract FE) standard-errors in parentheses

*Signif. Codes: ***: 0.01, **: 0.05, *: 0.1*

- DD design with demographic outcomes
- Suggestive of sorting away from risk by white/asian households

[▶ Go back](#)

[▶ HMDA match details](#)

Mechanism: FEMA accreditation

	$k \leq 0.1$ mi. (1)	$k \leq 0.2$ mi. (2)	$k \leq 0.3$ mi. (3)
Post \times k mi. of Water	-0.013* (0.007)	-0.012** (0.005)	-0.009** (0.005)
Post \times Intersects	-0.005 (0.019)	-0.007 (0.019)	-0.008 (0.019)
Post \times Intersects \times FEMA-accredited	0.052** (0.021)	0.053*** (0.021)	0.053*** (0.021)
Parcel FE	Yes	Yes	Yes
Sale Year-Levee Segment FE	Yes	Yes	Yes
Sale Year-Sale Month FE	Yes	Yes	Yes
Observations	1,244,323	1,244,323	1,244,323
R ²	0.948	0.948	0.948

Clustered (Tract FE) standard-errors in parentheses

*Signif. Codes: ***: 0.01, **: 0.05, *: 0.1*

Flood exposure specification

- Generate indicators of flood-related Presidential Disaster Declarations (PDDs) in annual bins
- Separately estimate the following specifications on the relevant subset of treatment and control parcels, restricting to transactions post levee construction

$$\log P_{it} = \sum_{\tau=-3}^3 \alpha_1^\tau \left(L_i \times PDD_{c(i)t}^\tau \right) + \zeta_i + \nu_{c(i)t} + \delta_t + \varepsilon_{it}$$

$$\log P_{it} = \sum_{\tau=-3}^3 \alpha_2^\tau \left(W_i \times PDD_{c(i)t}^\tau \right) + \zeta_i + \nu_{c(i)t} + \delta_t + \varepsilon_{it}$$

where

- $PDD_{c(i)t}^\tau$ is a binary variable that equals 1 if the transaction of parcel i occurs in a county c that experiences a federal disaster declaration τ years relative to sale year t and 0 otherwise
- $\nu_{c(i)t}$ is a county-by-year fixed effect
- Normalize treatment effects relative to $\tau = -1$

Pooled flood exposure results

	(1)	(2)	(3)
High Flood Exp.	-0.005* (0.003)	9.69×10^{-5} (0.003)	-0.001 (0.003)
High Flood Exp. \times Intersects	0.043*** (0.006)		0.044*** (0.006)
High Flood Exp. \times Near Water		-0.027*** (0.004)	-0.026*** (0.004)
Parcel FE	Yes	Yes	Yes
Sale Year-Levee Project FE	Yes	Yes	Yes
Sale Year-Sale Month FE	Yes	Yes	Yes
Observations	745,302	745,067	858,428
R ²	0.959	0.958	0.958

- Restrict data to transactions that occur after levee construction
- Regress log of real sale price on interactions between relevant treatment indicators and an indicator of whether a transaction is “high flood exposed”
 - Define as a transaction of a parcel falling within a county with a greater than 75th percentile value of lagged 24-month count of flood-related storm events (NOAA)

Effects of levee construction on NFIP outcomes

	$k \leq 0.1$ mi.		$k \leq 0.2$ mi.		$k \leq 0.3$ mi.	
	Take-up (1)	\$/Claim (2)	Take-up (4)	\$/Claim (5)	Take-up (7)	\$/Claim (8)
Post \times Intersects	-0.03*** (0.009)	-518.3 (4,120.9)	-0.03*** (0.009)	-269.9 (3,680.2)	-0.03*** (0.009)	-283.2 (3,675.6)
Post \times k mi. of Water	0.006 (0.007)	6,581.3** (3,315.2)	0.001 (0.008)	5,478.6* (3,181.0)	0.005 (0.009)	5,414.9* (3,216.0)
Sale Year FE	Yes	Yes	Yes	Yes	Yes	Yes
Tract FE	Yes	Yes	Yes	Yes	Yes	Yes
Levee Project FE-Sale Year FE	Yes	Yes	Yes	Yes	Yes	Yes
Observations	19,284	1,374	19,284	1,374	19,284	1,374
R ²	0.9	0.9	0.9	0.9	0.9	0.9

Clustered (Tract FE) standard-errors in parentheses
*Signif. Codes: ***: 0.01, **: 0.05, *: 0.1*

Regress aggregate NFIP outcomes, Y_{ct} , on a balanced panel at the census tract-by-year level:

$$Y_{ct} = \beta_1(T_{ct} \times L_c) + \beta_2(T_{ct} \times W_c) + \xi_c + \mu_{l(c)t} + \delta_t + \epsilon_{ct}$$

where ξ_c , $\mu_{l(c)t}$, and δ_t are tract, levee-by-year, and year fixed effects

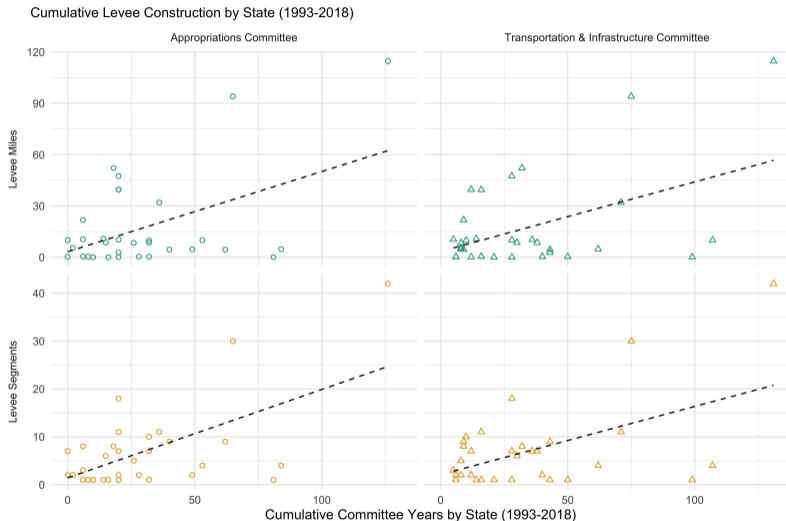
[▶ Go back \(learning\)](#)

[▶ Go back \(BCA\)](#)

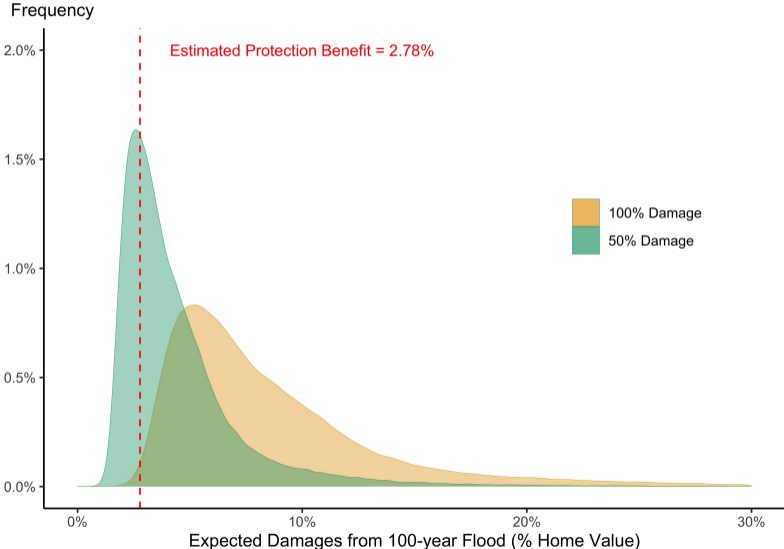
Aggregate benefits and costs

	Mean	Std. Dev.	Min.	Max.	N
Protection Benefits (\$Mil./mi.)					
ZTRAX Housing Stock Estimate	1.066	2.136	0.007	10.930	37
USACE Housing Stock Estimate	9.608	14.027	0.000	71.202	37
Costs (\$Mil./mi.)					
Construction Costs					
Total	60.781	157.651	0.189	852.161	37
Federal	49.007	130.027	0.003	664.098	29
Non-Federal	15.385	38.060	0.005	188.063	27
Spillover Effects	13.799	40.799	0.008	238.268	37
Fiscal Externalities					
Effective Tax Rate: Leveed Area	0.035	0.049	0.010	0.226	33
Effective Tax Rate: Spillover Area	0.032	0.044	0.006	0.208	34
Protection Benefits (\$Mil./mi.)					
ZTRAX Housing Stock Estimate					
2% real interest rate	0.943	1.694	0.000	6.951	37
3.5% real interest rate	0.539	0.968	0.000	3.972	37
USACE Housing Stock Estimate					
2% real interest rate	21.086	73.863	0.000	449.851	37
3.5% real interest rate	12.049	42.207	0.000	257.058	37
Spillover Effects (\$Mil./mi.)					
2% real interest rate	34.368	144.968	0.000	866.797	37
3.5% real interest rate	19.639	82.839	0.000	495.313	37

Local representation and levee construction are positively correlated



Incomplete capitalization of flood risk changes



Extensive margin impacts

Dependent Variable:	asinh(Home Age)		
	(1)	(2)	(3)
Model:			
Post x Intersects	-0.233** (0.095)	-0.214** (0.095)	-0.202** (0.095)
Post x k mi. of Water	0.223*** (0.052)	0.193*** (0.037)	0.159*** (0.034)
Parcel FE	Yes	Yes	Yes
Sale Year-Levee Segment FE	Yes	Yes	Yes
Sale Year-Sale Month	Yes	Yes	Yes
$k \leq$	0.1 mi.	0.2 mi.	0.3 mi.
Observations	1,244,323	1,244,323	1,244,323
R ²	0.915	0.915	0.915

Clustered (Tract FE) standard-errors in parentheses

*Signif. Codes: ***: 0.01, **: 0.05, *: 0.1*

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