Levees and levies:
Local financing of climate infrastructure maintenance and housing market dynamics

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Introduction

- Flood protection infrastructures play an important role for climate adaptation.
  - US Flood protection levees: 22% of counties, 21.3M population, $2.85T property value.
  - Flood protection infrastructures forecast to represent 60% of the $500 billion US adaptation costs by 2100 (Hummel et al, 2021).

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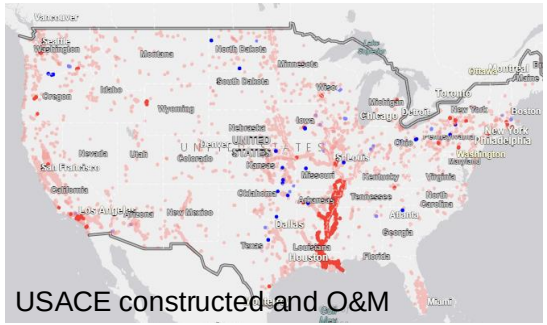
  - Flood protection infrastructures forecast to represent 60% of the $500 billion US adaptation costs by 2100 (Hummel et al, 2021).
  - Lifespan of 100 years: substantial maintenance investments.

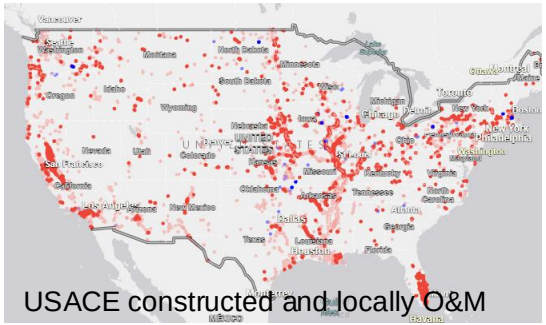
    Previous literature: immediate economic benefits of new construction (Bradt and Aldy, 2022; Kelly and Molina, 2023; Benetton et al., 2024). Limited attention paid to long-term maintenance.

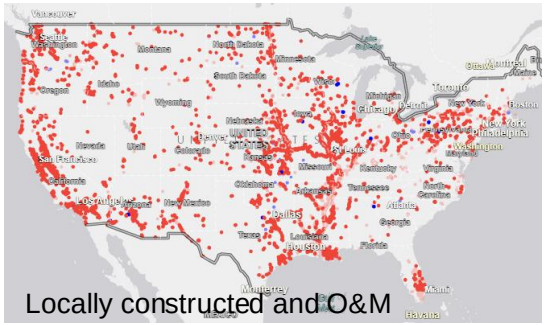
Introduction

- Levee maintenance is local responsibility: 79.5% maintained by municipalities and special districts, which heavily rely on local property tax revenue.

sponsor







"Local governments rarely have the resources necessary to properly maintain a levee system" (ASCE 2021)

"A financial record review of 44 levee districts indicates that only 45 percent of those districts are financially sound." (Iowa Department of Homeland Security and Emergency Management 2022)

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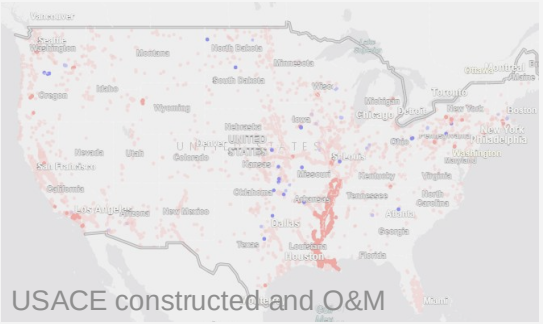
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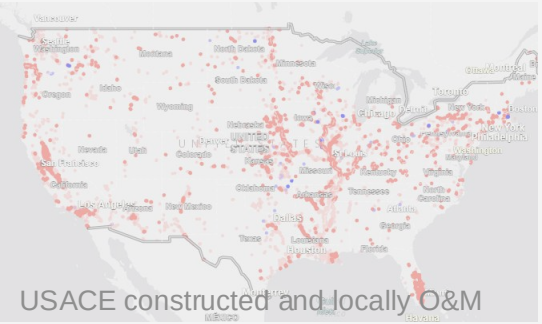
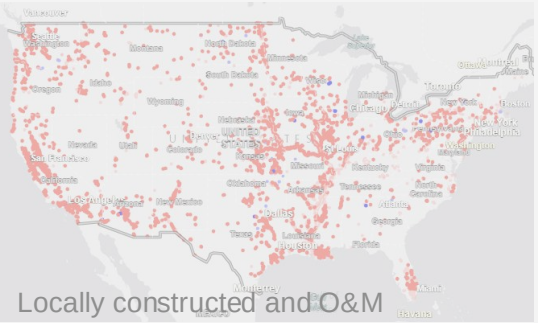

USACE constructed and locally O&M


Locally constructed and O&M

- 40% US levees in “unacceptable” maintenance quality. $21 billion needed to address performance risk of moderate to high-risk levees (USACE 2018).


Hurricane Katrina 2005


Spring 2019 Midwest


2023 Town of Pajaro

Neighborhood Feedback Loop

- Local public finance is “pro-cyclical”.
  Urban Doom Loop (Nieuwerburgh, 2021)

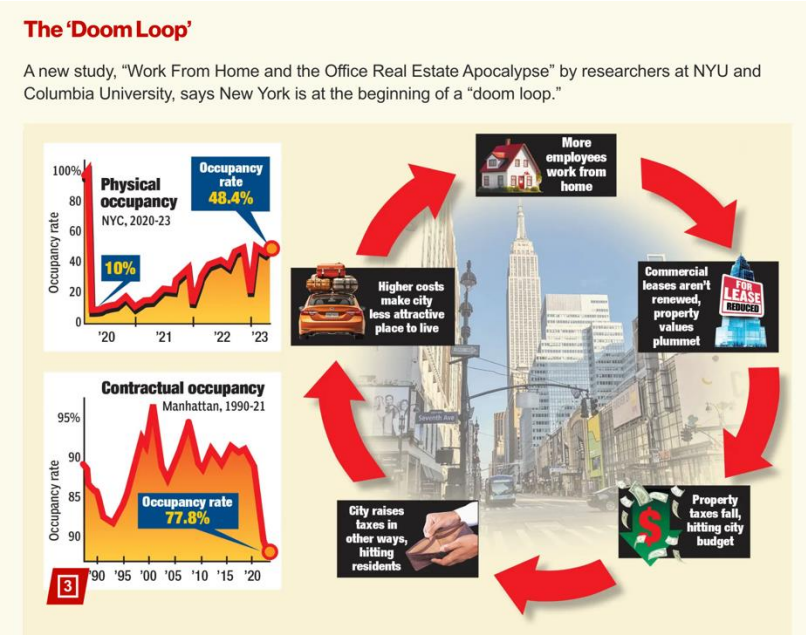
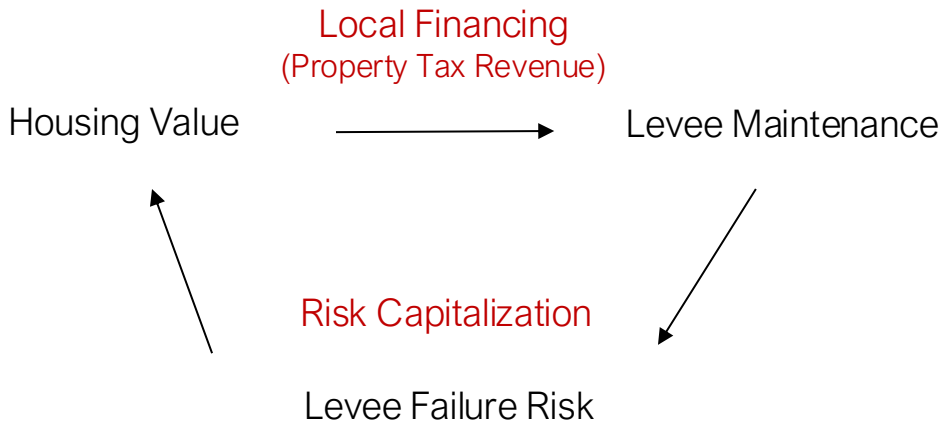


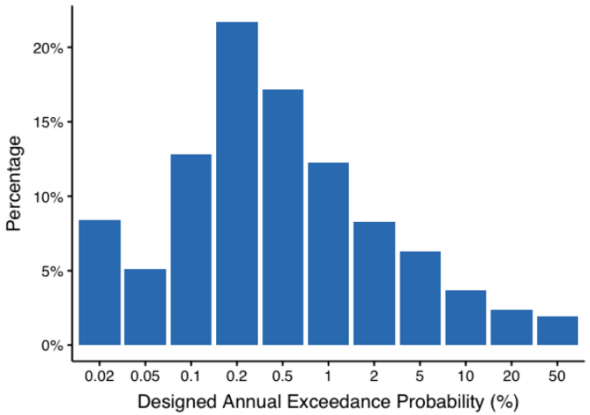
Figure Source: https://nypost.com/2023/06/08/work-from-home-and-empty-offices-leading-to-doom-loop-for-nyc/



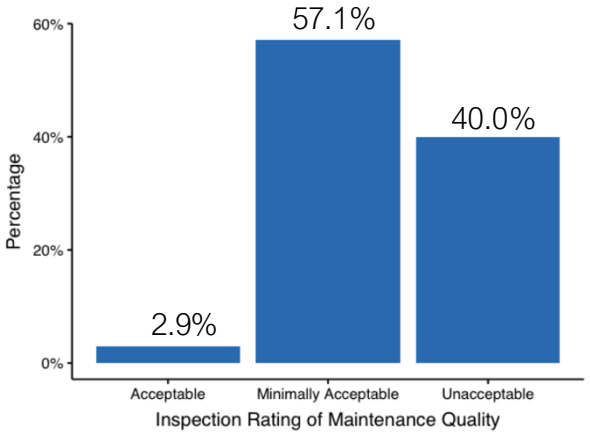
Maintenance Quality: Inspection Rating

- Inspection records from US Army Corps of Engineers (USACE):
  - Under PL 84-99: Eligibility of Rehabilitation and Inspection Program (RIP).
  - Maintenance quality rating: “Acceptable”, “Minimally Acceptable”, “Unacceptable”.
  - Also designed protection level (e.g., 0.2% AEP/ 500-year flood).

(a) Designed Protection Level



(b) Maintenance Quality



RIP

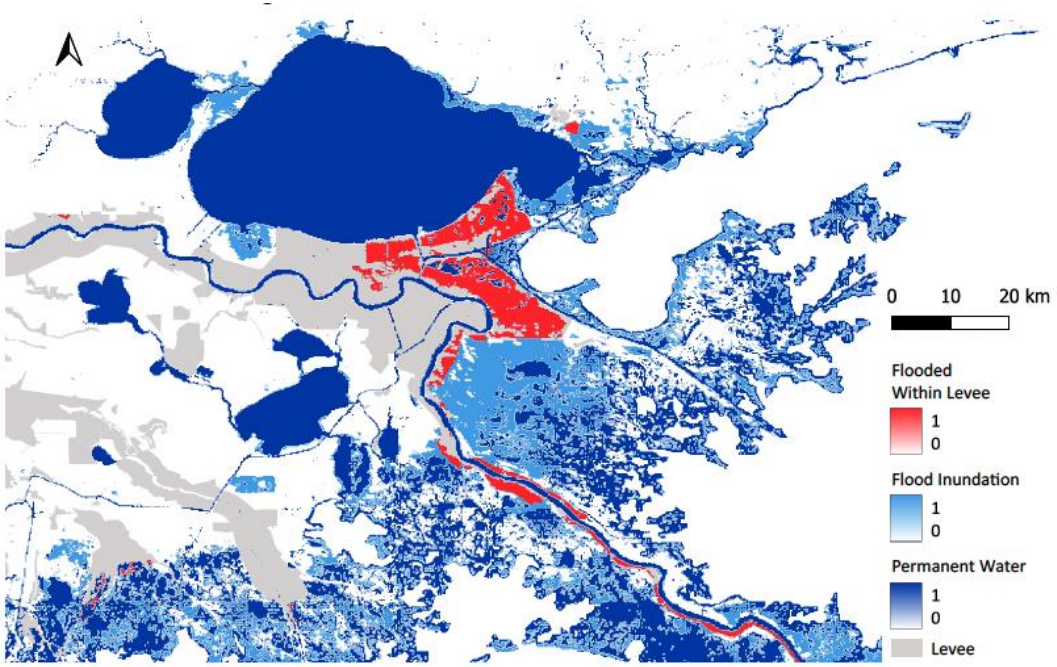
Levee Failure: Satellite Imagery

- Moderate Resolution Imaging Spectroradiometer (MODIS).
- Daily, 250-meter resolution.
- Flood inundation mapping method: Tellman et al. 2021

a) Flood events from Dartmouth Flood Observatory (DFO)

b) Water detection algorithms on imageries using Google Earth Engine

3-day standard algorithms + empirically derived thresholds to the short-wave-infrared, near-infrared, and red bands (bands 7, 2, and 1) from MODIS



Example: Hurricane Katrina

Validation

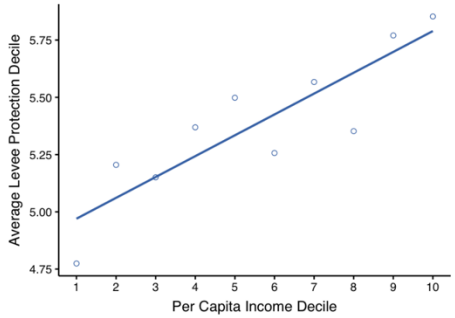
Method reference: Tellman, B., Sullivan, J. A., Kuhn, C., Kettner, A. J., Doyle, C. S., Brakenridge, G. R., Erickson, T. A., & Slayback, D. A. (2021). Satellite imaging reveals increased proportion of population exposed to floods. Nature, 596(7870), 80–86.

Motivating Facts: Inequality in Levee Quality

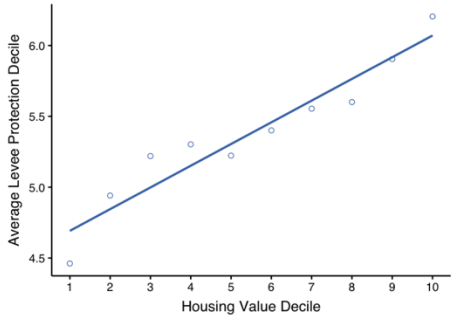
- 1 SD increase in tract income:
  - 8.3 percent increase in levee protection
  - 9.6 percent (5.6 percentage point) increase in (minimally) acceptable quality.

regression CBA

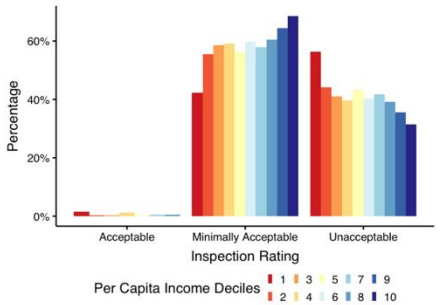
(a) Per Capita Income and Designed Protection



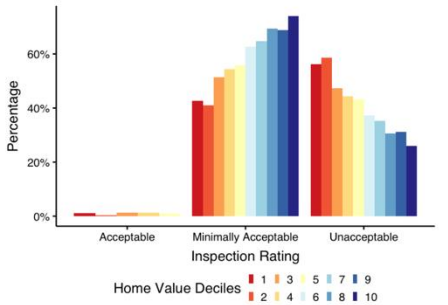
(b) Median Home Value and Designed Protection



(c) Per Capita Income and Maintenance Quality



(d) Median Home Value and Maintenance Quality



Local Fiscal Capacity and Levee Quality

- Local fiscal capacity plays a role:
  Income disparity in levee maintenance is particularly salient when municipal governments or special districts serve as local sponsors.

Table 3: Income inequality in levee maintenance quality by local sponsorship

		(Minimally) Acceptable Quality		
Local Sponsor	All	State/County	Municipality	Special District
	(1)	(2)	(3)	(4)
Log(Per Capita Income)	0.084^{***}	0.053	0.113^{***}	0.094^{***}
	(0.016)	(0.033)	(0.027)	(0.020)
Log(Levee Population)	0.038^{***}	0.050^{***}	0.077^{***}	0.042^{***}
	(0.004)	(0.011)	(0.013)	(0.005)
State FE	Yes	Yes	Yes	Yes
Protection level FE	Yes	Yes	Yes	Yes
Floodzone ratio control	Yes	Yes	Yes	Yes
Observations	2,340	463	731	1,091
Adjusted R^2	0.535	0.651	0.434	0.712

causal

Maintenance Impacts Levee Failure Risk

- Maintenance quality impacts levee failure risk.
- Maintenance deficiency moderates income disparity in levee failure risk.

consistent sample

	Times flooded within levees since 2000		
	(1)	(2)	(3)
Log(Per Capita Income)	−0.287**	−0.246*	−0.166
	(0.128)	(0.130)	(0.139)
Floodzone Ratio	0.655***	0.686***	0.545***
	(0.178)	(0.179)	(0.191)
Log(Protection Level)		−0.325***	−0.231***
		(0.057)	(0.075)
Acceptable Quality			−1.185***
			(0.167)
State FE	Yes	Yes	Yes
Ownership FE	Yes	Yes	Yes
Observations	2,089	2,062	1,700
Adjusted R^2	0.273	0.284	0.289

Levee Failure on Housing Value

- Event study (Callaway & Sant'Anna estimator) to identify the causal effect of levee failure using satellite imagery of 103 flooding events in the past two decades. event summary

$$HPI_{ift} = \sum_{\tau=-5}^{6} \beta_\tau \left(LeveeFail_{if} \times EventTime_{ft}^{\tau} \right) + \delta_i + \theta_{st} + \left(X_i \times Year_y \right) \eta + \epsilon_{ift}$$

- HPI_{ift}: FHFA Repeated Sale Index
- $LeveeFail_{if}$: 1(Flood Inundation Within Levee)
  - Any flooding (> 0%)
  - Large flooding (> 25%)
- $EventTime_{ft}^{\tau}$: Years from Event
- δ_i, θ_{st}: Census Tract FE, State by Year FE

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1(Flood Inundation Within Levee)
- Any flooding (> 0%)
- Large flooding (> 25%)

Years from Event

Census Tract FE, State by Year FE

Controls: Tract Income & FSF Tract Flood Risk

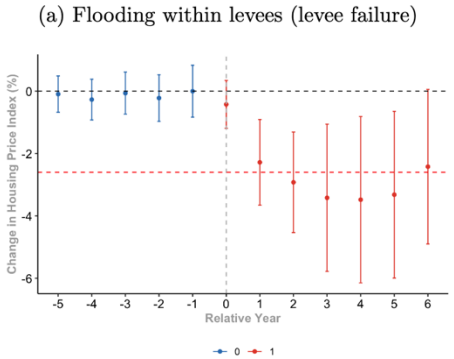
Interact with year to get differential time trends.

- Parallel trend assumption: Census tracts experiencing levee failures would have followed the same housing price trend as other levee-dependent census tracts without such failure events.
  - Housing price trends could be different: Differences in neighborhood income and flood risk.

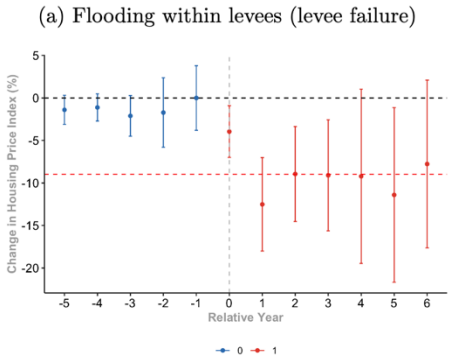
Levee Failure on Housing Value

- Levee failure:
  - 3-9% reduction in tract housing prices.
  - Persistent.

Any flooding (> 0%)



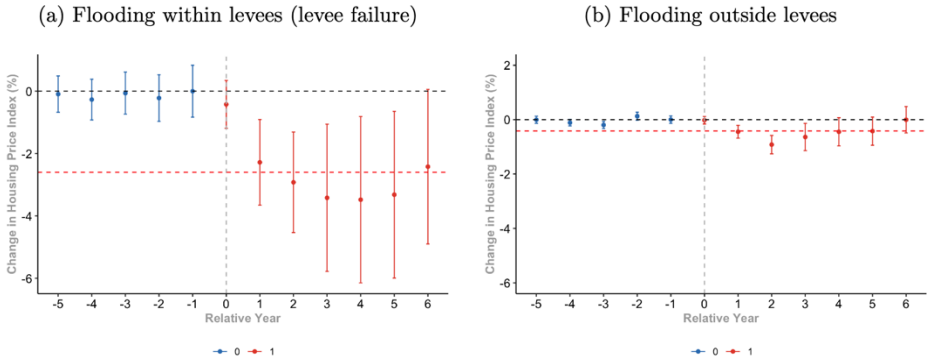
Large flooding (> 25%)



Levee Failure on Housing Value

- Levee failure:
  - 3-9% reduction in tract housing prices.
  - Persistent.
- Flooding outside of levees:
  - Small and transitory impacts.
  - Temporary price increase as supply outweighs demand for large shocks (Tran and Wilson, 2020; Graff Zivin, Liao, and Panassié, 2023).

Any flooding (> 0%)



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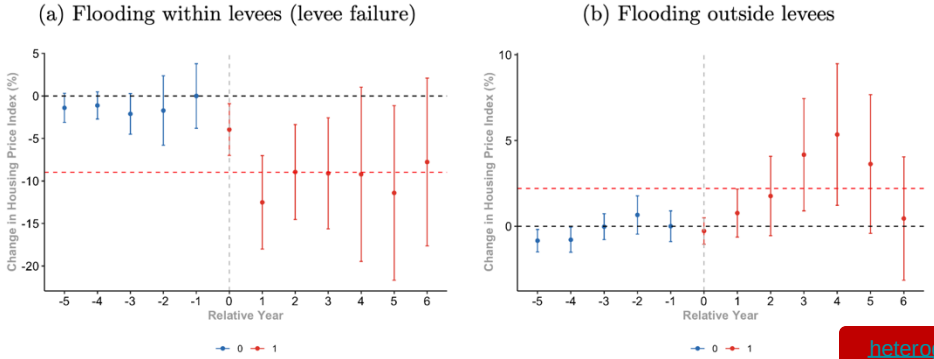


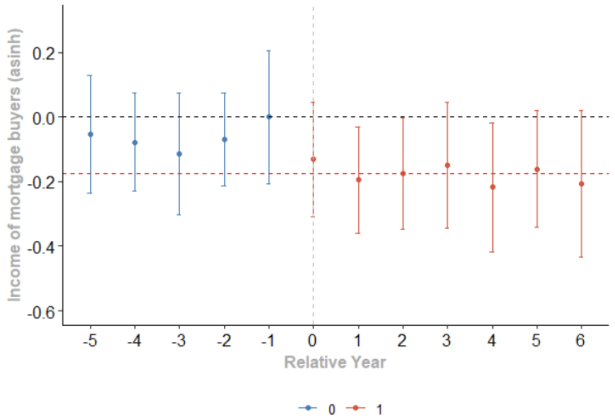
heterogeneity

Levee Failure on Income Sorting

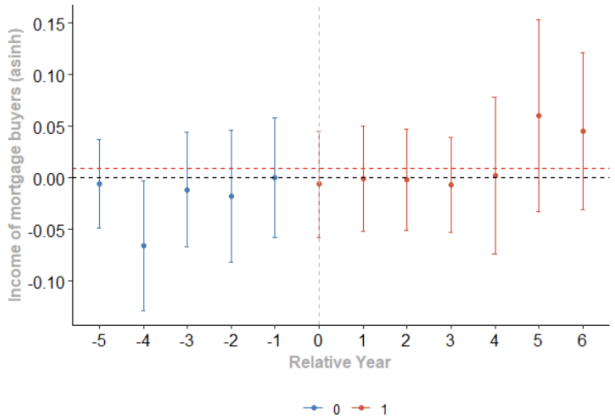
- Home Mortgage Disclosure Act (HMDA) Data.
- Negative income sorting: New mortgage buyers are lower income after levee failure; no sorting effect for flooding outside levees.

Figure 7: Effect of extensive flooding on income of new mortgage buyers

(a) Flooding within levees (levee failure)



(b) Flooding outside levees



Levee Failure on Local Fiscal Capacity

Local public finance implications?

- Revenue:

Reduction in Property Tax.

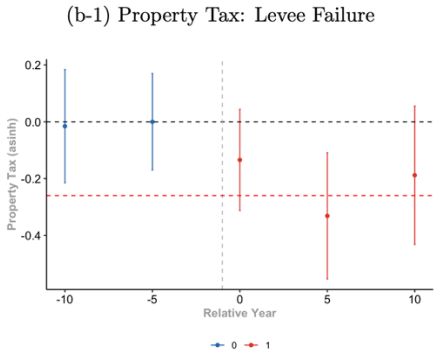
Increase in IG Transfer.

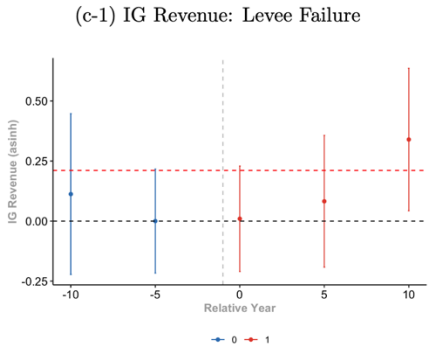
5.6% decrease in Total Revenue.

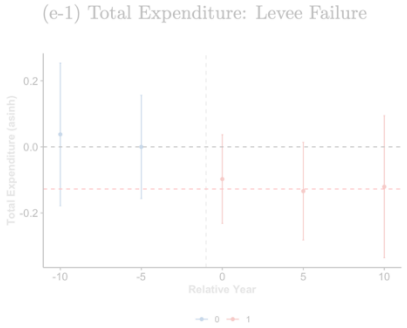
- Expenditure:

Reduction in total expenditure.

No increase in capital outlay.







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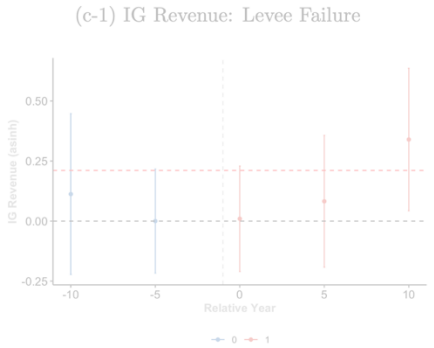
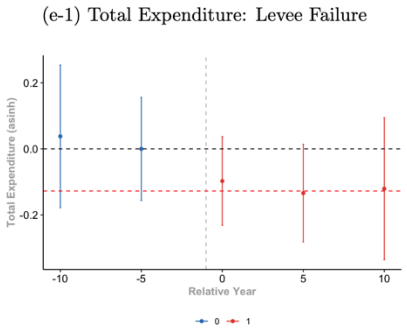
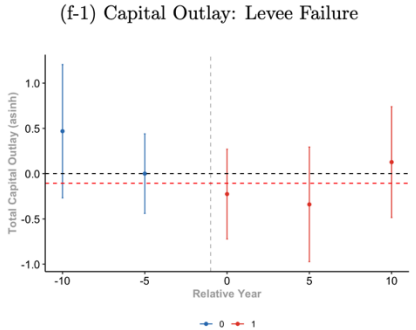
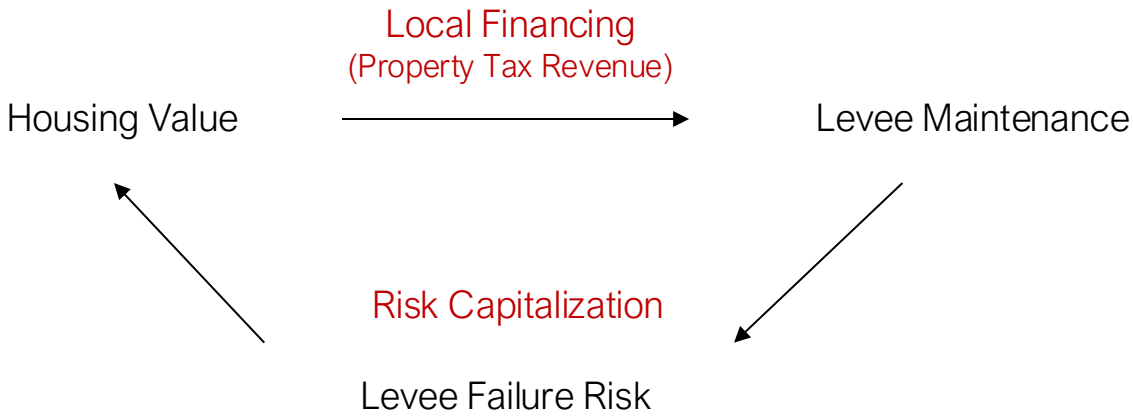






Summary

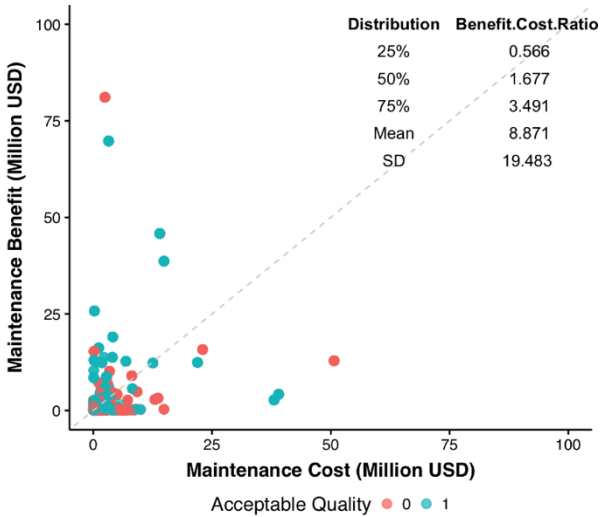
- I provide evidence that local financing of levee maintenance: Self-reinforcing Feedback Loop
  - Local Financing Effect: Housing value affects local fiscal capacity and levee maintenance quality.
  - Capitalization Effect: Levee maintenance deficiency affects levee failure risks and impact housing value and local fiscal capacity.



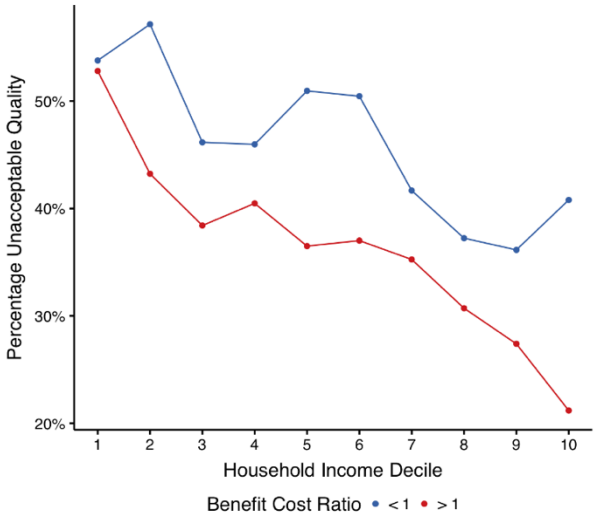
Cost Benefit Implications

- Levee maintenance has average benefit-cost ratio of 8.81.
- 36.37% of NPV positive levees not well-maintained. Extra annual flood loss of $456 million (2019 USD).
- Maintenance inefficiency increases with decreasing census tract income.

(a) Annual Benefit and Cost



(b) Maintenance Quality by Tract Income



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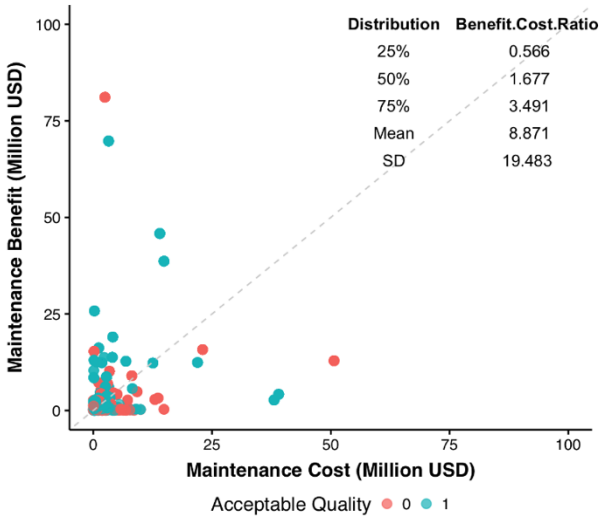

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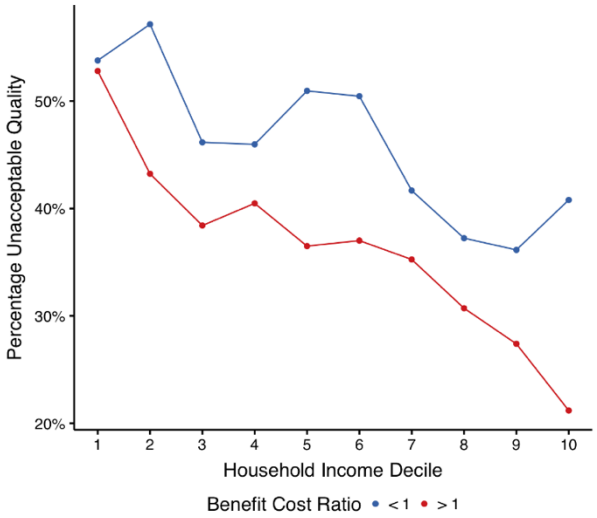

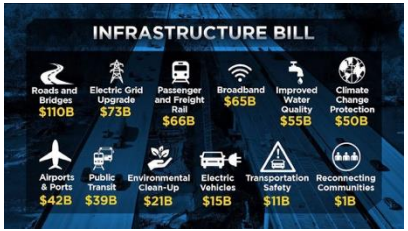

Thank You

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Levee Responsibility

Table S1: Levee system level data summary

	Federally Constructed	Locally Constructed
Maintained by special districts	541 (33.1%)	690 (13.1%)
Maintained by municipalities	535 (32.8%)	614 (11.7%)
Maintained by county	162 (9.9%)	772 (14.7%)
Maintained by state	208 (12.7%)	44 (0.8%)
Other	106 (6.5%)	436 (8.3%)
Unknown	81 (5.0%)	2694 (51.3%)
Having designed protection level from USACE	1591 (97.4%)	667 (12.7%)
Having designed protection level from FEMA	1592 (97.5%)	4849 (92.4%)
Having inspection rating for maintenance quality from USACE	1433 (87.7%)	266 (5.1%)
Total Systems	1633	5250

Note: Summaries are conducted at the levee system level. Federally constructed levees are constructed by USACE. When a levee systems is maintained by multiple local levee sponsors, the highest level of government is used. For example, if both state government and municipal government are local sponsors for the same levee system, this levee is considered maintained by state government. Designed protection level and inspection rating from USACE are accessed from the National Levee Database (NLD). The designed levee protection level from FEMA is obtained via FOIA request. FEMA expands upon NLD by using Fathom-US 2.0 database to associate frequency-based water surface elevations with levee crest profile in order to estimate designed protection.

Back

Levee Responsibility

Table S2: Levee census tract level data summary

	Federally Constructed	Locally Constructed
Maintained by special districts	1960 (41.9%)	533 (21.3%)
Maintained by municipalities	1628 (34.8%)	603 (24.1%)
Maintained by county	377 (8.1%)	371 (14.8%)
Maintained by state	498 (10.6%)	38 (1.5%)
Other	148 (3.2%)	163 (6.5%)
Unknown	71 (1.5%)	798 (31.8%)
Having designed protection data from USACE	4619 (98.6%)	736 (29.4%)
Having designed protection data from FEMA	4610 (98.4%)	2362 (94.3%)
Having inspection rating for maintenance from USACE	4231 (90.4%)	384 (15.3%)
Total Systems	4682	2506

Note: Summaries are conducted at the levee protected census tract level. Federally constructed levees are constructed by USACE. When a levee systems is maintained by multiple local levee sponsors, the highest level of government is used. For example, if both state government and municipal government are local sponsors for the same levee system, this levee is considered maintained by state government. Designed protection level and inspection rating from USACE are accessed from the National Levee Database (NLD). The designed levee protection level from FEMA is obtained via FOIA request. FEMA expands upon NLD by using Fathom-US 2.0 database to associate frequency-based water surface elevations with levee crest profile in order to estimate designed protection.

Back

Theoretical Framework

- Local government's objective function:

$$\max_{m} B(m) - C(m) = f(m) \cdot d \cdot V \; - \; p_m m \qquad (1)$$

$B(m) = f(m) \cdot d \cdot V$: Benefit of maintenance investment; $f(m)$ reduced probability of flooding, d damage ratio, V property value. $C(m) = p_m m$: Levee maintenance cost.

- Subject to budget constraint: $p_m m + \; p_c c + p_k \, I_g \leq tV + T + G$

t property tax rate; V property value; T other own-source revenue; G Intergovernmental transfer.

Lagrangian Formulation: $f(m) \cdot d \cdot V \; - \; p_m m - \lambda \, (p_m m + \; p_c c \; + p_k \, I_g \; - tV - T - G)$

- First order condition and differentiating with respect to housing value V:

$$\frac{dm}{dV} = \frac{\frac{\partial f(m)}{\partial m} \cdot d - \frac{\partial \lambda}{\partial V} \cdot p_m}{-\frac{\partial^2 f(m)}{\partial m^2} \cdot d \cdot V} \qquad (2)$$

Benefit Effect Revenue Effect

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Rehabilitation and Inspection Program (RIP)

- Under Public Law 84-99, active in RIP enrollment: federal money for levee repair post-disaster.
- Annual & Periodic (every five year) inspections by professional engineers conducted for enrolled levee systems. Checklist.
- Results: Acceptable (“A”); Minimally Acceptable (“M”); Unacceptable (“U”).
  M: maximum of two years for correction before inactive RIP; U: immediate inactive RIP.

Federal Program or Activity	Eligible Locally Operated Levee Projects	Disaster-Related Timing of Levee Work	Max. Federal Cost Share	Type of Levee Work Eligible	Significance of Levees' Current Role in Program	Action Required for Levee Project to Access Program	Avg. Program Funding for FY2005-FY2009 (in millions)
Corps—RIP	RIP active levees and well-maintained levees	Post-disaster	100% for federally constructed, 80% for locally constructed	Repair of damage from a natural event	Significant, majority of work funded	Owner applies; Corps evaluates the eligibility and performs the work when funds become available	$1,849

Source: Report from Congressional Research Service (2011).

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Validation

- Validate the identified levee failures against the USACE Levee Loading and Incidence Database (LLID) (Flynn et al., 2021) and news reports about levee breaches.
- Misclassification rate: 4.9%.

Table S3: Manual validation of levee failure

	All Tracts (1)	Filtered Tracts (2)
Confirmed True	156 (46.2%)	143 (70.1%)
Unsure	111 (32.8%)	51 (25.0%)
Confirmed False	71 (21.0%)	10 (4.9%)
Total	338	204

Note: Only events with flood inundation above 25% of a census tract have been manually inspected. Filtered tracts indicate census tracts within FEMA flood map and outside of Florida. Census tracts not included in FEMA flood map tend to be rural areas with few infrastructures. Census tracts in Florida have high levee protection level yet are susceptible to hurricane induced floodings, leading to more prevalent misclassifications of levee failure. "Confirmed True" indicates cases that align with USACE levee loading and incidence database records (Flynn et al., 2021) or news confirming failure at specific locations. "Unsure" indicates cases that are not in USACE records and with news providing information without specified location. "Confirmed False" indicates no failure records in both USACE database and news.

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Motivating Facts: Inequality in Levee Quality

- 1 SD increase in income: 8.3 percent increase in levee protection and 9.6 percent (5.6 percentage point) increase in (minimally) acceptable quality.

	Log(Protection Level)		(Minimally) Acceptable Quality	
	(1)	(2)	(3)	(4)
Log(Per Capita Income)	0.180***		0.122***	
	(0.036)		(0.018)	
Log(Housing Value)		0.193***		0.190***
		(0.030)		(0.015)
Log(Protection Level)			0.131***	0.124***
			(0.011)	(0.011)
Log(Levee Population)	0.087***	0.088***	0.027***	0.023***
	(0.009)	(0.009)	(0.005)	(0.005)
State FE	Yes	Yes	Yes	Yes
Ownership FE	Yes	Yes	Yes	Yes
Floodzone Ratio Control	Yes	Yes	Yes	Yes
Observations	2,915	2,870	2,340	2,300
Adjusted R^2	0.543	0.548	0.443	0.473

consistent sample

Consistent Sample I

	Log(Protection Level)		(Minimally) Acceptable Quality	
	(1)	(2)	(3)	(4)
Log(Per Capita Income)	0.063*		0.122***	
	(0.035)		(0.018)	
Log(Housing Value)		0.140***		0.190***
		(0.029)		(0.015)
Log(Protection Level)			0.131***	0.124***
			(0.011)	(0.011)
Log(Levee Population)	0.072***	0.074***	0.027***	0.023***
	(0.009)	(0.009)	(0.005)	(0.005)
State FE	Yes	Yes	Yes	Yes
Ownership FE	Yes	Yes	Yes	Yes
Floodzone Ratio Control	Yes	Yes	Yes	Yes
Observations	2,340	2,300	2,340	2,300
Adjusted R^2	0.606	0.611	0.443	0.473

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USACE Construction Formula

Figure S2: Example levee project cost-benefit analysis

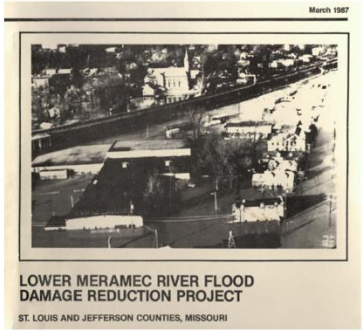

TABLE 3

FLOOD EFFECTS FOR SELECTED EVENTS
EXISTING CONDITIONS
(Meramec River Communities between Miles 0 and 51)

Flood Event[1/]	Number of Structures Flooded	Commercial Damage ($000)	Residential Damage ($000)
2	123	21.5	152.9
5	361	83.7	778.1
10	890	2,024.3	3,107.6
25	1,549	9,085.4	8,187.9
50	1,979	19,939.5	13,354.0
100	2,323	32,775.0	19,177.2
500	3,064	59,751.4	31,141.3
SPF	3,889	76,596.6	42,332.3

1/ Numbers indicate the flood's average recurrence interval in years.

TABLE 11
VALLEY PARK LEVEE
HEIGHT OPTIMIZATION

Level of Protection[1/]	Total First Costs[2/]	Total Average Annual Costs	Total Annual Project Benefits	Average Annual Net Benefits
50	$10,758,000	$ 929,900	$ 849,000	-$80,900
100	$11,775,000	$1,015,100	$1,193,100	$178,000
300	$16,603,000	$1,463,800	$1,379,600	-$84,200
SPF	$23,929,000	$2,101,200	$1,494,200	-$607,000

Notes: Figure sources from USACE 1987 plan formulation document.

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Consistent Sample II

Table S2: Income and history of flood inundation within levees for subset of levees with maintenance quality data

	Times flooded within levees since 2000		
	(1)	(2)	(3)
Log(Per Capita Income)	−0.280**	−0.273*	−0.166
	(0.141)	(0.140)	(0.139)
Floodzone Ratio	0.553***	0.560***	0.545***
	(0.195)	(0.194)	(0.191)
Log(Protection Level)		−0.320***	−0.231***
		(0.075)	(0.075)
Acceptable Quality			−1.185***
			(0.167)
State FE	Yes	Yes	Yes
Ownership FE	Yes	Yes	Yes
Observations	1,700	1,700	1,700
Adjusted R^2	0.260	0.268	0.289

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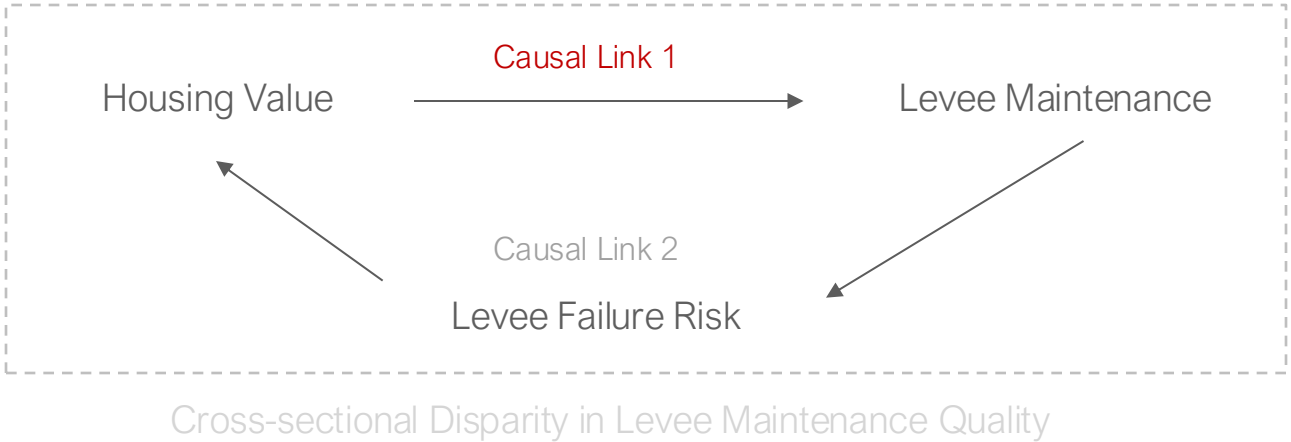
Identifying Feedback Loop

- Identification Challenge: Simultaneity (Reverse Causality)
  - Causal Link 1: Bartik-type Instruments of exogeneous economic shocks.
  - Causal Link 2: Exogenous levee failure shocks.



Housing Value on Levee Maintenance

- Bartik-type instruments: 1980 CZ industry composition × 1980s National industry growth rate.

$$Maintenance_i = \beta\, \Delta H_{i,1980-2019} + \alpha\, H_{i,1980} + \gamma\, DesignProtection_i + \delta\, FloodRisk_i + \epsilon_i$$

Tracts started with the same housing value, designed levee protection, and location flood risk in 1980

$$x_l = \sum_{k=1}^{K} z_{lk,1980}\, g_k$$

Historical Industry composition in 1980

Share (random)

National Industry growth rates after 1980

Shift

randomness

Housing Value on Levee Maintenance

- Bartik-type instruments: 1980 CZ industry composition × 1980s National industry growth rate.

	Specification 1		Specification 2	
	Δ (log housing value) 1980 to 2019 (1)	(Minimally) Acceptable Maintenance (2)	% change housing value 1980 to 2019 (3)	(Minimally) Acceptable Maintenance (4)
First Stage				
Industry Growth IV	36.657***		177.219***	
	(5.966)		(33.996)	
First-stage F	30.542		21.5261	
TSLS				
Housing value change		0.714***		0.150***
		(0.161)		(0.038)
Controls				
1980 home value	Yes	Yes	Yes	Yes
Flood zone ratio	Yes	Yes	Yes	Yes
Levee Population	Yes	Yes	Yes	Yes
Levee Protection	Yes	Yes	Yes	Yes
State FE	Yes	Yes	Yes	Yes
Observations	1,438	1,256	1,438	1,256
Adjusted R^2	0.174	0.372	0.157	0.202

Notes: *p<0.1; **p<0.05; ***p<0.01. US census tract is used as the unit of analysis. Change in log housing value and percentage change in housing value from 1980 and 2019 are presented as Specifications 1 and 2 respectively. In Specification 2, a factional form of change is used (i.e., a value of 1 corresponds to a 100% increase). The Bartik industry growth IVs are constructed using the 1980 industry composition for each of the 722 commuting zones times the national growth rate for each industry in 1980-1990.

79% cross-sectional inequality

- Alternative Bartik-type IVs:
  (1) Technology Shock
  (Computerization; Industry routine work share)
  (2) Trade Shock
  (China shock; Industry import share from China)

  Qualitatively and quantitatively consistent.

alternative iv mechanism

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Bartik IV

- Top 10 industries in Bartik IV: Results robust when using different industries as IV.
- 1980 industry allocation effectively random with respect to flood risk and levee protection.

Table S4: Top ten Rotemberg weight industries

Industry	Weight	National growth rate	Beta	First-stage F
Farm machinery and equipment (311)	0.1460	-0.0492	0.3841	46.3628
			(0.2816)	
Landscape and horticultural services (20)	0.1004	0.1925	0.6791**	15.6159
			(0.2605)	
Blast furnaces, steelworks, rolling and finishing mills (270)	0.0878	-0.0419	-0.1662	2.1930
			(0.7206)	
Guided missiles, space vehicles, and parts (362)	0.0821	0.1009	1.0770*	14.3126
			(0.4718)	
Computer and data processing services (732)	0.0699	0.1083	0.7792**	59.8142
			(0.3711)	
Real estate, including real estate-insurance offices (712)	0.0620	0.0461	0.7303*	33.2234
			(0.4302)	
Coal mining (41)	0.0618	-0.0413	0.5546***	5.3166
			(0.1485)	
Insurance (711)	0.0600	0.0301	0.8170**	5.6968
			(0.3866)	
Hotels and motels (762)	0.0599	0.0497	1.2681**	8.0085
			(0.5268)	
Miscellaneous entertainment and recreation services (810)	0.0582	0.0791	0.9556**	18.3305
			(0.3628)	

Notes: Weight column shows Rotemberg weights, reflecting the importance of each industry in the Bartik IV following Goldsmith-Pinkham et al. (2020). The Beta column shows the TSLS results using the shift-share instrument constructed from each specific industry. The F-stat indicates the corresponding first-stage F-statistic. Standard errors are clustered at the state level.

Table S5: Factors affecting industry share in 1980 for the top ten industries

Industry	Log home value in 1980	Flood zone share	Log levee protection
Farm machinery and equipment (311)	-0.0007	-0.0017	0.0002
	(0.0014)	(0.0025)	(0.0004)
Landscape and horticultural services (20)	0.0002	-0.00003	-0.0003
	(0.0001)	(0.0002)	(0.0002)
Blast furnaces, steelworks, rolling and finishing mills (270)	0.0047	0.0002	-0.0005
	(0.0050)	(0.0012)	(0.0006)
Guided missiles, space vehicles, and parts (362)	-0.0004	0.0013**	-0.0008
	(0.0008)	(0.0006)	(0.0006)
Computer and data processing services (732)	-0.0001	0.00005	-0.0001
	(0.0003)	(0.0003)	(0.0003)
Real estate, including real estate-insurance offices (712)	0.0008	-0.0002	-0.0003
	(0.0005)	(0.0008)	(0.0004)
Coal mining (41)	-0.0003	0.0001	0.0001
	(0.0004)	(0.0009)	(0.0003)
Insurance (711)	-0.0007	0.0010	0.0009
	(0.0009)	(0.0015)	(0.0007)
Hotels and motels (762)	0.0009	0.0017*	0.0010***
	(0.0006)	(0.0010)	(0.0003)
Miscellaneous entertainment and recreation services (810)	-0.00003	0.0005*	-0.0001
	(0.0002)	(0.0003)	(0.0001)

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Bartik IV

Table 6: Alternative IVs: Technology and China Shock

	Specification 1		Specification 2	
	Δ (log housing value) 1980 to 2019	(Minimally) Acceptable Maintenance	% change housing value 1980 to 2019	(Minimally) Acceptable Maintenance
	(1)	(2)	(3)	(4)
Panel A. Technology Shock				
First Stage				
Routine Occupation	3.248***		16.929***	
	(0.464)		(2.640)	
First-stage F	43.406		21.526	
TSLS				
Housing value change		0.740***		0.145***
		(0.139)		(0.029)
Panel B. China Shock				
First Stage				
Import from China	-0.048***		-0.222***	
	(0.016)		(0.093)	
First-stage F	14.329		11.374	
TSLS				
Housing value change		0.548***		0.109**
		(0.203)		(0.043)
Controls				
1980 home value	Yes	Yes	Yes	Yes
Flood zone ratio	Yes	Yes	Yes	Yes
Levee Population	Yes	Yes	Yes	Yes
Levee Protection	Yes	Yes	Yes	Yes
State FE	Yes	Yes	Yes	Yes

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Bartik IV Mechanism

	Changes in Log Revenue from 1977 to 2017			
	Total Revenue	Property Tax Revenue	Federal Transfer	State Transfer
	(1)	(2)	(3)	(4)
Industry Growth IV	50.111***	61.081***	1.613	45.963**
	(13.945)	(17.648)	(31.760)	(20.754)
State FE	Yes	Yes	Yes	Yes
Floodzone share	Yes	Yes	Yes	Yes
Levee population	Yes	Yes	Yes	Yes
Levee protection	Yes	Yes	Yes	Yes
Observations	632	632	632	632
Adjusted R^2	0.157	0.246	0.199	0.201

	Changes in Log State Transfer from 1977 to 2017				
	General Support	Housing & Community Development	Highway	Public Welfare	Other
	(1)	(2)	(3)	(4)	(5)
Industry Growth IV	0.835	−3.455	50.269**	25.722*	21.986
	(21.902)	(15.506)	(21.746)	(13.563)	(28.326)
State FE	Yes	Yes	Yes	Yes	Yes
Floodzone share	Yes	Yes	Yes	Yes	Yes
Levee population	Yes	Yes	Yes	Yes	Yes
Levee protection	Yes	Yes	Yes	Yes	Yes
Observations	632	632	632	632	632
Adjusted R^2	0.546	0.159	0.258	0.210	0.305

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Flooding Event Summary

Table S8: Census tract flooding history summary

# Tracts	83,953
Share of tracts ever flooded	31.40%
Share of tracts ever flooded above 25%	1.81%
Share of tracts flooded above 25% repeatedly	0.59%
Share of tracts ever flooded in levee	2.36%
Share of tracts ever flooded in levee above 25%	0.28%
Share of tracts flooded in levee above 25% repeatedly	0.07%
# Tracts in flood zone	12,340
Share of flood zone tracts ever flooded	59.34%
Share of flood zone tracts ever flooded above 25%	6.67%
Share of flood zone tracts flooded above 25% repeatedly	2.63%
Share of flood zone tracts ever flooded in levee	9.29%
Share of flood zone tracts ever flooded in levee above 25%	1.35%
Share of flood zone tracts flooded in levee above 25% repeatedly	0.23%

Notes: Flood zone tracts indicate more than 25% of land areas within SFHA, without considering the protection effect of levees. If a census tract is moved out of the flood zone due to levees, it is still considered to be in the flood zone.

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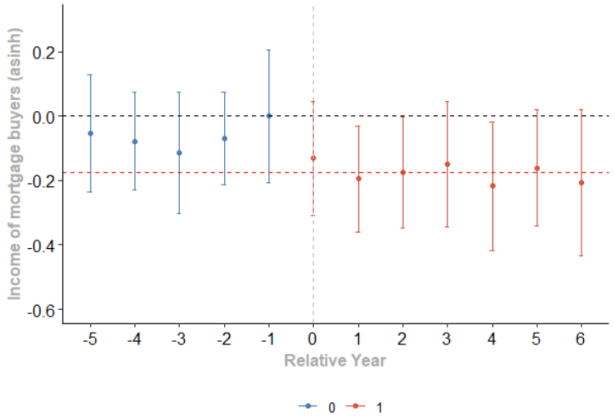
Levee Maintenance on Housing Value

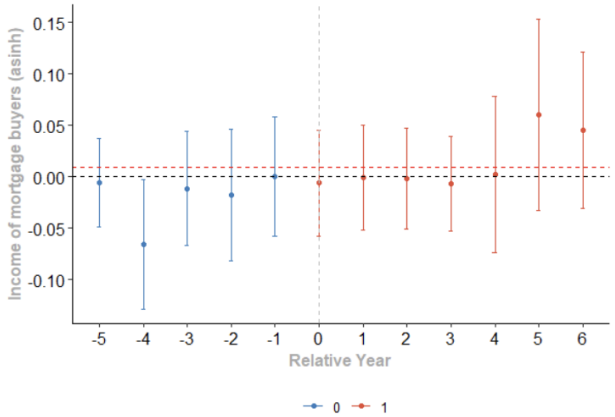
- Income composition: Home Mortgage Disclosure Act (HMDA) Data.
- Negative income sorting: New mortgage buyers are lower income after levee failure; no sorting effect for normal flooding.

Figure 7: Effect of extensive flooding on income of new mortgage buyers

(a) Flooding within levees (levee failure)



(b) Flooding outside levees



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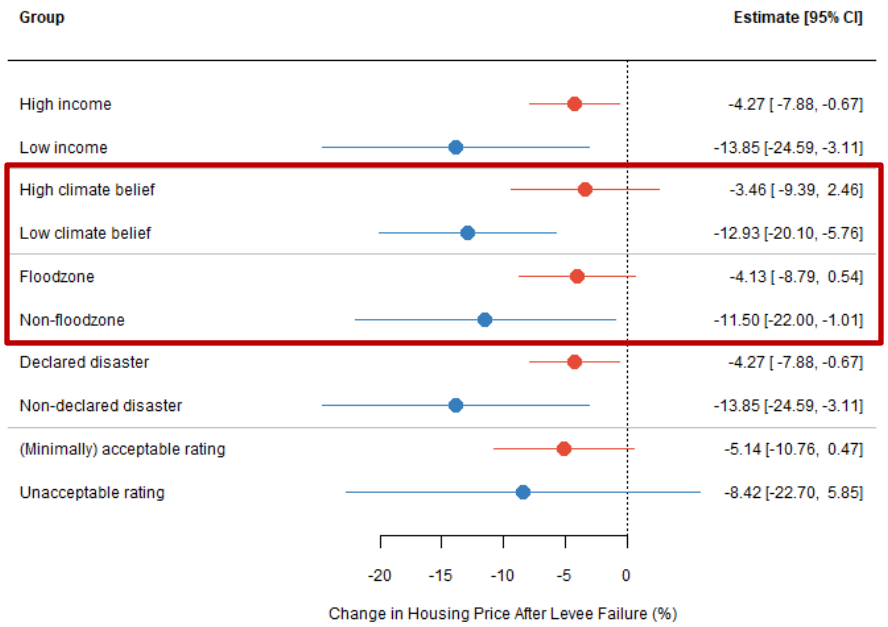
Levee Failure Effect Mechanism



- Suggestive evidence on mechanisms:

(1) Unpriced climate risk

Climate belief

Flood zone status

(2) Fiscal capacity for recovery

Income

Disaster declaration

random forest

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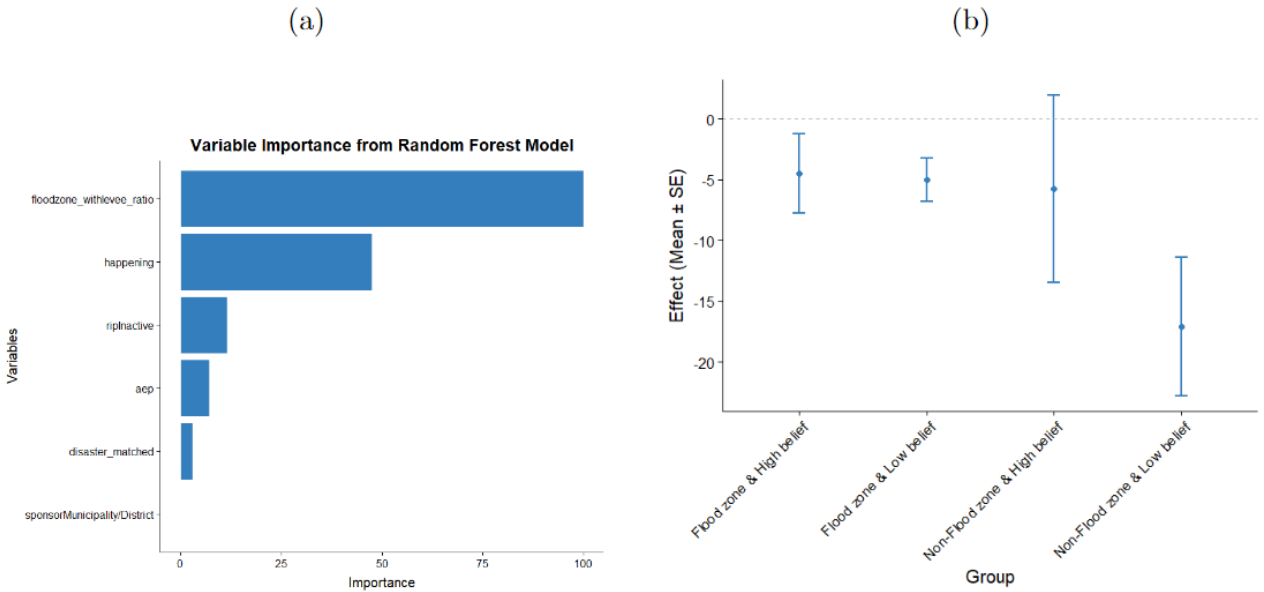
Levee Failure Effect Mechanism

Figure S7: Random forest feature importance selection and sub-group results



Notes: Census tracts with more than 25% area protected by levees and over 25% area in FEMA 100-year flood zone without considering levee protection are kept in the figure. A levee with protection level of 100 is able to withstand 100-year flood.

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