Private Benefits from Public Investment in Climate Adaptation and Resilience

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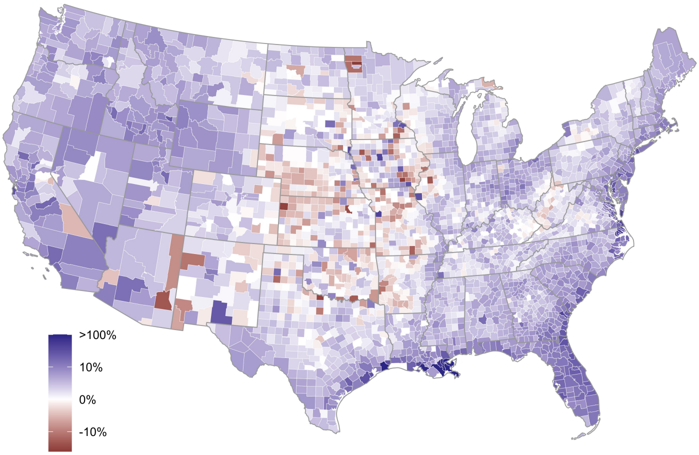
Climate change and flood risk in the US

Estimated Change in Properties with Flooding (2021-2051)



Source: First Street Foundation and Authors' calculations

- Flood events most costly disasters in US
  - 2017: $\sim$\$300B in damages (NOAA)
- Share of US properties at risk of regular flooding $\uparrow$ 8.2% over next 30 years (FSF)

Managing flood risk in the US

- Infrastructure Investment and Jobs Act: \$50+ billion for climate adaptation
- Historically, major form of flood risk adaptation: levees ▸ Adaptation types

Summary

- With growing natural hazard risks, policymakers face increasing imperative to invest in public adaptation
  - $\rightarrow$ **Research question:** Who benefits and by how much?

- 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

- Findings:
  1. Estimate subsidized flood protection benefits amount to 2% 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
  4. Ex post, USACE-constructed levee costs appear to exceed benefits

Related literature

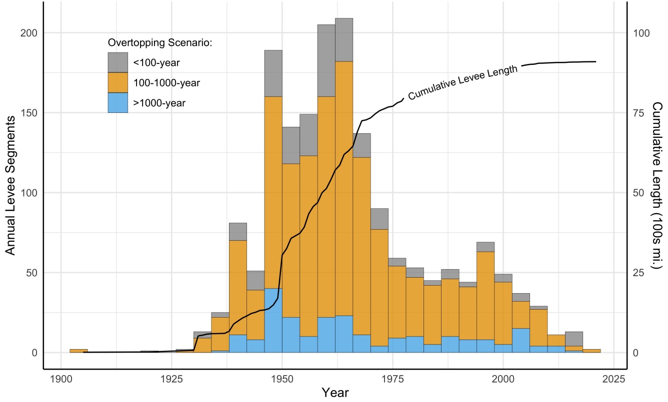
- Individual-level adaptation and adaptation policy
  - Auffhammer, 2022; Barreca et al., 2016; Baylis and Boomhower, 2021; Burke and Emerick, 2016; Kahn, 2016; Wagner, 2021
- Capitalization of flood risk and adaptive investments
  - Beltrán et al., 2019; Bernstein et al., 2019; Bin et al., 2008; Bin 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

Outline

What is a levee?

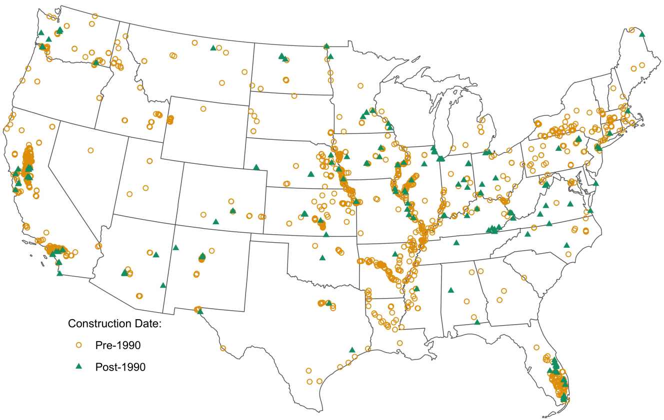
- Man-made structure that diverts water flow during flood stages
- Provides flood protection to defined area, up to a certain flood severity
- Imposes flood risk spillovers to downstream/upstream areas (Heine and Pinter, 2012; Remo et al., 2018)

Federal levee construction



- 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 that manage consequences (e.g., NFIP)
- Why study levees?

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 project data with home sale data from Zillow (1990-present)

▸ Summary stats.

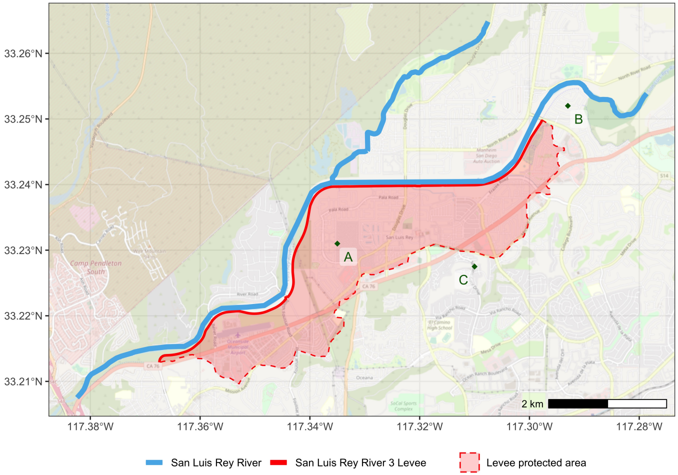
Additional data

- *USACE National Levee Database* $\longrightarrow$ levee construction date
- *Home Mortgage Disclosure Act (HMDA)* $\longrightarrow$ transaction-level demographic data for a subset of transactions
- *US Geological Survey National Hydrography Dataset* $\longrightarrow$ distance to nearest waterway
- *NOAA Storm Events Database* $\longrightarrow$ annual county-level counts of flood-related storm events

▸ Summary stats.

Effects of levee construction

San Luis Rey River 3 Levee - Oceanside, CA



- Identification challenges:
  - Siting endogeneity
  - Heterogeneous effects

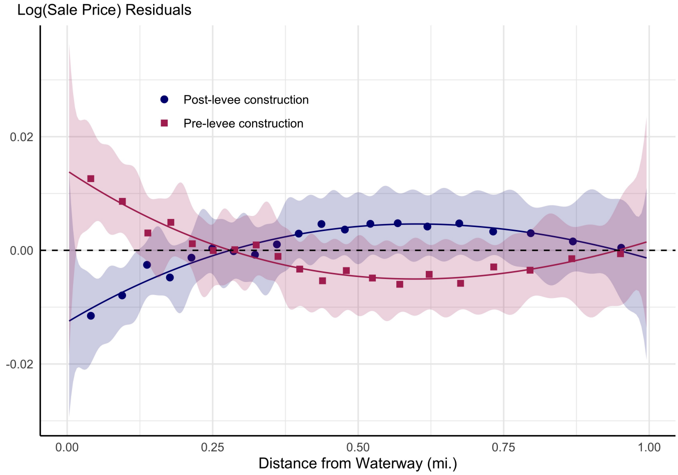
- Potential effects of levee construction:
  1. *Protection effects* (A)
  2. *Spillover effects* (B)
  3. *Macro effects* (A, B, C)

$\Rightarrow$ Compare pre-/post-levee construction changes in prices

▸ Details

▸ Additional effects

Defining property exposure



▸ Flexible treatment def.

- Treatment status of a transaction of parcel i at time t can be entirely defined using the following indicators:

$$T_{it} = \mathbb{1}\{\text{Sale occurs post levee construction}\}$$
$$L_i = \mathbb{1}\{\text{Parcel is within a leveed area}\}$$
$$W_i = \mathbb{1}\{\text{Parcel is adjacent to a waterway}\}$$

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

- T_{it} and L_i easily defined from ZTRAX, USACE, and FSF data

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)

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

$$\log(P_{it}) = \overbrace{\alpha_1}^{\text{protection effect}} (T_{it} \times L_i) + \underbrace{\alpha_2}_{\text{spillover effects}} (T_{it} \times W_{it}) + \xi_i + \mu_{l(i)t} + \delta_t + \varepsilon_{it}$$

  - ξ_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

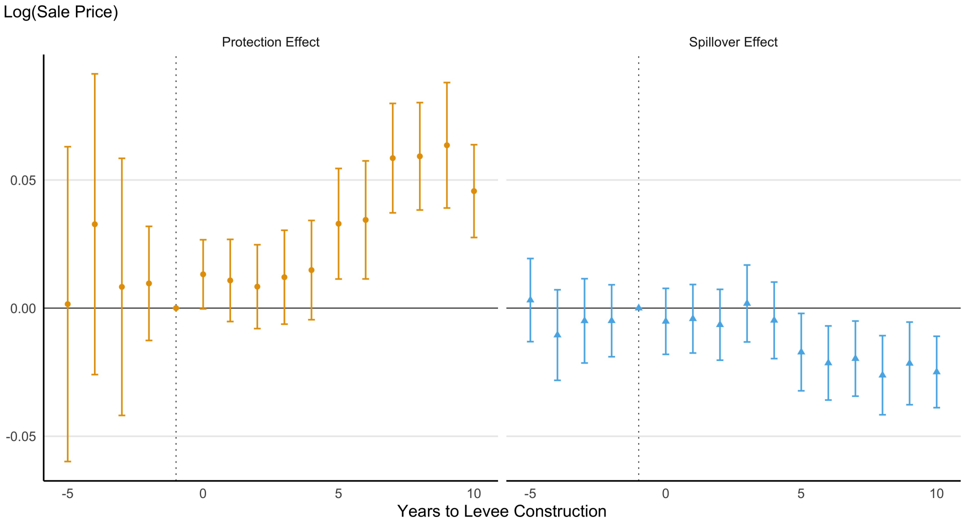
Main capitalization estimates

	$k \leq 0.1$ mi.		$k \leq 0.2$ mi.		$k \leq 0.3$ mi.	
	(1)	(2)	(3)	(4)	(5)	(6)
Post × Intersects (α_1)	0.098***	0.029***	0.095***	0.028***	0.092***	0.027***
	(0.015)	(0.009)	(0.015)	(0.009)	(0.015)	(0.009)
Post × k mi. of Water (α_2)	-0.062***	-0.013*	-0.062***	-0.011**	-0.064***	-0.008*
	(0.012)	(0.007)	(0.009)	(0.005)	(0.008)	(0.005)
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	1,244,323	1,244,323	1,244,323	1,244,323	1,244,323	1,244,323
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*

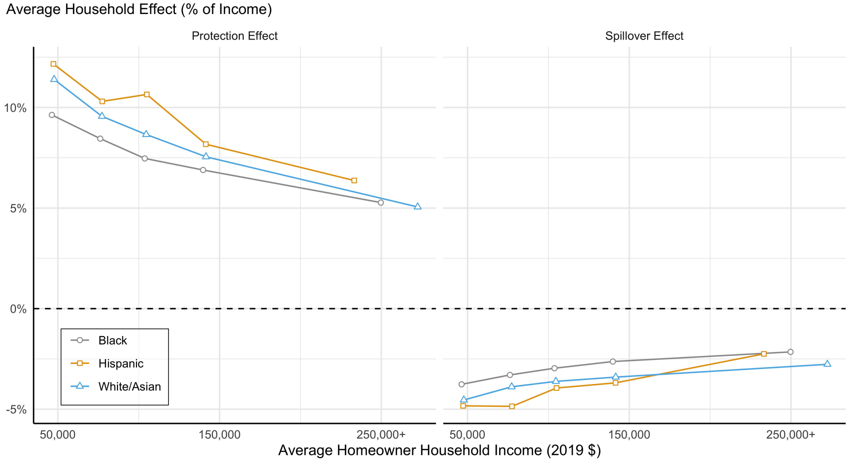
▸ Flexible treatment def. ▸ Additional effects

Dynamic effects of levee construction



Details

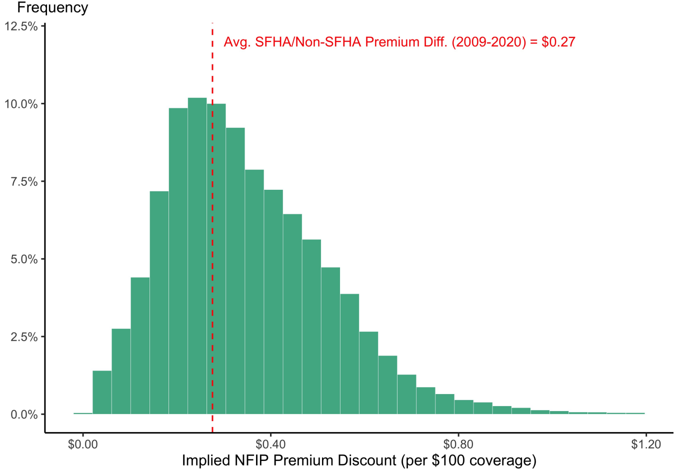
Incidence of protection benefits and spillover costs



- Evidence of differential sorting ex-post by race/ethnicity
  - ▸ Differential sorting

▸ HMDA match

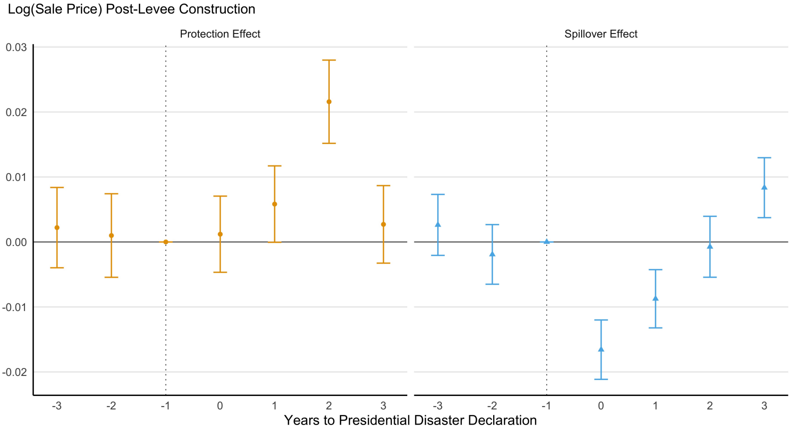
Mechanism: NFIP premium discounts



▸ NFIP outcomes

- Assume capitalized protection benefits entirely from PDV of reduced NFIP premiums
  - Full coverage for 30 yrs, 5% discount rate $\Rightarrow$ Δ premium
- Implied Δ premium exceeds nationwide SFHA/non-SFHA premium diff on average
- While NFIP discount plays a role, other factors likely
  - SFHA take-up 48% nationwide
  - 25% of segments in sample are not FEMA-accredited

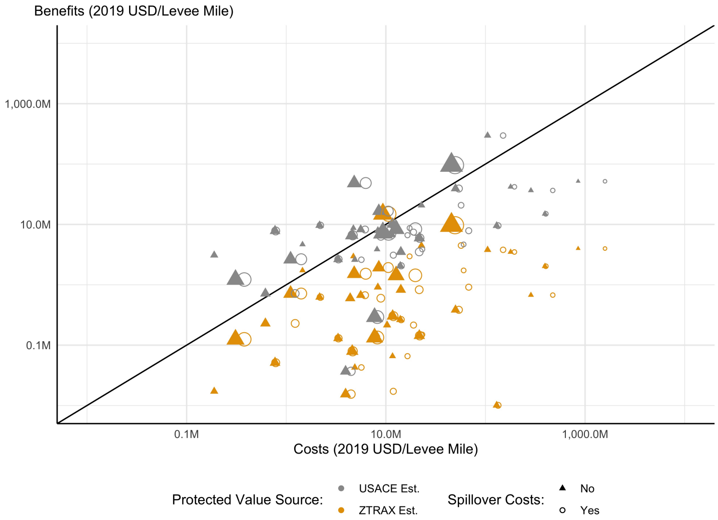
Mechanism: Learning from flood exposure



- Households learn about flood risk (Bakkensen and Barrage, 2021; Gallagher, 2014)
- Post-levee construction event study using flood-related Presidential Disaster Declarations

▸ Details ▸ Pooled results ▸ NFIP claims

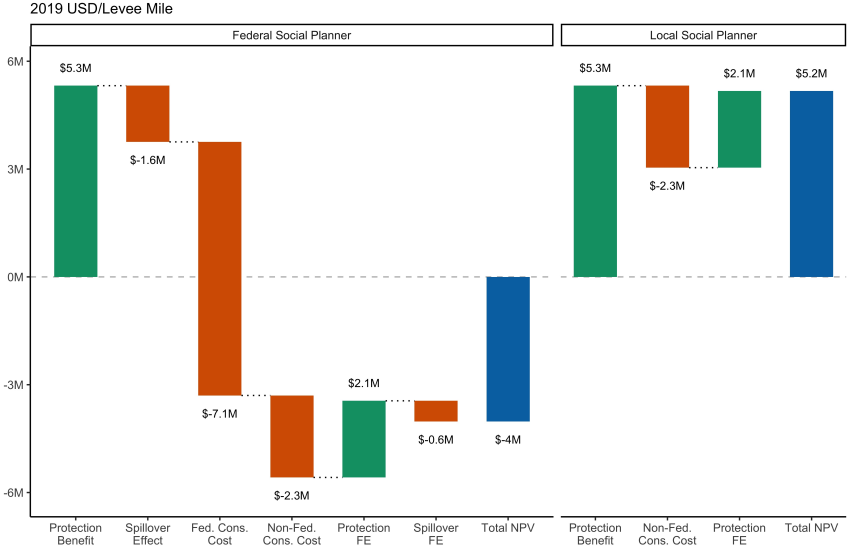
Estimated benefit cost ratios



- Types of benefits/costs
    1. Capitalized effects
    2. Local public finance externalities
    3. Construction costs
- Collect construction cost data for 37 projects
- Normalize benefits and costs by levee size
    - Points proportional to levee size

▸ Benefit and cost components

External costs and local political economy



- 30% of projects in sample impose spillovers on external counties
- Levee construction and Congressional representation

▸ Committee membership

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

- 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

Thank you

Please reach out with comments/questions
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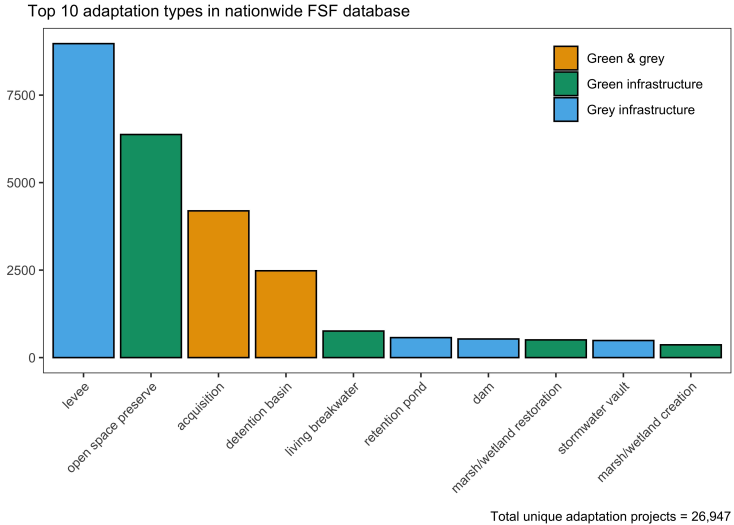
Backup Slides

Flood risk adaptation project types



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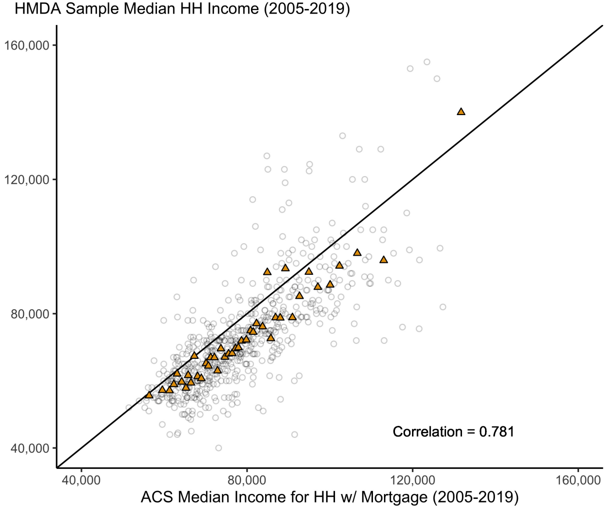
Transaction-level demographic data



- 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)

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Summary statistics

	Unmatched Sample		HMDA Sample			
	Mean	Std. Dev.	Mean	Std. Dev.	Diff. in Means	Std. Error
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			

Go back

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

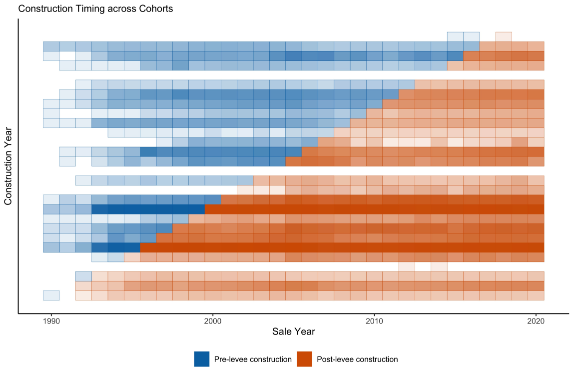
$$
\begin{aligned}
\Delta_t P_A &= Macro + Protect &&= \alpha_1 + \Delta_t \mu_{l(i)t} + \Delta_t \delta_t \\
\Delta_t P_B &= Macro + Spillover &&= \alpha_2 + \Delta_t \mu_{l(i)t} + \Delta_t \delta_t \\
\Delta_t P_C &= Macro &&= \Delta_t \mu_{l(i)t} + \Delta_t \delta_t
\end{aligned}
$$

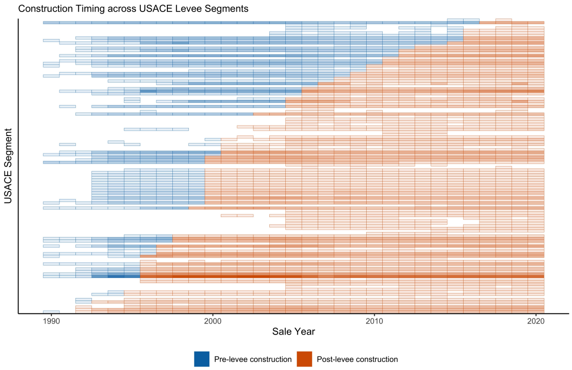
- We can therefore identify the protection and spillover effects with the following double differences (DD):

$$
\begin{aligned}
(Protect)_{DD} &= \Delta_t P_A - \Delta_t P_C = \alpha_1 \\
(Spillover)_{DD} &= \Delta_t P_B - \Delta_t P_C = \alpha_2
\end{aligned}
$$

Go back

Staggered treatment





▸ Go back

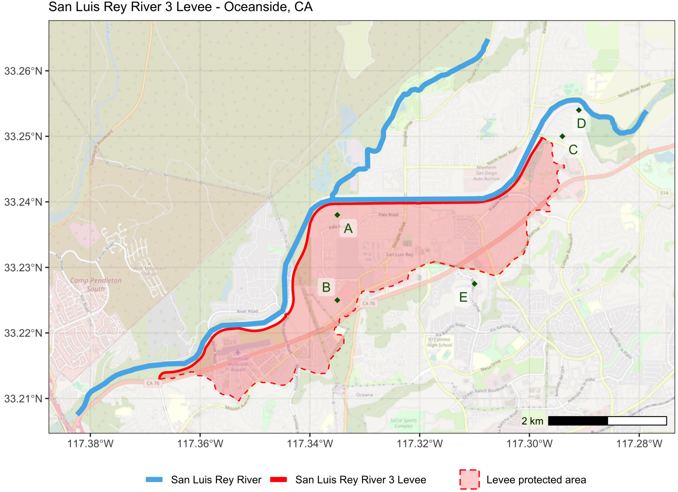
Flexibly defined proximity-based treatment

	(1)	(2)
Post × Intersects	0.113***	0.030***
	(0.016)	(0.009)
Post × Distance to Water Bins		
[0.0, 0.1 mi]	-0.072***	-0.017**
	(0.012)	(0.007)
(0.1, 0.2 mi]	-0.062***	-0.010*
	(0.009)	(0.005)
(0.2, 0.3 mi]	-0.060***	-0.003
	(0.008)	(0.005)
(0.3, 0.4 mi]	-0.054***	-0.003
	(0.008)	(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*

Go back

Broader set of effects of levee construction



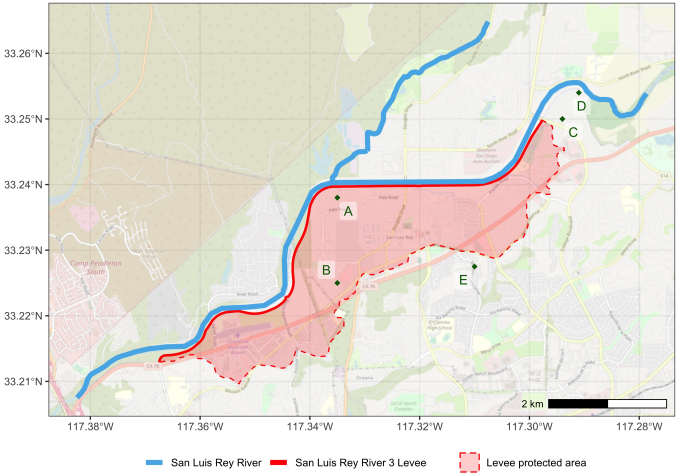
Potential effects of levee construction:

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:

$$
\begin{aligned}
\Delta_t P_A &= Macro + Protect + Adjacency \\
&\quad + Salience \\
\Delta_t P_B &= Macro + Protect \\
\Delta_t P_C &= Macro + Adjacency + Spillover \\
\Delta_t P_D &= Macro + Spillover \\
\Delta_t P_E &= Macro
\end{aligned}
$$

$\Rightarrow$ 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 x Intersects (α_1)	0.098***	0.026***	0.097***	0.027***	0.095***	0.027***
	(0.015)	(0.008)	(0.015)	(0.009)	(0.015)	(0.009)
Post x k mi. of Levee (α_2)	-0.0005	-0.019	0.054*	0.014	0.070***	0.018
	(0.043)	(0.029)	(0.029)	(0.015)	(0.024)	(0.011)
Post x k mi. of Water (α_3)	-0.062***	-0.014**	-0.063***	-0.012***	-0.066***	-0.009*
	(0.012)	(0.007)	(0.009)	(0.005)	(0.008)	(0.005)
Post x Intersects x k mi. of Levee (α_4)	-0.068	-0.021	-0.101***	-0.043**	-0.110***	-0.037**
	(0.050)	(0.035)	(0.037)	(0.019)	(0.032)	(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*

Go back

Event study specification

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

$$\log P_{it} = \sum_{\tau=-5}^{10} \alpha_1^{\tau} \Big(L_i \times \mathbb{1}\{t = (LeveeYear_i + \tau)\} \Big) + \xi_i + \mu_{l(i)t} + \delta_t + \varepsilon_{it}$$

$$\log P_{it} = \sum_{\tau=-5}^{10} \alpha_2^{\tau} \Big(W_i \times \mathbb{1}\{t = (LeveeYear_i + \tau)\} \Big) + \xi_i + \mu_{l(i)t} + \delta_t + \varepsilon_{it}$$

where

- $LeveeYear_i$ indicates the year parcel i's nearest levee segment is constructed
- $\mathbb{1}\{t = (LeveeYear_i + \tau)\}$ 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 $\tau = -1$

▸ Go back

Sorting post-levee construction

	log(Income) (1)	White/Asian (2)	Black (3)	Hispanic (4)
Post × Intersects	0.001	0.043***	-0.006	-0.041**
	(0.013)	(0.012)	(0.004)	(0.020)
Post × Distance to Water Bins				
[0.0, 0.1 mi]	-0.017	-0.043***	0.019***	-0.033**
	(0.011)	(0.010)	(0.005)	(0.015)
(0.1, 0.2 mi]	0.0006	-0.028***	0.010*	-0.010
	(0.009)	(0.008)	(0.005)	(0.012)
(0.2, 0.3 mi]	-0.009	-0.028***	0.014***	0.007
	(0.008)	(0.008)	(0.004)	(0.012)
(0.3, 0.4 mi]	-0.004	-0.013*	0.005	0.0003
	(0.008)	(0.007)	(0.003)	(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*

▸ Go back

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

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

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

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 $\tau = -1$

Go back

Pooled flood exposure results

	(1)	(2)	(3)
High Flood Exp.	-0.005*	9.69×10^{-5}	-0.001
	(0.003)	(0.003)	(0.003)
High Flood Exp. × Intersects	0.043***		0.044***
	(0.006)		(0.006)
High Flood Exp. × Near Water		-0.027***	-0.026***
		(0.004)	(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)

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Effects of levee construction on NFIP outcomes

	Protection Effect			Spillover Effect		
	Take-up	Pr(Claim)	$/Claim	Take-up	Pr(Claim)	$/Claim
	(1)	(2)	(3)	(4)	(5)	(6)
Post × Intersects	-0.034***	-0.107***	-80.8			
	(0.009)	(0.018)	(950.6)			
Post × Near Water				0.007	0.033***	2,919.7**
				(0.007)	(0.010)	(1,205.4)
Sale Year FE	Yes	Yes	Yes	Yes	Yes	Yes
Tract FE	Yes	Yes	Yes	Yes	Yes	Yes
Sale Year-Levee Project FE	Yes	Yes	Yes	Yes	Yes	Yes
Observations	19,284	33,458	4,019	19,284	33,458	4,019
R^2	0.935	0.378	0.769	0.934	0.377	0.770

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:

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

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

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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

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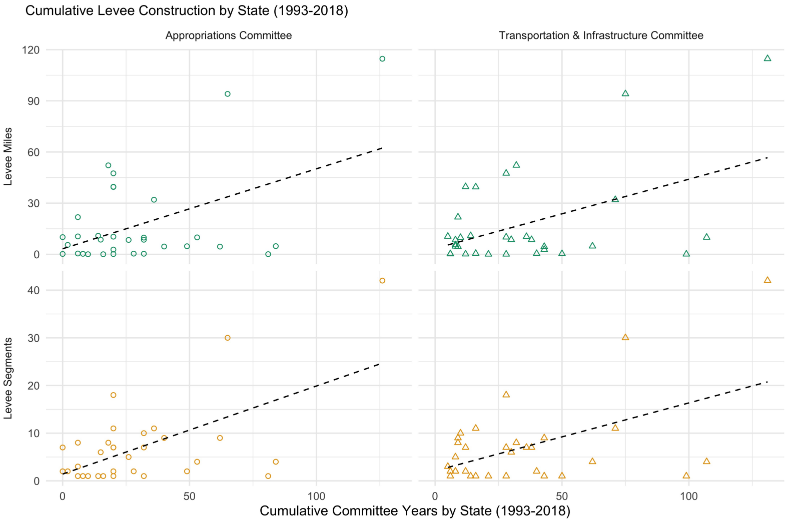
External costs and local political economy



- House committee membership data from Grossman et al., 2022
- Positive correlation between USACE levee construction and local representation

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