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

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Abstract

When climate infrastructure is financed through local property taxes, infrastructure quality and housing values are mutually dependent. I examine how this interdependence shapes long-term neighborhood dynamics. Using novel data on levee quality and performance, I show that lower-income neighborhoods are disproportionately protected by levees with maintenance deficiencies, raising failure risk. Exploiting exogenous shocks to local economic conditions and levee failures, I find that declining housing values causally degrade levee maintenance, while levee failures reduce housing values and local revenues. These bi-directional dynamics generate a feedback loop of fiscal stress and climate vulnerability, contributing to systematic underinvestment in resilience infrastructure.

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1 Introduction

A longstanding tension in public finance lies between the goals of alleviating budget constraints and aligning incentives. In the context of climate resilience, this trade-off shapes debates over how to finance the construction and maintenance of critical adaptation infrastructure: Should local governments bear the fiscal burden to internalize risk and mitigate moral hazard, or should higher-level governments provide centralized support to promote equity and stabilize public investment? This question, central to the design of social insurance (Shavell, 1979) and fiscal federalism (Oates, 1999), has taken on new urgency under climate change, where infrastructure failures can impose severe economic shocks on vulnerable communities and set off cycles of fiscal distress, disinvestment, and urban decline (Van Nieuwerburgh, 2022).

This paper provides empirical evidence on a feedback loop between housing values and climate infrastructure quality that is amplified when maintenance is financed locally. While recent work has emphasized the potential moral hazard created by federal investments (Henkel et al., 2022), much less is known about the long-run consequences of relying on local fiscal capacity to sustain resilience infrastructure. I study this question in the context of U.S. flood protection levees, which protect 21.3 million people, 6.12 million buildings, and $2.85 trillion in property value (USACE, 2023). Levee construction is often federally cost-shared, and design standards are determined by benefit–cost analysis, resulting in higher protection for higher-value areas. Long-run maintenance, by contrast, is primarily the responsibility of local sponsors like municipalities and special districts—that rely heavily on local property taxes and operate under tight fiscal constraints (ASCE, 2021; Benson, 2022)[1]. As a result, maintenance quality varies widely: 40 percent of levee systems are rated "Unacceptable" by the U.S. Army Corps of Engineers (USACE), indicating risk of failure before reaching their designed protection levels[2]. Despite its importance, little is known about what determines local maintenance quality or its long-run economic consequences. Because levee failures can cause substantial property damage and erode local tax bases—as seen by the 2005 Hurricane Katrina (Pruitt, 2020), 2019 Midwest Flooding (Smith et al., 2019), and 2023 Pajaro River Flooding (Rust and James, 2023)—maintenance that depends on local economic conditions may reinforce a feedback loop between infrastructure quality and neighborhood economic decline.

[1] According to the National Levee Database (NLD), 23.7% levee systems (65.1% levee protected census tracts) are federally constructed. Both federally and locally constructed levee systems are primarily maintained by local sponsors, with 80% of levee systems managed by municipalities and special districts (see Figure S3, Table S1 and Table S2 for detailed levee responsibility).

[2] Throughout the paper, levee failure refers to flood inundation within levee-protected areas.

Identifying the feedback loop empirically is challenging because infrastructure quality and realized performance are rarely observed jointly at scale. I overcome this challenge by assembling a novel dataset that links designed protection standards, maintenance quality, and flood outcomes for levees nationwide. Specifically, I merge the engineered protection levels of levees from FEMA's Risk Rating 2.0 database obtained through the Freedom of Information Act (FOIA) [3] with the maintenance inspection records from the USACE National Levee Database [4]. I then spatially link these system-level levee quality measures to satellite-based measures of actual inundation within levee-protected areas at 250-meter resolution spanning 103 major flood events since 2000 to track realized levee performance. This integration enables the first national analysis linking maintenance quality to realized performance within the same flood protection systems while controlling for designed protection.

I begin by documenting cross-sectional patterns in levee quality. Consistent with the federal benefit–cost framework, a one standard deviation increase in housing value is associated with a 10 percent increase in designed protection levels. Higher-value neighborhoods are also substantially more likely to receive adequate maintenance: a one standard deviation increase housing value is associated with an 18 percent (11 percentage point) increase in the probability of receiving an acceptable or minimally acceptable maintenance rating. The maintenance-value gradient is substantially stronger for levees managed by municipalities and special districts than those involved higher levels of government, suggesting the potential importance for local fiscal capacity beyond value of protection. Using satellite-based measures of realized performance, I show that maintenance deficiencies substantially increase levee failure risk and account for a large share of the observed income gradient in failure exposure. Controlling for maintenance quality reduces income-based disparities in failure risk by 32 percent and renders them statistically insignificant.

While the descriptive evidence establishes a strong association between neighborhood housing values and levee maintenance quality, the direction of causality remains unclear. To identify the causal effect of local economic conditions on levee maintenance, I exploit exogenous variation in housing value growth generated by the national computerization shock of

[3] While the NLD reports annual exceedance probability (AEP)—the probability that floodwater levels exceed a given threshold in any given year—for some levees, coverage is highly incomplete for locally constructed levees. FEMA's Risk Rating 2.0 data extend engineered protection level measurement to over 90% of levee systems by integrating frequency-based flood surface elevations with levee crest profiles (Tables S1 and S2).

[4] The inspection records classify maintenance quality as "Acceptable", "Minimally Acceptable", or "Unacceptable". USACE conducts regular inspections of levees within its portfolio to determine eligibility for the Rehabilitation and Inspection Program (RIP), which provides federal assistance for post-disaster levee repair. More details are in the Data section.

the 1980s. Commuting zones with greater pre-existing routine task intensity in 1950 were differentially exposed to subsequent information technology adoption, generating higher growth in housing value and property tax revenue. I use a Bartik-style instrument based on this technology shock to isolate variation in housing value growth orthogonal to levee quality and flood risk[5]. The 2SLS estimates indicate that a 10 percent increase in housing values raises the probability of receiving a (minimally) acceptable maintenance rating by approximately 1.5 percentage points (2.6 percent), comparable in magnitude to the cross-sectional relationship.

These maintenance disparities may, in turn, affect local economic conditions. To identify this reverse channel, I exploit quasi-random levee failures over the past two decades. To distinguish the effect of infrastructure failure from flooding itself, I also estimate impacts for flood events in areas without levee protection. Consistent with prior research, flooding alone has only transitory changes in housing values. In contrast, levee failures reduce housing prices by 3–9 percent, with no evidence of recovery over the six-year post-event window, and induce negative income sorting. I find suggestive evidence that these housing market responses translate into local fiscal impacts: municipal total revenue declines by 5.8 percent following levee failures, with property tax losses exceeding post-disaster intergovernmental transfers. The resulting revenue shortfall reduces local expenditures and constrains post-disaster capital outlays[6].

Local maintenance of levees has been a subject of ongoing congressional debate, yet no consensus has been reached on how responsibility should be shared across levels of government (Keegan et al., 2011). Understanding the consequences of local fiscal reliance is increasingly important in light of the federal government's recent pullback from climate resilience spending. My results suggest that when maintenance depends on local economic conditions—whether because of local fiscal capacity or value of protection—housing markets and infrastructure quality can become mutually reinforcing. Under decentralized financing, this feedback is particularly strong as changes in property values directly affect the resources available for future maintenance. Beyond equity concerns, the outcomes appear economically important: I estimate an average benefit-cost ratio of 9 for levee maintenance under conservative assumptions, yet 34.8 percent of levees with positive net present value remain

[5]Housing value serves as a summary measure of local economic conditions—capturing income, employment, amenities, etc.—and as a direct proxy for fiscal capacity given local governments' reliance on property taxes (Table S11)

[6]While data on special districts are limited, their greater reliance on property taxes and more limited access to federal funding suggest that these estimates likely a lower bound.

under-maintained, disproportionately in low-income, fiscally constrained neighborhoods. A back-of-envelope calculation implies annual efficiency losses of at least $282 million (2019 USD), a figure likely to grow as climate change intensifies.

This paper contributes to three threads of literature. First, it contributes to the growing body of research on the economic impacts of climate risk and adaptation. Closest to this project, recent work examines how levees, wetlands, and other flood control infrastructures affect insurance take-up (Vinnakota and Ziff, 2025), insurance claims (Taylor and Druckenmiller, 2022), and real estate values (Fell and Kousky, 2015; Bradt and Aldy, 2022; Hsiao, 2023; Kelly and Molina, 2023). There is also a growing literature that uses dynamic spatial equilibrium models to study how public investments in climate adaptation infrastructure may generate moral hazard by encouraging development and population growth in high-risk areas (Balboni, 2025; Ouazad and Kahn, 2025; Hsiao, 2023). These studies primarily focus on new construction, while this is the first study to look at long-term maintenance, an increasingly urgent issue with aging infrastructures.

More broadly, this paper adds to literature on the urban economic impacts of climate risk. Prior research shows that flood risk affects insurance and housing prices (Bin and Landry, 2013; Atreya et al., 2013; Gallagher, 2014; Ortega and Taşpınar, 2018; Bernstein et al., 2019; Murfin and Spiegel, 2020; Gourevitch et al., 2023; Graff Zivin et al., 2023), household finance (Gallagher and Hartley, 2017; Deryugina et al., 2018; Billings et al., 2022), and local public finance (Shi and Varuzzo, 2020; Liao and Kousky, 2022; Jerch et al., 2023; Chen, 2020; Miao et al., 2024). Structural spatial equilibrium models have further documented the macroeconomic and welfare impacts of climate change across locations and implications for optimal adaptation (Desmet et al., 2021; Cruz and Rossi-Hansberg, 2024; Bilal and Rossi-Hansberg, 2023; Fried, 2022). While much of this literature focuses on the direct impacts of climate risk exposure, this paper emphasizes how adaptation infrastructure mediates these impacts. In particular, protective infrastructure may amplify the economic impacts of flooding by generating a false sense of security (the "new news" effect) (Holtermans et al., 2024; Ding et al., 2023) [7], crowding out private adaptation (Vinnakota and Ziff, 2025; Bradt et al., 2021; Weill, 2022), or imposing larger post-disaster fiscal burdens for capital outlays (Jerch et al., 2023), thereby magnifying economic impacts when protection systems fail.

[7] Although previous research does suggest information provision can facilitate risk capitalization before disasters (Hino and Burke, 2020; Gourevitch et al., 2023; Lee, 2023; Ostriker and Russo, 2024; Mulder and Kousky, 2023), households are generally uninformed about residual risk behind levees (Ludy and Kondolf, 2012), and USACE levee inspection results are mainly communicated to local levee sponsors instead of the public (US Army Corps of Engineers, 2024).

Second, the paper contributes to the literature on local public goods provision and infrastructure finance. A long-standing body of work has examined the efficiency and distributional implications of decentralized public goods provision (Tiebout, 1956; Oates, 1972; Hamilton, 1975; Glaeser, 2013), as well as the local economic impacts of infrastructure investment (Aschauer, 1989; Baum-Snow et al., 2005; Cellini et al., 2010; Winston, 2013). More recent studies have documented widespread underinvestment in infrastructure maintenance across sectors, including roads, schools, and utilities (Kahn and Levinson, 2011; Gertler et al., 2024; McRae, 2015; Filardo et al., 2019; Herold, 2024). These patterns are often attributed to short-term fiscal constraints (Bumgarner et al., 1991; Swanstrom et al., 2002; Kim and Ebdon, 2021) or political incentives (Pagano, 2008; Bock and Blemings, 2024). I contribute to this literature by showing that maintenance underinvestment can emerge endogenously through a feedback loop between infrastructure quality, property value, and local fiscal capacity. This dynamic also connects to the urban decline literature, which emphasizes how fiscal distress and disinvestment reinforce one another in economically disadvantaged areas (Glaeser and Gyourko, 2005; Beauregard, 2006; Brueckner and Helsley, 2011; Beauregard, 2013).

Third, this paper contributes to the literature on environmental and social justice. A large body of research has shown that low-income and minority communities are disproportionately exposed to environmental risks (Qiang, 2019; Hausman and Stolper, 2021; Currie et al., 2023; Vahedifard et al., 2023; Galster et al., 2024), often attributed to individual behaviors such as residential sorting (Bakkensen and Ma, 2020; Bakkensen and Barrage, 2022; Bernstein et al., 2022) or unequal access to private adaptation (Sun et al., 2017; Bradt et al., 2021). I extend this work by identifying a collective, structural mechanism: decentralized fiscal systems systematically constrain public resilience investment in disadvantaged areas, reinforcing inequality in climate exposure through feedbacks. This mechanism complements broader research on spatial inequality in public goods such as education and local services (Bénabou, 1996; Fernandez and Rogerson, 1996; Swanstrom et al., 2002; Chetty and Friedman, 2010; Zheng and Graham, 2022), and provides empirical groundings for models of cumulative disadvantage driven by neighborhood feedback dynamics (Durlauf, 1995, 1996; Lundberg and Startz, 1998). A distinct feature of the climate context is that disasters impose acute negative shocks to property markets, accelerating disinvestment and amplifying the long-run consequences of initial disparities.

2 Data

2.1 Levee Quality Data

Levees are a key component of flood protection infrastructure in the United States, with over 7,000 levee systems covering more than 22 percent of US counties (ASCE Inter-Institute Levee Committee, 2010; USACE, 2023). I obtain levee data from the National Levee Database (NLD), developed by the U.S. Army Corps of Engineers (USACE) (USACE, 2023) [8]. The NLD includes geographic location, design characteristics, sponsor type, maintenance inspection ratings, construction year, and population and property protected by the system.

Levee quality has two dimensions: the designed protection level and maintenance condition. Designed protection levels vary greatly across system, ranging from 50% to 0.02% annual exceedance probability (AEP)—the probability that floodwater levels exceed a given threshold in any given year (Figure 3a). The actual performance of levees critically depends on long-term maintenance. Most levees were built between 1940 and 1980 (Bradt and Aldy, 2022), and many exhibit substantial deterioration(ASCE, 2021).

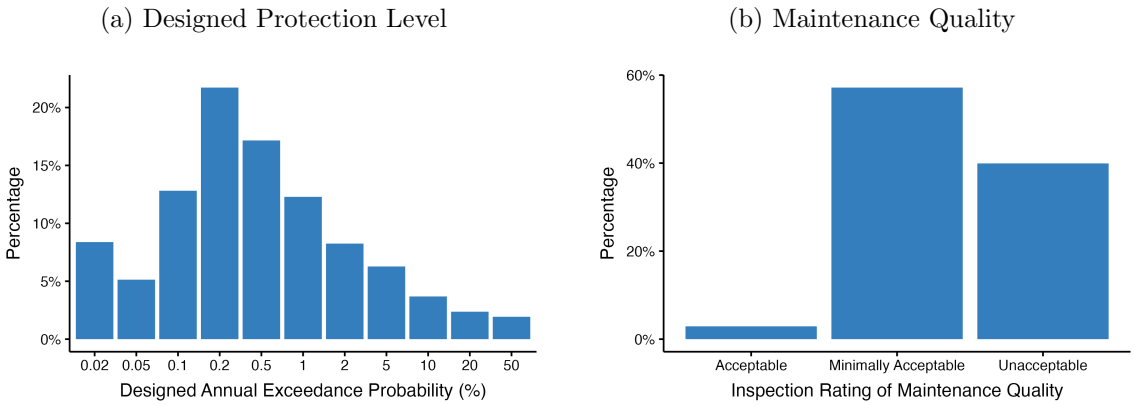
Maintenance quality is assessed through USACE's Rehabilitation and Inspection Program (RIP) [9]. Levees are rated as "Acceptable", "Minimally Acceptable", or "Unacceptable". A rating of "Unacceptable" indicates serious maintenance deficiencies that may cause the system to fail in flood and renders it ineligible for federal assistance unless corrected. According to the 2023 National Levee Database, 2.9 percent of levees are rated "Acceptable", 57.1 percent "Minimally Acceptable", and 40.0 percent "Unacceptable" (Figure 3b).

While the NLD includes both federally and locally constructed levees, coverage for locally constructed systems is limited: only 12.7 percent have design-level data, and just 5.1 percent have maintenance ratings (Table S1, S2). To fill these gaps, I submitted Freedom of Information Act (FOIA) requests to FEMA to obtain levee overtopping risk estimates from Risk Rating 2.0, based on the Fathom-US 2.0 model (FEMA, 2022). These data extend protection-level coverage to 92.4 percent of locally constructed levees and 94.3 percent of levee-protected tracts. Maintenance data gaps persist, and because locally maintained

[8] I accessed the NLD API portal in 2023 to collect the most recent information for each levee by that time.

[9] Under Public Law 84-99, the USACE supports local repair efforts through the RIP, which covers 100% repair costs for federally constructed and 80% for locally constructed levees. Levees must have been inspected and be "Active" in RIP status before the flood to qualify for post-disaster assistance (USACE, 2006).

Figure 1: Quality of US flood protection levees



Notes: Data sources from the National Levee Database (NLD). Designed annual exceedance probability of 1% indicates designing to protect against 100 year floods. Inspection rating is from the routine inspection to determine eligibility for the Rehabilitation and Inspection Program. USACE sends engineers to conduct visual inspections on levees to give categorical rating on maintenance quality.

systems are less likely to be inspected and generally lower in quality, my estimates likely understate the true extent of maintenance deficiencies.

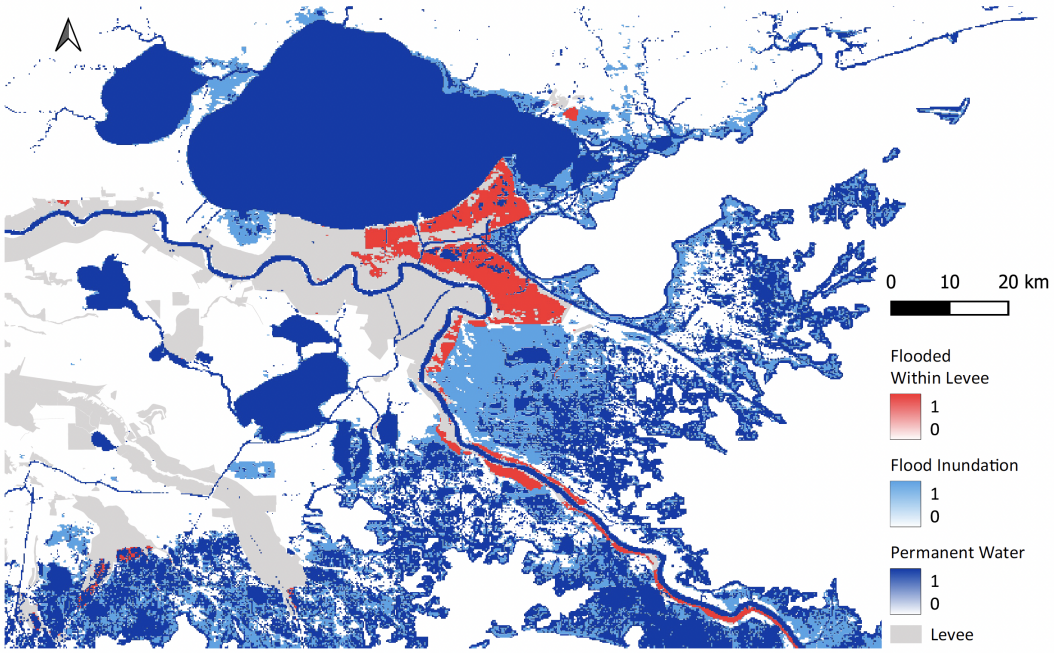
2.2 Levee Performance Data

To measure historical levee performance, I construct a levee failure database using satellite-based flood detection. Following the approach of Tellman et al. (2021), I use Moderate Resolution Imaging Spectroradiometer (MODIS) satellite imagery and Google Earth Engine to detect inundation at 250-meter resolution for 103 major flood events from 2000 to 2021. For 2000–2018, I use Tellman's publicly available flood maps. For 2019–2021, I identify major flood events from the Dartmouth Flood Observatory and apply their water detection algorithm, using 3-day standard algorithms and empirically derived thresholds to the short-wave-infrared, near-infrared, and red bands (bands 7, 2, and 1) from MODIS [10].

I define levee failure as flood inundation within levee-protected areas, driven either by over-topping (hydrological failure) or breaching (structural failure). The largest flood events in levees occurred in 2008, 2019, and 2015 due to Midwest floods (Figure S1a), while Hurricane Katrina (2005) affected the largest population (Figure S1b). Figure 2 illustrates detected flood inundation within levee boundaries during Katrina. The method accurately captures major failures in New Orleans and is applied to other flooding events nationwide.

[10]This approach has been validated against 30 meter resolution Landsat scenes, achieving an accuracy of 83%. Some events may be missed due to cloud cover, flash flooding, or urban canopy.

Figure 2: Flood inundation and levee failure mapping for Hurricane Katrina



Notes: Dark blue areas show permanent water. Light blue areas show flood inundation. Grey areas show levee-protected areas. The red color shows locations with flood inundation inside levee systems. The map is made by the author using QGIS.

When constructing the levee failure database, I exclude flood events affecting fewer than 10 pixels ($0.625km^2$) to reduce false positives. For estimating economic impacts of levee failures, I further focus on large events in which inundation affects at least 25% of a census tract's area. I validate the resulting failure classifications of these major events against the USACE Levee Loading and Incidence Database (LLID) (Flynn et al., 2025) and news reports (Table S3). Among classified failures, 13.7% lack corroboration from either source, driven primarily by hurricane-induced drainage issues in Florida and undocumented flooding in rural tracts outside FEMA's flood zone mapping. Restricting to tracts outside Florida with valid flood zone data reduces the unconfirmed share to 4.5%. The main analysis therefore excludes Florida and non-FEMA-mapped tracts; results are robust to their inclusion. Using AI to replace manual validation gives higher confidence on the classification results: It confirms 90.3% of classified failures directly, identifies a further 5.1% as consistent with documented large-scale flooding at the relevant location and time, and finds no supporting evidence for only 4.5% of observations.

2.3 Local Economic Data

Neighborhood Socio-economic Data I use 2019 American Community Survey (ACS) data at the census tract level to measure per capita income and median housing value [11]. For long-run housing value trends, I use 1980 data from the U.S. Decennial Census, normalized to 2010 tract boundaries using the area-weighted crosswalk from Lee and Lin (2018). These variables underpin the Bartik-style technology-shock instruments. Historical industry shares (1980) and national growth rates are compiled at the US commuting zone level for 3-digit IND1990 industries, following (Goldsmith-Pinkham et al., 2020; Autor et al., 2013). The dataset includes 228 industries and 722 commuting zones in the continental US.

Housing Price Index I track housing price dynamics using the Federal Housing Finance Agency (FHFA) Housing Price Index (HPI), a repeat-sales index available annually at the census tract level since 1975 [12]. Unlike commercial transaction datasets (e.g., Zillow, CoreLogic), the FHFA HPI data is based on mortgage data and thus is not affected by state-level housing transaction price disclosure rules. This feature is particularly important for Midwestern states reliant on levee protection, such as Louisiana, Mississippi, and Missouri, where transaction data are limited due to non-disclosure regulations (Nolte et al., 2021).

Local Public Finance I collect municipal-level data from the U.S. Census of Governments (1967–2017) to evaluate fiscal impacts of levee failure.[13] The dataset includes detailed revenue and expenditure data, and is the most comprehensive source of local government finance in the U.S. (Pierson et al., 2015). I focus on municipalities and townships, which rely heavily on property taxes. Because the local government surveys are most complete for years ending in "2" or "7," I structure the fiscal analysis using five-year intervals.

2.4 Flood Risk Data

Flood risk exposure is measured using FEMA's Special Flood Hazard Areas (SFHAs), also known as 100-year flood zones. To reflect baseline exposure rather than post-adaptation status, I reclassify areas removed from SFHAs due to levee protection as flood-exposed. I supplement these data with property-level flood risk estimates from the First Street Foundation (FSF), aggregated to the tract level. FSF assigns flood risk scores (on a 1–10 scale) to individual properties based on elevation, location, and existing adaptation measures. I

[11] I used 2019 data to avoid pandemic-related distortions. Results are robust to using 2021 ACS data.

[12] see https://www.fhfa.gov/data/hpi

[13] While the Census of Governments also covers special districts, including levee districts, those data are incomplete. For instance, most fiscal records for Louisiana's levee districts end in 1986.

compute the tract-level average flood risk score to capture residual flood risk conditional on levee protection.

Table 1: Summary statistics

	Unit	Mean	SD	N
Panel A. Socio-economic data				
Per capita income	census tract	33,468.060	17,656.704	73,250
Median housing value	census tract	271,248.828	246,013.461	71,958
Panel B. Levee and flood risk data				
Levee protection	levee system	304.694	734.152	6,503
Levee maintenance (unacceptable quality)	levee system	0.400	0.490	1,717
Levee failure experience	levee-dependent tract	0.137	0.344	4,687
Flood zone share	census tract	0.124	0.199	69,891
First Street Foundation average flood risk score	census tract	1.964	1.257	84,784
Panel C. Economic outcome (panel data)				
Housing Price Index	census tract	206.466	132.998	1,912,118
Total revenue	municipality/ town	20,658.879	592,824.608	742,497
Property tax revenue	municipality/ town	4,306.105	112,728.131	742,497
Intergovernmental transfer revenue	municipality/ town	4,604.192	184,165.068	742,497
Total expenditure	municipality/ town	20,967.749	612,178.370	742,497
Capital outlay expenditure	municipality/ town	3,213.985	79,612.123	742,497

Notes: Summary statistics are presented at the raw data level. Socio-economic data is from 2019 American Community Survey. Levee protection and maintenance data are from USACE and at the levee system level. Levee maintenance is a dummy variable indicating acceptable or minimally acceptable maintenance quality. Levee failure history data is from satellite imagery and at the census tract level for levee-dependent communities (i.e., with more than 25% land areas protected by levee systems). It is represented as a dummy variable indicating whether a tract has experienced levee failure since 2000. Flood zone share from the FEMA flood map and First Street Foundation flood risk data are all at the census tract level. Flood zone indicates 100-year flood zone without considering the levee protection effect (i.e., if an area is moved out of the flood zone due to levee, it is still considered within the flood zone). Housing price index (HPI) from the Federal Housing Finance Agency (FHFA) is a yearly panel data at the census tract level from 1975 to 2022. Municipal finance data from the Census of Local Government are from 1967 to 2017 at five-year intervals (Pierson et al., 2015), with municipality/town as the unit of observation. Revenue and expenditure variables are reported in thousands of US dollars.

2.5 Measurement Units

The empirical analysis combines data measured at different geographic and institutional levels (Table 1). The primary unit of analysis is the census tract, which approximates a neighborhood-level housing market. Housing values, income, flood risk, flood zone exposure,

and historical floodings are all measured at this level. Each tract is classified by whether it is protected by a levee by overlaying with levee systems, and protected tracts are assigned the design protection level and maintenance quality of the corresponding levee system. I use census tracts because flood risk, flood exposure, and housing market outcomes vary substantially within levee systems. Aggregating to the levee system level would mask this heterogeneity and attenuate estimates of the effects of localized flooding and levee failures.

Two analyses use alternative units of observation or inference. First, because levee maintenance is administered by levee sponsors (e.g., municipalities, levee districts, and, in some cases, county, state, or federal agencies) and fiscal outcomes are measured only at the sponsor level, analyses of public finance use the sponsor as the unit of observation (e.g., Table 6 and Figure 8). These analyses focus primarily on municipalities and towns because fiscal data for levee districts are limited. Second, the analysis of the effect of local housing values on levee maintenance exploits economic shocks defined at the commuting zone (CZ) level following Autor and Dorn (2013). Because treatment varies at the CZ level, standard errors are clustered at the commuting zone rather than the census tract level.

3 Motivating Facts: Inequality in Levee Quality

Flood protection levees are critical adaptation infrastructure, yet their quality varies substantially across U.S. neighborhoods. Using levee quality measures introduced in the Data section, I document systematic disparities across communities with differing economic conditions.

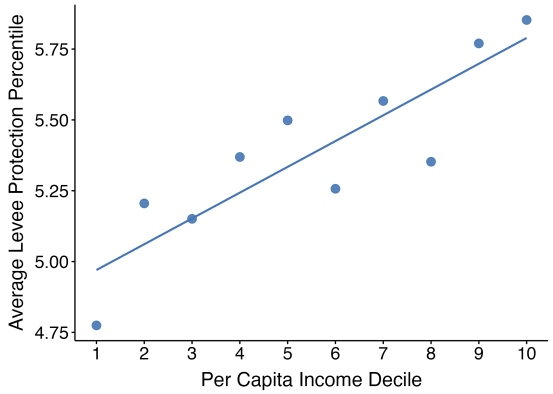
Descriptive evidence reveals that census tracts with lower income and housing values are more likely to be protected by levees with lower design standards and poor maintenance (Figure 3). Among tracts dependent on levees for flood protection, lower income tracts are disproportionately behind levees with lower designed protection levels (Figure 3a) and more likely to have unacceptable maintenance quality (Figure 3c). These disparities are even more pronounced when using housing value—more directly linked to the property tax base—as a measure of local economic status (Figure 3b and Figure 3d).

The income gradient in designed protection levels attenuates once we control for state fixed effects, flood risk exposure, and the population protected by each levee (Table 2) [14]. In

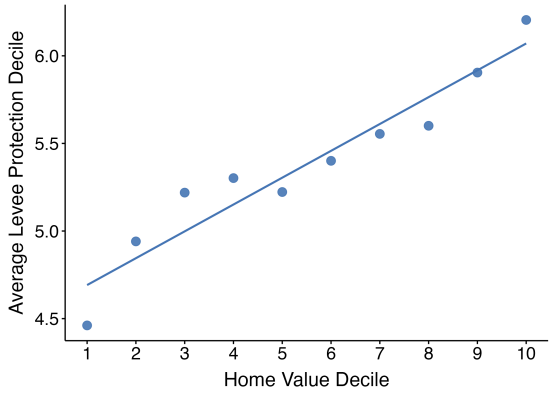
[14] In the full sample that includes levees without maintenance ratings, the income gradient in protection

Figure 3: Relationship between levee quality and income/ home value

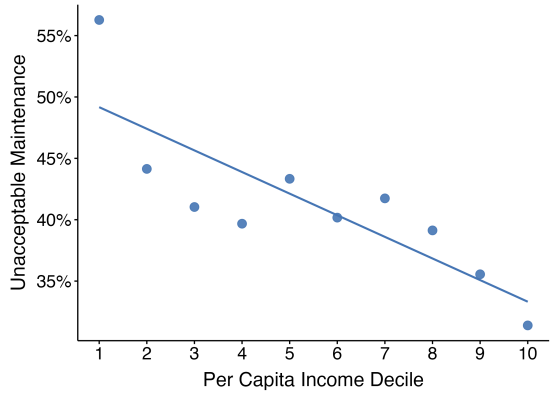
(a) Per Capita Income and Designed Protection



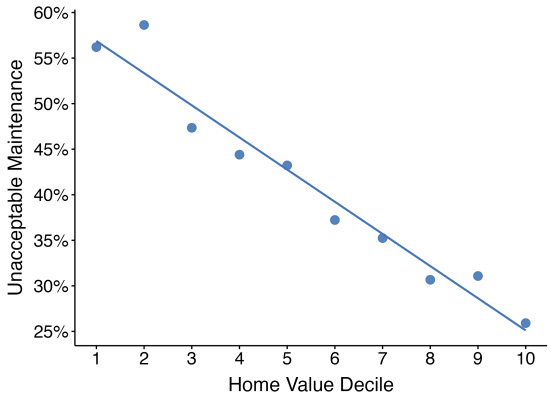
(b) Median Home Value and Designed Protection



(c) Per Capita Income and Maintenance Quality



(d) Median Home Value and Maintenance Quality



Notes: The unit of analysis is the census tract. Income and home value data are from the 2019 American Community Survey; levee protection levels are from FEMA Risk Rating 2.0 levee database and maintenance quality ratings are from the inspection records in the USACE National Levee Database. The sample is restricted to levee-reliant communities, defined as tracts with more than 25% of land protected by levees. Income, housing value, and protection level deciles are computed within state to account for cross-state variation in flood risk and levee design. Figure S4 shows the distribution of income across absolute levee protection levels in California and Louisiana, the two states with the largest number of levee systems. While California's levees levees predominantly provide 100-200 year flood protection and Louisiana's 500-1000 year protection, the income gradient is evidence within both state. The original categories of the inspection records of maintenance include "Acceptable","Minimally Acceptable", and "Unacceptable", with proportions summing to 100%. Figure S5 shows the income distribution for each of these original maintenance rating categories.

contrast, disparities along the maintenance margin remain pronounced. Conditional on designed protection level, higher-income and higher-value neighborhoods are significantly

remains statistically significant (Table S5). Levees missing maintenance records are disproportionately locally constructed systems, for which local economic conditions may play a larger role in determining initial design standards. Maintenance responsibilities primarily fall on local sponsors regardless of whether the levees are federally or locally constructed.

more likely to have levees rated at least minimally acceptable. Quantitatively, a one standard deviation increase in log income (0.442) is associated with a 2.3 percent increase in designed protection and a 6.5 percent (3.8 percentage point) increase in the probability of having levees of (minimally) acceptable maintenance quality [15]. Housing value exhibits greater explanatory power for both designed protection and maintenance quality.

Table 2: Levee quality and neighbourhood socio-economic conditions

	Log(Protection Level)		(Minimally) Acceptable Quality	
	(1)	(2)	(3)	(4)
Log(Per Capita Income)	0.052		0.086***	
	(0.034)		(0.017)	
Log(Housing Value)		0.136***		0.146***
		(0.031)		(0.014)
Log(Levee Population)	0.081***	0.077***	0.038***	0.035***
	(0.016)	(0.016)	(0.006)	(0.005)
State FE	Yes	Yes	Yes	Yes
Protection level FE	No	No	Yes	Yes
Floodzone ratio control	Yes	Yes	Yes	Yes
Observations	2,300	2,300	2,300	2,300
Adjusted R^2	0.606	0.610	0.536	0.553

Notes: *p<0.1; **p<0.05; ***p<0.01. The unit of observation is the census tract. Levee protection is measured by return period (e.g., 500-year protection). Maintenance quality is a binary indicator equal to 1 if the levee is rated as "Acceptable" or "Minimally Acceptable". Per capita income and median housing value are from the 2019 American Community Survey. Population refers to number of residents protected by levees based on the National Levee Database. The sample is restricted to levee-reliant tracts, defined as more than 25% of land area protected by levees, and to tracts with data on maintenance quality. Results are robust without restricting the sample to tracts with non-missing maintenance data (Table S5).

The stronger relationship with housing values is consistent with institutional features of levee provision. For design protection, disparities likely reflect the cots-benefit framework used in levee construction. In federally built systems, USACE selects protection levels that maximize the benefit–cost ratio, where benefits are largely measured as avoided property damage. Areas with higher property values therefore generate larger measured benefits and are more likely to receive higher designed protection [16]. Maintenance, however, is predominantly the

[15] Calculated as $0.442 \times 0.086/0.585$, where 0.585 is the sample mean of (minimally) acceptable maintenance quality.

[16] See Figure S2 for an example of a USACE cost-benefit analysis.

responsibility of local sponsors, except in limited cases involving federal navigation (Figure S3). Among levees with similar design standards, variation in maintenance quality is plausibly linked to differences in local fiscal capacity. Because property taxes are the primary revenue source for most local sponsors, housing values directly impact the resources available for long-term maintenance.

Consistent with this interpretation, heterogeneity by local sponsorship type reveals that economic disparities in maintenance quality are concentrated among levees maintained by municipalities and special districts (Table 3). According to 2017 Census of Governments, municipalities derive a median of 30% of total revenue (42% of own-source revenue) from property taxes, and levee districts rely on property taxes for over 90% in both revenue categories. In contrast, levees sponsored by the USACE, or co-sponsored by state or county governments with access to broader tax bases, exhibit weaker housing value and income gradient.

To assess whether disparities in levee quality translate into differential exposure to failure [17], I examine the relationship between income and levee failure (Table 4). Lower-income communities are significantly more likely to experience levee failure after controlling for natural flood risk (Column 1). Controlling for designed protection levels explains part of this disparity (Column 2), as higher-income neighborhoods are more likely to be protected by levees built to withstand severe floods, but a sizable income disparity in failure remains. However, once maintenance quality is added (Column 3), the income coefficient declines by 32 percent and becomes statistically insignificant. This suggests that maintenance deficiencies are a key driver of income-based disparities in failure risk. Column 4 replaces the continuous protection level controls with protection-level fixed effects to address concerns about correlation between designed protection and maintenance quality. The results are quantitatively similar.

Taken together, the descriptive evidence reveals substantial disparities in levee quality across neighborhoods with different economic conditions. Conditional on designed protection levels, lower-income and lower-housing-value tracts are more likely to face elevated failure risk due to poor levee maintenance. Because levee failure can depress housing values and weaken the local tax base, these disparities could lead to a neighborhood-level feedback loop. In

[17] Throughout the manuscript, levee failure is defined as flood inundation with in levee-protected areas could be driven by both overtopping and breaching.

Table 3: Economic inequality in levee maintenance quality by sponsorship

	(Minimally) Acceptable Quality			
	(1)	(2)	(3)	(4)
Log(Housing Value) × Local	0.173***	0.146***		
	(0.016)	(0.016)		
Log(Housing Value) × Federal/State/County	0.067**	0.054*		
	(0.030)	(0.028)		
Log(Per Capita Income) × Local			0.133***	0.099***
			(0.017)	(0.018)
Log(Per Capita Income) × Federal/State/County			0.073*	0.053
			(0.042)	(0.037)
Log(Levee Population)	0.017***	0.031***	0.017***	0.031***
	(0.005)	(0.005)	(0.005)	(0.005)
Log(Protection Level)	0.126***		0.134***	
	(0.014)		(0.014)	
Sponsor type indicator	Yes	Yes	Yes	Yes
State FE	Yes	Yes	Yes	Yes
Protection level FE	No	Yes	No	Yes
Floodzone ratio control	Yes	Yes	Yes	Yes
p-value: Local = Federal/State/County	0.001	0.002	0.183	0.256
Observations	2,288	2,288	2,288	2,288
Adjusted R^2	0.532	0.586	0.516	0.573

Notes: *p<0.1; **p<0.05; ***p<0.01. Unit of analysis is the U.S. census tract. Income and housing value are from the 2019 American Community Survey. The dependent variable is a binary indicator equal to 1 if the levee is rated as "Acceptable" or "Minimally Acceptable" maintenance quality. The sample is restricted to levee-dependent tracts, defined as tracts with more than 25% area protected by levees. Sponsor classifications are from the National Levee Database. "Federal/State/County" includes levees that sponsored by USACE or locally sponsored levees with involvement from state or county governments."Municipality" includes both cities and towns. "Special district" refers to levee, water, or flood control districts. Levee systems with multiple sponsors are assigned to the highest-level entity (e.g., state takes precedence over municipal). Regressions control for levee protection levels to account for variation in initial design standards.

the next section, I move beyond descriptive patterns to formally examine the bi-directional causal relationship between local economic conditions and maintenance quality.

Table 4: Income and history of flood inundation within levees

	Times flooded behind levee since 2000			
	(1)	(2)	(3)	(4)
Log(Per Capita Income)	-0.286**	-0.300**	-0.203	-0.218
	(0.137)	(0.136)	(0.141)	(0.141)
Floodzone Ratio	0.559***	0.582***	0.572***	0.610***
	(0.205)	(0.205)	(0.202)	(0.205)
Log(Protection Level)		-0.296***	-0.209**	
		(0.082)	(0.083)	
Acceptable Quality			-1.122***	-1.177***
			(0.271)	(0.275)
State FE	Yes	Yes	Yes	Yes
Protection level FE	No	No	No	Yes
Observations	1,700	1,700	1,700	1,700
Adjusted R^2	0.257	0.265	0.284	0.287

Note: *p<0.1; **p<0.05; ***p<0.01. The unit of observation is the census tract. Standard errors are clustered at the census tract level. Income refers to per capita income from the 2019 American Community Survey. The sample is restricted to levee-reliant tracts, defined as those with at least 25% of land area protected by levee systems. Flood zone ratio denotes the share of tract area within FEMA's 100-year flood zone. Protection level reflects the levee's designed flood return period (e.g., 500 indicates protection against a 500-year flood). Acceptable maintenance is a binary indicator equal to 1 if the levee is rated "Acceptable" or "Minimally Acceptable" in USACE inspection records. All regressions include state and levee ownership (federal vs. non-federal) fixed effects. Levee failure is defined as inundation within the levee-protected area exceeding 10 grid cells (i.e., 0.625 square kilometers). Table S4 presents robustness with a full sample across without restricting to tracts with maintenance quality data.

4 Identifying Neighborhoods Feedback Loop

The cross-sectional correlation between housing values and levee maintenance quality does not establish the direction of causality. For a self-reinforcing neighborhood feedback loop to exist, a bi-directional causal relationship is required: local economic conditions influence infrastructure quality, and infrastructure performance, in turn, affect local economic outcomes. This section presents empirical evidence for both directions of this relationship.

It is important to note that, throughout the analysis, I use housing value as a reduced-form proxy for local economic conditions to maintain tractability. Housing value reflects key neighborhood fundamentals—including income, employment, amenities, and public service quality—and serves as a direct proxy for fiscal capacity in a system where local governments rely heavily on property tax revenue. It also plays a central role in location based infrastructure investment decisions, making it a particularly relevant metric in the context of levee. The estimated effects should therefore be interpreted not as the narrow impact of housing prices, but as capturing the broader link between neighborhood economic strength and infrastructure quality under decentralized public finance.

4.1 Impact of Local Housing Value on Levee Maintenance

I begin by estimating the causal effect of local economic conditions, proxied by housing value, on levee maintenance quality. The key identification challenge is simultaneity: higher housing values may improve levee maintenance, but levee quality also affects housing values by altering perceived flood risk. Consequently, cross-sectional correlations between housing values and levee quality confound cause and effect.

Identification strategy. I address the identification challenge by exploiting the national computerization shock of the 1980s as an instrument for local housing value growth (Autor and Dorn, 2013). The rapid decline in computing capital prices beginning in the early 1980s induced widespread automation of routine tasks, with larger effects in commuting zones more specialized in routine-task-intensive industries. These commuting zones attracted larger inflows of high-skill, high-wage workers—whose productivity complements computing capital—generating upward pressure on local housing values (Moretti, 2013) [18]. The instrument

[18]The computerization shock polarized labor markets by displacing middle-skill routine workers and expanding low-skill service employment (Autor and Dorn, 2013). However, low-skill workers are disproportionately renters and are unlikely to be marginal bidders in owner-occupied housing markets. The net effect on housing values is therefore driven by the inflow of high-wage workers, whose higher willingness to pay raises equilibrium prices.

is constructed following Autor and Dorn (2013): for each commuting zone j, exposure is $RS_j = \sum_i E_{i,j,1950} \times R_{i,-j,1950}$, where $E_{i,j,1950}$ is the 1950 share of employment in industry i and $R_{i,-j,1950}$ is the leave-one-state-out routine task intensity of industry i. Fixing both components in 1950, decades before the onset of computerization and prior to most U.S. levee construction, ensures that variation in RS_j reflects predetermined economic structure unrelated to subsequent infrastructure decisions or flood risk.

The research design investigates the impacts of housing value changes since 1980 on levee maintenance quality, conditional on 1980 housing values, population, designed levee protection levels, and flood zone share. This specification enables comparisons across neighborhoods with similar initial conditions but divergent housing value trajectories driven by differential technology exposure. Because most levees were newly constructed by 1980 and thus likely in good condition, cross-sectional differences in maintenance quality today plausibly reflect changes since 1980—making the design analogous to an instrumented difference-in-differences.

The exclusion restriction requires that, conditioning on the controls, exposure to computerization affects subsequent changes in levee maintenance quality only through its effect on housing values growth (which serve as a summary measure of local economic conditions and are most relevant for local public finance), thereby ruling out reverse causality from levee maintenance to housing values. Three pieces of evidence support this. First, the instrument is uncorrelated with pre-shock neighborhood characteristics—such as income and homeownership rates in 1980—after conditioning on controls (Columns 1–2 of Table S6). Second, there is no relationship between the instrument and housing values in 1960 or 1970 (Columns 3–4), ruling out pre-existing divergent trends. Third, the Rotemberg weight diagnostics (Table S14), overidentification tests (Figure S14), and industry-share balance tests (Table S15) collectively show that the estimates are robust and not driven by any narrow set of industries (Supplementary Note B).

Main results. Table 5 reports the IV estimates. The first stage is strong: greater routine-task exposure in 1950 predicts substantially higher housing value growth over 1980–2019 due to the technology shock. The 2SLS estimates show that this housing value growth significantly improves the probability of receiving an acceptable or minimally acceptable maintenance rating (Columns 2 and 4). A 10 percent increase in housing values raises this probability by approximately 1.5 percentage points, a 2.6 percent increase relative to the sample mean. This magnitude closely matches the corresponding cross-sectional coefficient

(Column 4 of Table 2), suggesting that reverse capitalization from infrequent levee failures contributes little to the observed disparities.

Table 5: The Effect of neighborhood housing value on levee maintenance quality: Evidence from the computerization 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)
First Stage				
Routine Occupation	3.148***		20.110***	
	(0.552)		(3.207)	
First-stage F-statistic	32.488		39.325	
TSLS				
Housing value change		0.978**		0.153**
		(0.453)		(0.070)
Controls				
1980 home value	Yes	Yes	Yes	Yes
1980 population	Yes	Yes	Yes	Yes
Floodzone share	Yes	Yes	Yes	Yes
Levee protection FE	Yes	Yes	Yes	Yes
State FE	Yes	Yes	Yes	Yes
Observations	1,887	1,887	1,887	1,887
Adjusted R^2	0.362	0.050	0.287	0.192

Notes: *p<0.1; **p<0.05; ***p<0.01. The unit of analysis is the U.S. census tract. Standard errors are clustered at the commuting zone level, consistent with the level at which the technology shock varies. Specifications 1 and 2 use the change in log housing values and the percentage change in housing values (in fractional form) between 1980 and 2019 respectively. In Specification 2, a value of 1 corresponds to a 100% increase in housing value. The routine occupation instrument is the predicted routine employment share for each commuting zone, constructed using local industry shares in 1950 and national leave-one-out (excluding the state the commuting zone) industry routine task intensity in 1950, following Autor and Dorn (2013): $RS_j = \sum_{i=1}^{I} E_{i,j,1950} \times R_{i,-j,1950}$,where $E_{ij,1950}$ is the share of employment in industry i in commuting zone j, and $R_{i,-j,1950}$ is the routine task share in industry i in all other states.

Results are quantitatively similar in a restricted sample of levees with known construction year and are constructed between 1970 and 1980 (Table S7). Because these systems were newly constructed prior to the onset of the technology shock, they plausibly began with uniformly high maintenance quality. Cross-sectional differences observed today in this subsample can therefore be interpreted cleanly as reflecting subsequent changes in maintenance quality rather than pre-existing differences.

Mechanisms. The IV estimates establish that housing value growth causally improves levee maintenance, but do not by themselves distinguish the mechanism. I now consider potential mechanisms and examine evidence for each.

Fiscal capacity. Higher housing values in levee-protected neighborhoods expand the property tax base, increasing the resource available for levee maintenance. This mechanism is institutionally plausible because levee districts derive over 90 percent of revenue from property taxes on the protected areas, and municipalities rely heavily on property taxation (Table S11). To evaluate this channel, I examine whether the technology shock increases fiscal capacity in levee-dependent municipalities (i.e., more than 25 percent of land area under levee protection). Table 6 shows that technology exposure increases total municipal revenue, primarily through property tax revenues (Columns 1–2). The fiscal capacity channel is also consistent with the cross-sectional evidence that the housing value gradient in maintenance is nearly three times larger under municipal and special-district sponsorship than under sponsorship by higher level governments (0.146 vs. 0.054; p-value for equality 0.002; Table 3).

Value of protection. An alternative explanation is that maintenance follows the same benefit–cost logic that governs levee design. If maintaining levees protecting higher-value assets generates larger benefits, sponsors may optimally allocate more maintenance to those systems regardless of financing. This channel is consistent with the positive relationship between housing values and maintenance across all sponsorship types (Table 3) and would also generate the feedback loop emphasized in this paper because housing value continues to affect subsequent maintenance investment. The sponsorship results, however, suggest that this channel does not fully account for the observed patterns. Because the value-of-protection criterion applies regardless of the sponsor's revenue source, it does not predict a steeper maintenance gradient under local sponsorship. I conduct additional analysis examining levees whose maintenance budgets are determined by state governments and are less responsive to local housing value shocks. Although the technology shock continues to increase housing

Table 6: Technology shock IV on municipal revenues in levee protected municipalities

	Changes in Log Revenue from 1977 to 2017				
	Total Revenue	Property Tax	Income Tax	Federal Transfer	State Transfer
	(1)	(2)	(3)	(4)	(5)
Routine Occupation	3.218*	7.362***	1.807	-6.798*	2.066
	(1.762)	(2.081)	(1.537)	(4.014)	(2.254)
1977 revenue	Yes	Yes	Yes	Yes	Yes
1977 population	Yes	Yes	Yes	Yes	Yes
Floodzone share	Yes	Yes	Yes	Yes	Yes
Levee protection FE	Yes	Yes	Yes	Yes	Yes
State FE	Yes	Yes	Yes	Yes	Yes
Observations	483	483	483	483	483
Adjusted R^2	0.301	0.364	0.929	0.309	0.234

Notes: *p<0.1; **p<0.05; ***p<0.01. Municipality (including township) is used as the unit of analysis. Only levee-dependent municipalities (i.e., with more than 25% area under levee protection) are kept. Standard errors are clustered at the commuting zone level. Municipal budget data from the Census of Government. Changes in log revenue by category from 1977 and 2017 are presented. The routine occupation instrument is the predicted routine employment share for each commuting zone, constructed using local industry shares in 1950 and national leave-one-out (excluding the state the commuting zone) industry routine task intensity in 1950, following Autor and Dorn (2013):
$RS_j = \sum_{i=1}^{I} E_{i,j,1950} \times R_{i,-j,1950}$,where $E_{ij,1950}$ is the share of employment in industry i in commuting zone j, and $R_{i,-j,1950}$ is the routine task share in industry i in all other states.

values in these areas, the estimated effect on maintenance is substantially smaller (0.031 versus 0.153 in the full sample; Table S8). The estimates are imprecise because of the limited sample size, so they cannot rule out economically meaningful effects. Nevertheless, the pattern is consistent with cross-sectional results that local fiscal capacity contributing to maintenance decisions in addition to the value-of-protection channel.

Other mechanisms may also explain the relationship yet are not consistent with the evidence. The technology shock may increase the share of high-income or highly educated residents, potentially increasing political demand for levee maintenance or improving a jurisdiction's ability to obtain state and federal assistance. However, these mechanisms predict maintenance improvements regardless of the sponsor's revenue structure, contrary to the sponsorship heterogeneity documented above. Likewise, federal and state transfers do not increase following technology-driven housing value growth; if anything, they decline (Column 4 of Table 6). Another possibility is that richer jurisdictions reallocate larger budgets toward levee-protected neighborhoods (e.g., for equity consideration) even if those neighborhoods contribute little to local revenues. I find no evidence supporting this mechanism: housing value growth does not improve maintenance for levees protecting a small share of municipal land area, where the protected area contributes relatively little to the municipal tax base (Table S9).

Taken together, while the evidence does not allow a clean separation between the fiscal-capacity and value-of-protection channels, the overall pattern is more consistent with fiscal capacity playing an additional role beyond value-based allocation. Both channels imply that housing values affect subsequent maintenance investment and therefore generate the central feedback mechanism identified in the paper. However, the feedback is likely to be stronger under local financing, where housing values directly determine the fiscal resources available for maintenance.

4.2 Impact of Levee Failures on Local Housing Value

Levee maintenance disparities driven by differences in local housing values and fiscal capacity can become self-reinforcing if infrastructure deficiencies in turn reduce neighborhood housing values, household incomes, and local revenues available for future investment. This feedback loop, in which infrastructure degradation and economic decline reinforce one another, resonates with theoretical models of "urban doom loops" and "cumulative urban decline". Despite its theoretical foundation, empirically identifying such dynamics is chal-

lenging: Infrastructure typically deteriorates gradually, and its effects are intertwined with broader socioeconomic changes, making causal attribution challenging.

Flood protection infrastructure offers a unique setting for identifying the feedback loop between infrastructure quality and local economic conditions. Unlike other public infrastructure, such as roads or schools, where residents can observe conditions through daily use, the condition of levee systems is largely unobservable until revealed by rare but high-impact flooding events. Prior research shows that residents are generally unaware of residual flood risk behind levees (Ludy and Kondolf, 2012), and that USACE levee inspection results are communicated to local sponsors rather than the public (US Army Corps of Engineers, 2024; Ludy and Kondolf, 2012)[19]. Due to this ex-ante information gap, households update their beliefs about levee quality primarily when infrastructure failures are revealed by actual flood events. I therefore can leverage the quasi-random timing and location of major floods to identify the causal effects of levee failure on local housing values and fiscal outcomes. While levee maintenance quality itself is not randomly assigned, flood shocks serve as plausibly exogenous events that reveal the economic consequences of under-maintained infrastructure.

Neighborhood Housing Value

To estimate the impact of levee failures on housing markets, I conduct event study analyses for 103 major flooding events from 2000 to 2021, using satellite imagery to precisely map inundation. As shown in Table S10, approximately 31.4% of census tracts (59.3% of flood zone tracts) experienced flooding during this period. This percentage drops to 2.36% (9.29% of flood zone tracts) when focusing on levee failures, where flooding occurs within levee systems. Although levee failure events are less frequent, they have a greater impact, with 11.9% of levee failure events resulting in extensive flood inundation of more than 25% of a tract's area.

I study the dynamic effects of levee failure on tract-level housing prices using a staggered difference-in-differences design. Let i index census tracts and t calendar years. Let G_i denote the first year tract i experiences levee failure. Levee failure is defined using two thresholds: (i) any flooding within levee-protected areas (i.e., above 0% of area flooded), and (ii) extensive flooding affecting more than 25 percent of the protected area. The latter definition more reliably captures structural failure (e.g., breaches), whereas the former may include more

[19] According to Ludy and Kondolf (2012), local residents are rarely informed about levee risk, *"Some respondents requested more information and one resident commented additionally, "I contacted Stockton City Hall after hearing this information and was glibly told I had little to worry about""*.

overtopping events; see validation in Table S3. The outcome Y_{it} is the FHFA repeated-sales housing price index. Standard errors are clustered at the tract level. A conventional two-way fixed effects (TWFE) event-study regression would take the form:

$$Y_{it} = \sum_{\tau=-5}^{6} \beta_\tau \mathbf{1}\{t - G_i = \tau\} + \delta_i + \theta_{s(i)t} + (X_i \times \lambda_t)\gamma + \varepsilon_{it}, \tag{1}$$

where δ_i and $\theta_{s(i)t}$ denote tract and state-by-year fixed effects. The vector X_i includes cross-sectional income and flood risk measures interacted with year indicators to allow for flexible differential trends [20]. Following Liao and Kousky (2022), I restrict the control group to levee-protected tracts within counties that experienced flooding in the past two decades and exclude tracts flooded outside levee systems.

Because staggered treatment timing and heterogeneous effects can bias conventional TWFE estimators (Goodman-Bacon, 2021; Callaway and Sant'Anna, 2021; Baker et al., 2022; de Chaisemartin and D'Haultfœuille, 2024), I follow Callaway and Sant'Anna (2021) and estimate cohort-specific group–time average treatment effects after partialling out fixed effects and controls. Dynamic effects are then obtained by aggregating these estimates over event time. I Identification relies on a parallel trends assumption: absent levee failure, treated tracts would have followed the same housing price trends as comparable levee-protected tracts. Identification comes from comparing tracts within the same state with similar income and flood risk, some of which experience levee failure due to idiosyncratic shocks such as extreme precipitation or hurricane paths [21].

Ideally, one would isolate failures attributable purely to maintenance deficiencies rather than hydrological extremes. In practice, however, these forces interact in complex ways, making it difficult to disentangle causes even ex post [22]. Given this ambiguity, I assume that households treat levee failure as a noisy signal of levee reliability without distinguishing failure causes. Under this belief-updating model, even well-maintained levees may be perceived as unreliable following failure, and the benefit of good maintenance lies in reducing the likelihood of levee failure. If households are more sophisticated and only revise beliefs when failure is attributed

[20] Flood risk is measured using the First Street Foundation (FSF) tract-level flood risk index, which adjusts hydrological exposure for levee design capacity. The index removes flood impacts below a levee's design threshold but does not account for maintenance deficiencies.

[21] The control group includes levee-protected tracts in the same state with comparable flood risk and income that did not experience failure. This group includes both tracts outside the realized flood path and those where levees successfully withstood flooding.

[22] For example, the relative roles of design flaws, maintenance deficiencies, and extreme hydrological conditions in the levee failures during Hurricane Katrina remain debated.

to maintenance deficiencies, then my estimates may understate the true economic costs of under-maintained levees, thus offering a conservative lower bound.

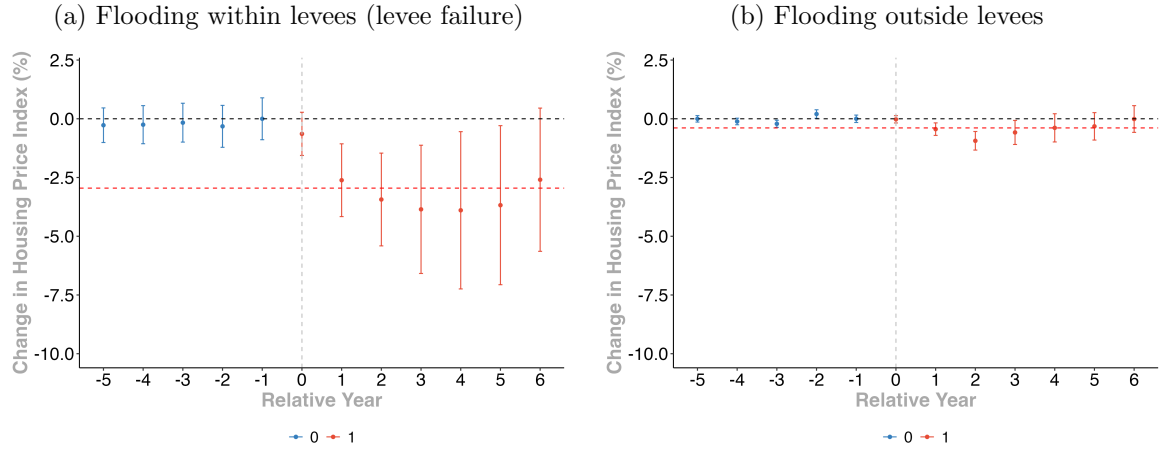
To establish a baseline for the effects of flooding independent of levee failure, I conduct parallel event studies for flooding events in areas without levee protection. In these analyses, both treatment and control tracts lack levee protection, and treated tracts are those that experienced flood inundation. This isolates the impact of flooding without the updating of levee quality. It provides a benchmark for interpreting the effects of levee failure relative to flooding alone and allows comparison with prior research on the capitalization of flood risk.

Figure 4 presents event study estimates for all flooding events, comparing the effects of levee failures and flooding outside levee systems on a common scale. Both treatment and control tracts exhibit parallel pre-trends in housing prices, supporting the identifying assumptions. Following the event, census tracts that experienced levee failure exhibit a persistent 2.6% decline in housing prices over six years of post-event window [23]. In contrast, tracts affected by flooding outside levees experience a modest 0.42% decline in prices, followed by a full recovery within six years.

One potential explanation for the difference in housing market impact is disaster severity: flood events that cause levee failures may be more extreme than typical flooding events. To assess this, I restrict the sample to large-scale flooding events where more than 25% of a census tract is inundated and re-estimate the effects (Figure 5). The divergence in outcomes is in fact more pronounced for these severe events. In tracts experiencing extensive flooding with levee failure, housing prices decline by 8.97% over the six years following the event, with no evidence of recovery within the six-year post-event window. In contrast, tracts experiencing extensive flooding outside levee systems exhibit a transitory housing price increase of 2.21% on average. This positive effect is consistent with the findings from some previous studies (Tran and Wilson, 2020; Graff Zivin et al., 2023; Contat et al., 2024), which attribute post-disaster housing appreciation to factors such as reduced housing supply (Graff Zivin et al., 2023), and "building back better" dynamics (Hornbeck and Keniston, 2017; Tran and Wilson, 2020).

[23] Given the limited post-event window, I cannot assess long-run permanence. The estimated effects remain similar, though less precisely estimated, when extending the analysis to ten years after the event (Figure S7).

Figure 4: Effect of levee failure and flooding outside levees on neighbourhood housing price



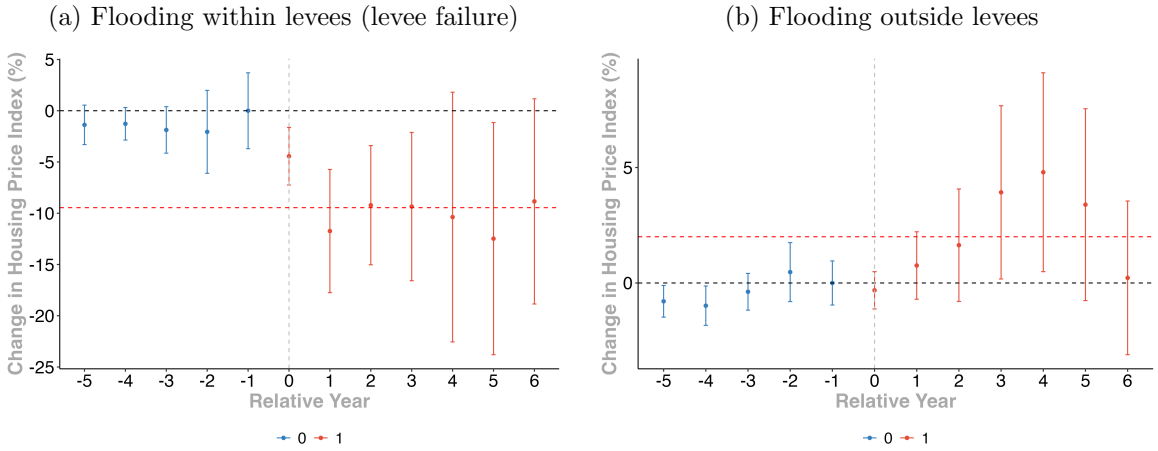
Notes: Treatment is defined as any flood inundation (flooded area above 0). For levee failure effects, both treatment and control tracts are protected by levees; treatment tracts experience flooding within the levee system. For flooding outside levees, both treatment and control tracts lack levee protection; treatment tracts are those that experienced flooding. Housing price index (HPI) changes are scaled to percentage terms using the average tract-level HPI. Event study estimates are based on the Callaway & Sant'Anna estimators (Callaway and Sant'Anna, 2021), which allows for dynamic treatment effects and corrects for bias in staggered adoption designs by estimating pseudo-treatment effects in pre-periods. Event-study coefficients are normalized relative to period -1 and divided by the mean of the outcome variable, so that plotted effects represent percentage changes.

While prior research has documented strong post-disaster economic recoveries in US housing market (Gallagher and Hartley, 2017; Liao and Kousky, 2022; Graff Zivin et al., 2023), the results here suggest that recovery trajectories differ markedly for flood-prone communities reliant on low-quality infrastructure for protection. To explore potential sources of this divergence, I examine heterogeneity across several dimensions (Figure 6) [24]. Point estimates indicate economically meaningful variations. In particular, housing price declines are larger in lower income tracts, consistent with credit constraints and regressive disaster aid (Billings et al., 2022). The effects also appear more pronounced in areas with lower levels of expressed climate concern and in locations outside FEMA flood zones, where flood risk may be less capitalized into property value and insurance coverage are more limited (Gourevitch et al., 2023; Bradt et al., 2021).

Despite these differences in point estimates, no subgroup differences are statistical significant. The negative impact of levee failure on housing prices is evident across all groups, and the estimated differences between them are statistically indistinguishable from zero. This pattern

[24]To address the concerns related to multiple hypothesis testing, I complete these analyses with a random forest model that evaluates the relative importance of heterogeneity dimensions (Figure S8).

Figure 5: Effect of extensive flooding on neighbourhood housing price

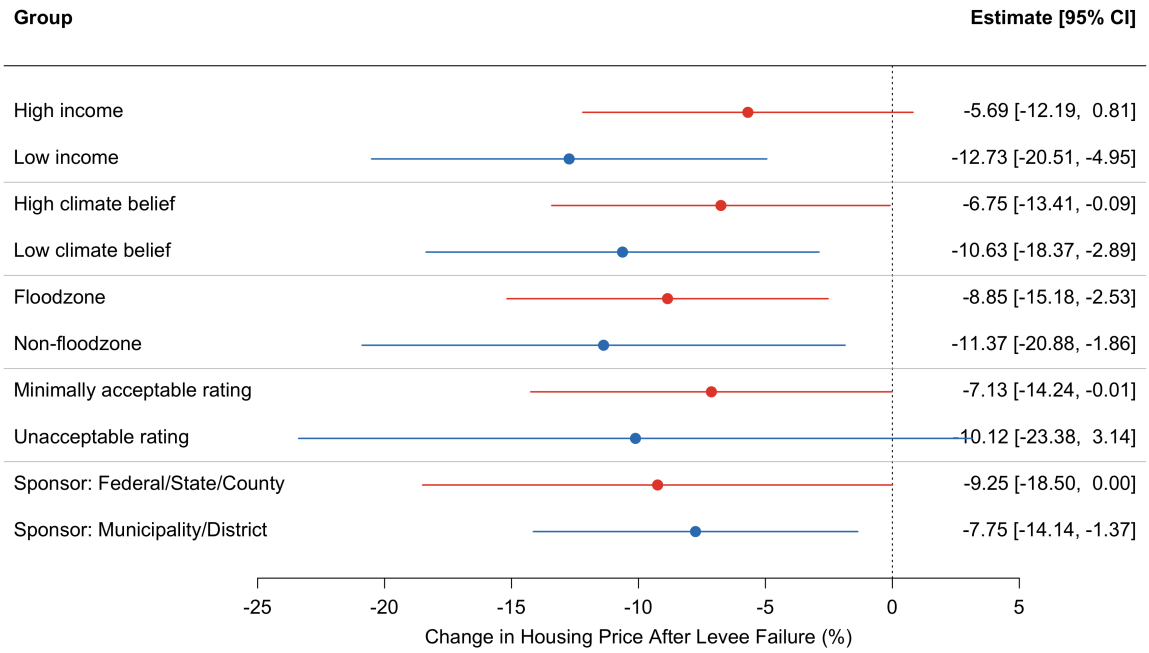


Note: Treatment is defined as extensive flooding, where flood inundation exceeds 25% of a census tract's area. For levee failure effects, both treatment and control tracts are levee-protected; treatment tracts experience extensive flooding within levees. For flooding outside levees, both groups lack levee protection; treatment tracts experience extensive flooding. Estimates are generated using the Callaway & Sant'Anna estimators (Callaway and Sant'Anna, 2021), which accounts for dynamic treatment timing and computes pseudo-treatment effects in pre-treatment periods. Event-study coefficients are normalized relative to period −1 and divided by the mean of the outcome variable, so that plotted effects represent percentage changes.

suggests that the economic consequences of levee failure are broadly shared rather than concentrated among particular vulnerable populations. The results are difficult to reconcile with explanations based solely on pre-existing differences in income or baseline flood risk between levee failure and general flooding events. Instead, they suggest levee failures have consequences beyond flooding itself, either by revealing previously unpriced residual flood risk or causing more persistent physical damage to properties and neighborhoods.

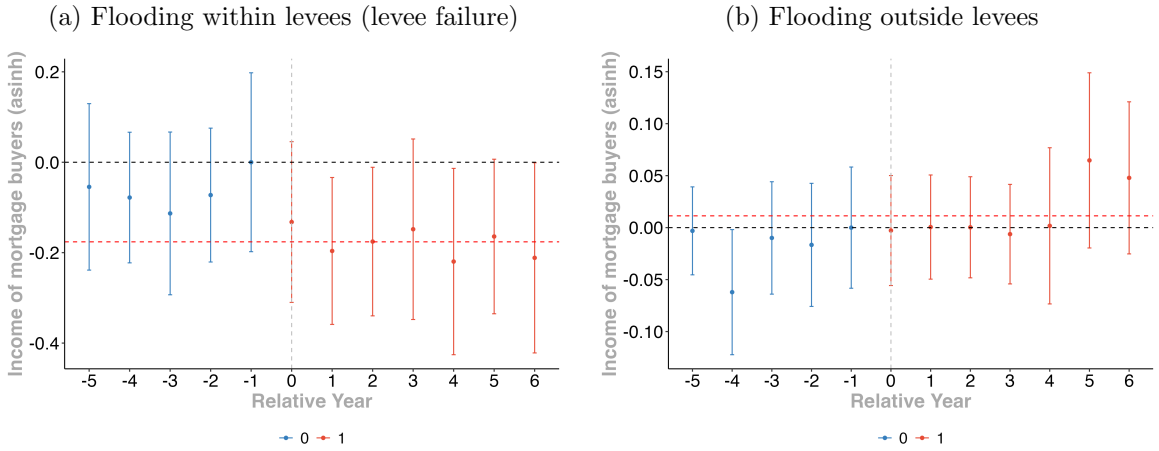
How do changes in housing market conditions affect the socio-demographic composition of neighborhoods? Using data from the Home Mortgage Disclosure Act (HMDA), I find that the average income of new mortgage buyers declines following levee failures (Figure 7). No comparable shift is observed after flooding events outside levee systems. This pattern suggests that levee failures trigger income sorting, with reduced property values driving the in-migration of lower income buyers or out-migration of the rich. Because lower-income households often face greater credit constraints and have fewer resources for post-disaster recovery, such sorting may reinforce neighborhood decline and exacerbate climate inequality over time.

Figure 6: Heterogeneous housing price responses to levee failure



Notes: Estimates are based on subgroup event study analyses, following the specification in Figure 5. Points represent the average housing price effect over the six years following levee failure; lines indicate 95% confidence intervals. Subgroups are defines using median splits. Climate belief data are from Yale Climate Opinion Survey.

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



Note: Treatment is defined as extensive flooding, where inundation exceeds 25% of a census tract's area. For levee failure effects, both treatment and control tracts are protected by levees; treatment tracts experience extensive flooding within levee systems. For flooding outside levees, both treatment and control tracts lack levee protection; treatment tracts experience extensive flooding. Estimates are based on the Callaway & Sant'Anna estimators (Callaway and Sant'Anna, 2021), which accounts for staggered treatment timing and computes pseudo-treatment effects in pre-event periods. Event-study coefficients are normalized relative to period −1.

Under the baseline setting, I compare census tracts experiencing levee failure with census tracts that do not, thus the control group includes both tracts outside the flooding area and those within the flooding area where levees successfully withstood the floods. A potential concern is that levee-protected tracts that withstand floods may experience a positive price effect, as the event could signal levee quality. If so, the baseline estimates would overestimate the negative effects of levee failure due to control group price increase. To assess this, I estimate the housing price changes in levee-protected tracts near flooding but did not experience inundation to test for positive capitalization from flood avoidance. As shown in Figure S9a, I find no evidence of positive price effects. If anything, housing prices decline modestly 2–3 years post-disaster, although the effect is transitory. This suggests that residents may view near-miss flooding events as warnings rather than reassurances of infrastructure quality.

Another concern is that the spillover effects of flooding events to nearby tracts could bias the estimation of housing price effects of flooding. To assess this, I examine non-flooded, non-leveed tracts near flooding events and find no evidence of negative spillover effects on housing prices (Figure S9b). This suggests that the limited long-term housing price effects observed for general flooding are not driven by contamination of the control group.

Local Public Finance Implications

The housing market impacts of levee failure do not directly imply fiscal consequences for local governments, as post-disaster transfers from federal and state programs may offset lost tax revenue (Henkel et al., 2022; Miao et al., 2024). To assess the net effect on fiscal capacity, I examine long-term changes in municipal budgets following levee failures, using municipal-level data (including municipalities and townships) from the Census of Governments. While many levee systems are maintained by special districts, comprehensive financial data exist only for municipalities. Since special districts rely more heavily on property tax revenue and receive less intergovernmental support, the estimates presented here likely represent a lower bound on the true fiscal impact.

I aggregate tract-level flood exposure to municipalities using population weights [25]. A municipality m is defined as treated if at least 10 percent of its population experienced flood inundation, following Liao and Kousky (2022). Levee-failure treatment is defined analogously as flooding affecting at least 10 percent of the population protected by levees. Because the Census of Governments finance data are collected every five years, I collapse the panel into five-year periods. Let G_m denote the first five-year period in which municipality m experiences flooding (or levee failure). A conventional event-study specification is:

$$Y_{mt} = \sum_{\ell \in \{-10,-5,0,5,10\}} \beta_\ell \mathbf{1}\{t - G_m = \ell\} + \delta_m + \theta_t + (X_m \times \lambda_t)\gamma + \varepsilon_{mt}, \tag{2}$$

where δ_m and θ_t denotes municipality and year fixed effects, and X_m includes crosssectional income and flood risk interacted with period indicators to allow for differential trends. The coefficient β_5 captures outcomes 5–9 years after exposure, and β_{10} captures outcomes 10–14 years after exposure. Outcomes Y_{mt} include outcomes such as population, revenues, and expenditures. I apply an inverse hyperbolic sine transformation (*asinh*) to allow for percent interpretation. Due to staggered treatment timing and potential heterogeneous effects, I follow Callaway and Sant'Anna (2021) and estimate cohort-specific group–time average treatment effects after partialling out fixed effects and controls, comparing treated with not-yet-treated municipalities. Dynamic effects are obtained by aggregating these cohort-specific estimates over event time, where each period corresponds to five years.

Because the local finance census is conducted every five years and property tax effects emerge only after reassessments—which can take up to five years—I focus on fiscal responses 5–9 and 10–14 years post-disaster, when these impacts are most likely to be observed in the

[25] I aggregate data from the census tract level to the municipality level using a crosswalk between census tracts and census places from the Geographic Correspondence Engine.

data. Levee failures are associated with substantially larger population losses. Municipalities affected by levee failures experience a 8.8% decline in population within a decade, nearly twice the 4.0% loss observed after major floods outside levee systems (Figure 8a). While both sets of municipalities receive increased intergovernmental transfers post-event (Figure 8c), 21.8% for levee failures and 16.2% for other floods, disbursements to leveed municipalities exhibit a more delayed response, which could be driven by the longer administrative timelines for levee-related federal assistance.

Despite this inflow of external funds, municipalities experiencing levee failures face a pronounced contraction in own-source revenues. Property tax revenue declines by 22.1%, with the largest reductions 5–9 years post-disaster—aligning with the timing of reassessments (Figure 8b). Although there is partial recovery in years 10–14, revenues remain below pre-event levels in the observed post-event window. In contrast, municipalities affected by flooding outside levees experience a more modest decline (8.7%) that dissipates within a decade. I find no statistically significant changes in charges, fees, and miscellaneous revenues, key sources that municipalities rely on alongside intergovernmental transfers and property taxes (Table S11 and Figure S10) [26]. Taken together, total municipal revenue declines by 5.8% following levee failures, as intergovernmental transfers do not fully offset losses in the local tax base (Figure 8d).

On the expenditure side, municipalities exposed to levee failures also contract spending in response to these revenue shortfalls. Total expenditures fall by 12.1% in the post-disaster period, precisely when demands for reconstruction and service provision are elevated (Figure 8e). Notably, in contrast to the typical post-disaster investment response, there is little evidence of a compensatory increase in capital outlays (Figure 8f). This pattern is consistent with binding fiscal constraints limiting local governments' ability to finance recovery and rebuild infrastructure, potentially amplifying longer-run economic and infrastructural decline.

Recent work emphasizes that percentage treatment effects are not well defined when the outcome includes a nontrivial mass at zero (Chen and Roth, 2024). Table S12 reports the prevalence of zero-valued observations for the municipal finance outcomes. More than 20% of capital outlay observations and 5% of property tax observations are zero, raising concerns about the percentage interpretations. To address this issue, I implement Lee bounds for

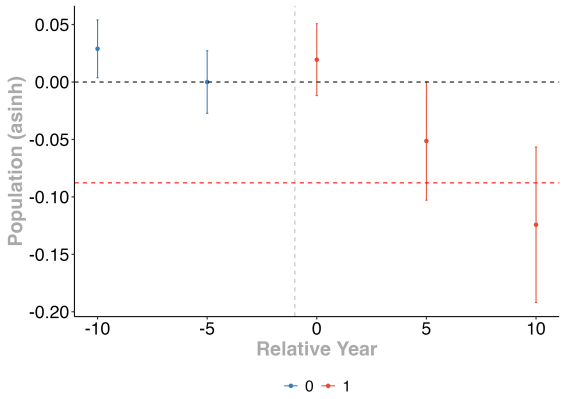
[26] If anything, there is a small and statistically insignificant increase in charges and fees following levee failures. As fines and forfeits are included in this category, such patterns may reflect harmful attempts to generate revenue under fiscal stress (Davis et al., 2023).

the intensive margin treatment effects (Lee, 2009; Chen and Roth, 2024) (Figure S11). The bounded estimates are consistent with the baseline results, implying a 6-26% reduction in property tax revenue and a lack of increase in capital outlay.

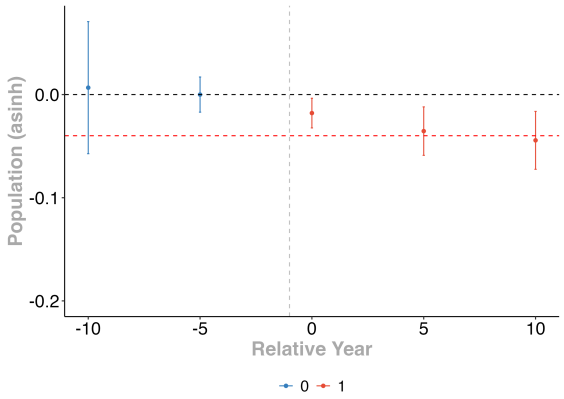
Because fiscal outcomes are observed only at five-year intervals, the analysis cannot fully disentangle post-disaster responses from slower-moving structural changes (such as economic decline and outmigration) or other confounding shocks occurring within the same window. The fiscal impact estimates should accordingly be interpreted as descriptive of the post-disaster fiscal trajectory rather than as strictly causal estimates of a specific mechanism. Nonetheless, the alignment between fiscal outcomes and housing market effects strengthens the case that infrastructure failure can impose lasting constraints on local public finance. In resource-constrained municipalities, these fiscal pressures may reinforce a downward spiral of disinvestment and decline under decentralized financing of levee maintenance.

Figure 8: Effect of flooding within and outside levees on local public finance

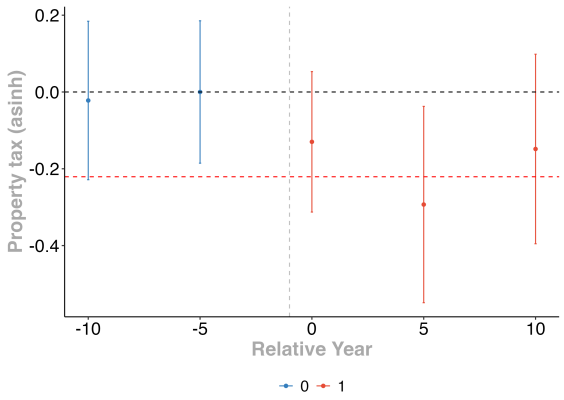
(a-1) Population: Levee Failure



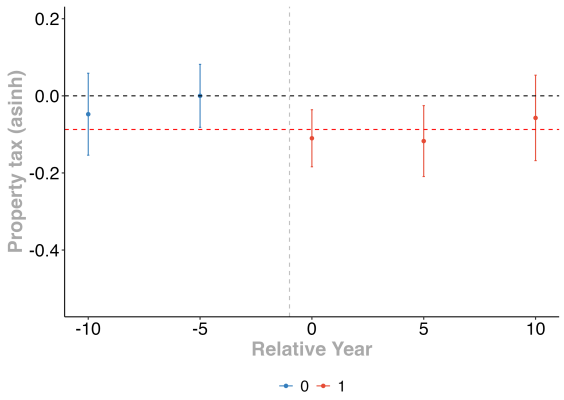
(a-2) Population: Flooding Outside Levees



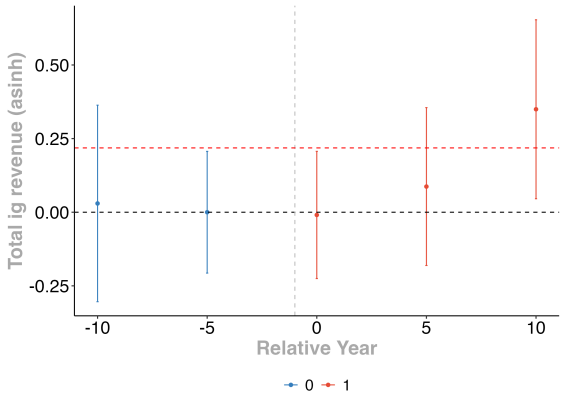
(b-1) Property Tax: Levee Failure



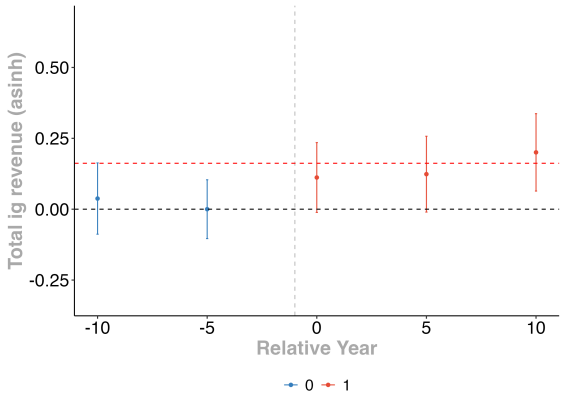
(b-2) Property Tax: Flooding Outside Levees



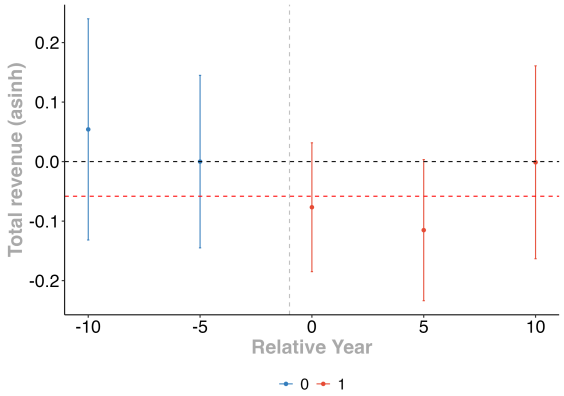
(c-1) IG Revenue: Levee Failure



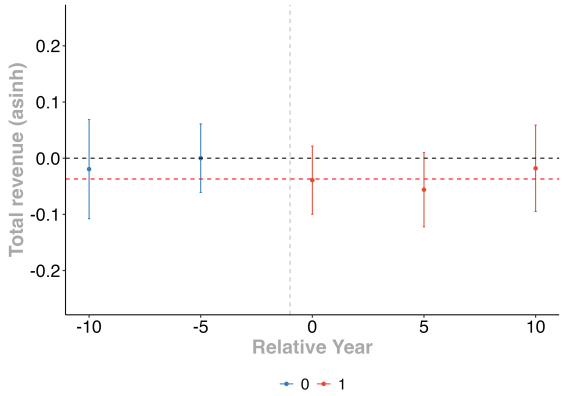
(c-2) IG Revenue: Flooding Outside Levees



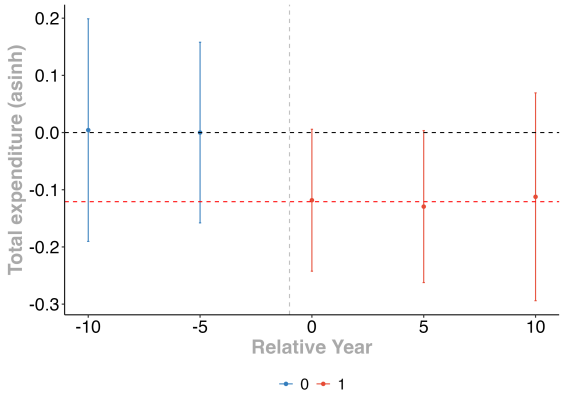
(d-1) Total Revenue: Levee Failure



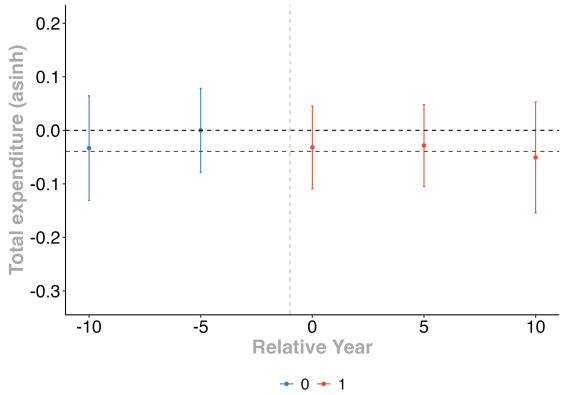
(d-2) Total Revenue: Flooding Outside Levees



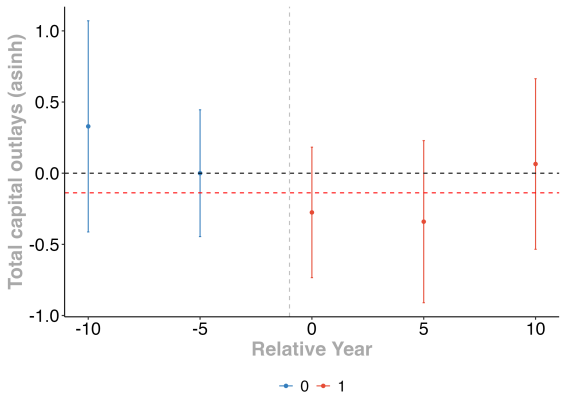
(e-1) Total Expenditure: Levee Failure



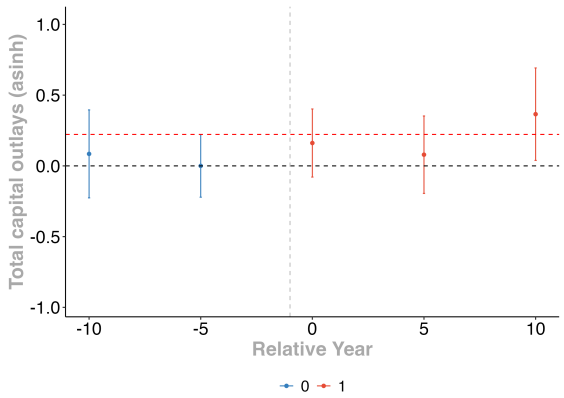
(e-2) Total Expenditure: Flooding Outside Levees



(f-1) Capital Outlay: Levee Failure



(f-2) Capital Outlay: Flooding Outside Levees



Notes: Treatment is defined as flooding affecting tracts containing at least 10% of the municipal population. Coefficients at 0, 5, and 10 represent effects observed 0–4, 5–9, and 10–14 years after the event, respectively. All outcome variables are transformed using the inverse hyperbolic sine; percentage effects are computed as $\Delta Y\% = e^{\hat{\beta} - 0.5\,\mathrm{var}(\hat{\beta})} - 1$ (Kennedy, 1981; Bellemare and Wichman, 2020). Standard errors are clustered at the municipality level. For levee failure estimates, both treatment and control groups include levee-protected municipalities. For flooding outside levees, both groups consist of municipalities without levees. Estimates use Callaway & Sant'Anna estimators (Callaway and Sant'Anna, 2021), which dynamically compute pseudo-treatment estimates of the average treatment effect in pre-treatment periods. Event-study coefficients are normalized relative to period −1.

5 Equity and Economic Implications

Local maintenance of levee systems is receiving increased congressional attention, but there is no clear consensus on the role of federal policies in this area (Keegan et al., 2011). Beyond levees, these debates extend to broader climate risk management efforts where local fiscal capacity plays a crucial role in sustaining long-term resilience, such as maintaining green infrastructure in flood-prone areas after property buyouts, reinforcing coastal barriers against storm surges, and creating defensible space zones to reduce wildfire risks. How do the findings in this research provide policy implications for the ongoing discussions about the shared responsibility for climate infrastructure investment between federal and local governments? Below, I discuss the policy implications from both climate justice and net present value (NPV) perspectives.

Climate Justice Perspective

From the climate justice perspective, my findings suggest that local financing of climate infrastructure maintenance exacerbates climate and economic inequality through a self-reinforcing feedback loop. Wealthier neighborhoods are often able to establish a positive feedback loop by investing in robust infrastructure, leading to lower flood insurance premiums under FEMA's Community Rating System (CRS). In contrast, fiscally constrained neighborhoods struggle to maintain infrastructure, which increases climate risk, depresses property values, and further weakens local budgets, thereby compounding economic vulnerability.

Current federal policies aimed at enhancing climate equity, such as the Inflation Reduction Act (U.S. Department of the Interior, 2023), the Bipartisan Infrastructure Bill (Flavelle, 2021), and Justice 40 primarily focus on funding new climate resilience infrastructure in disadvantaged communities. Due to the feedback loop created by local financing of maintenance, one-time investments in new infrastructure or upgrades may not yield lasting economic benefits without reforms to the financial systems that support ongoing maintenance. With $21 billion needed to improve moderate to high-risk levees in the US (ASCE, 2021), policy discussions need to incorporate the maintenance of existing infrastructure to ensure long-term resilience and prevent growing inequality. Potential reforms include shifting levee maintenance responsibilities to higher levels of government, providing federal subsidies for local maintenance, incentivizing new financial tools like resilience bonds to contract long-term maintenance investment, or integrating maintenance capacity into cost-benefit analyses

when choosing between to building new infrastructures or adopting alternative management strategies.

NPV Perspective

While the feedback loop highlights important climate equity implications, it does not directly address whether levee maintenance has a positive net present value (NPV) or if federal subsidies for levee maintenance are socially optimal beyond equity considerations. To investigate this, I conduct a back-of-the-envelope analysis of the NPV of maintenance investments for each levee system. Full methodological details are provided in Supplementary Note A.

The annual maintenance cost of levee is estimated as a fixed proportion of initial levee construction costs. I obtain the unit levee construction cost of $60.781 Million per mile (in 2019 USD) from Bradt and Aldy (2022) (Figure S12a) and use an annual maintenance and construction cost ratio of 0.232% from the USACE Valley Park Levee plan (Figure S12b). Therefore, the annual maintenance cost for each levee is calculated as $LeveeMile_i \times 60.781 Million \times 0.232\%$, where $LeveeMile_i$ is the length of levee system i sourced from the National Levee Database.

The maintenance benefits are estimated as the avoided property damages from levee failure. First, I obtain the total property value protected by each levee system from USACE's 2019 national property inventory, which measures the replacement cost value of both residential and non-residential structures from county appraisal tax databases [27]. Second, I calculate the probability of failure under flood events of varying severity, as well as the expected property damage ratio, using statistics from USACE reports (Figure S13). If failure occurs, the expected damage is 12.87% of protected value. Third, I estimate that maintaining levees to at least a minimally acceptable quality would have reduced the probability of levee failures by 11% between 2000 and 2021 (Table S13), corresponding to an annual risk reduction of 0.49% [28]. The implied annual maintenance benefit is $ProtectedValue_i \times 0.49\% \times 12.87\%$. This framework yields a highly conservative estimate of maintenance benefits as it only considers property damages under historical climate conditions. In reality, levee failures also lead to

[27] County appraisers use the dimensions of the building and the square footage, the interior and exterior materials used to build the structure, the function of the building, and the HVAC and plumbing makeup for the structure, to determine a new replacement cost for each structure. It is thus not subject to the strategic reporting of property owners. Depreciation is then applied based on age and condition. See USACE (2014) for more details.

[28] This is a conservative estimate that excludes repeat failures within these 22 years, due to the challenges in calibrating property damage when levees and buildings are not yet fully repaired.

mortality, infrastructure damage, and broader economic costs—all of which are expected to grow as climate change raises flood frequency and intensity.

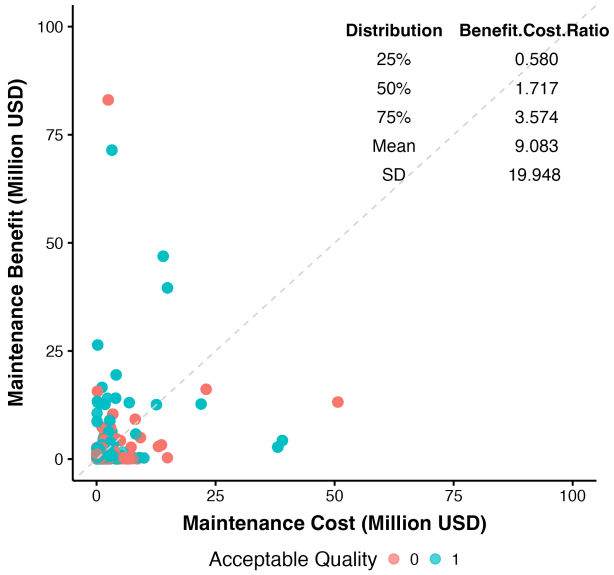
Figure 9a presents estimated annual maintenance benefits and costs for levee-protected tracts. On average, the benefit-cost ratio is 9.1—each dollar invested in maintenance avoids roughly nine dollars in property damage. Despite this high return, 34.8% of levees with benefit-cost ratios above one are still rated as having "unacceptable" maintenance quality. This underinvestment is systematically concentrated in poorer areas: in the lowest-income tracts, over half of economically efficient levees are under-maintained, with the rate declining monotonically with income (Figure 9b). These patterns suggest binding fiscal or borrowing constraints that inhibit efficient investment. If all NPV-positive levees were adequately maintained, the annual flood losses in the US can be reduced by $325 million (in 2019 USD), approximately 6% of all national flood-related property and crop damages (NOAA, 2024). Net of maintenance costs, this implies annual efficiency gains of $157 million—or approximately $282 million under the assumption that levees with missing maintenance ratings exhibit similar rates of underinvestment as those with observed ratings.

While local fiscal capacity is a key determinant of maintenance quality, it is unlikely to be the only constraint. Even in the highest-income neighborhoods, over 20% of levees with positive NPV remain under-maintained. This points to structural frictions beyond fiscal constraints. First, levee maintenance generates a fiscal externality. Underinvestment at the local level imposes costs on the federal government—particularly through post-disaster aid and the National Flood Insurance Program (NFIP)— weakening local incentives to internalize the full social cost of failure. Second, levee maintenance is subject to an intertemporal externality due to limited salience. Unlike schools or roads, whose quality is continuously observable, the benefits of levee maintenance are realized only during infrequent disasters. This reduces political accountability and creates incentives for current officials to defer maintenance, shifting the risks and costs of failure onto future administrations. These frictions compound the chronic underinvestment problem under decentralized maintenance regimes, reinforcing the feedback loop identified earlier and exacerbating long-run economic inefficiencies in climate resilience infrastructure.

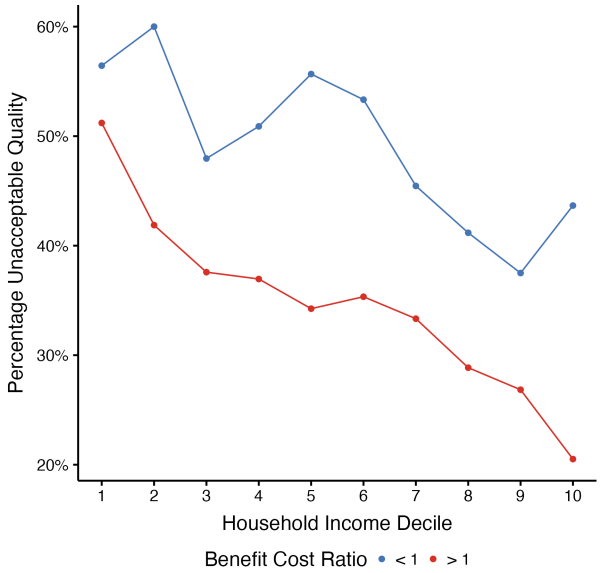
This analysis focuses on the maintenance margin. In practice, the maintenance decisions are intertwined with broader policy margins, such as whether to build adaptation infrastructure at all, and how much federal support to provide through subsidized insurance and

Figure 9: Benefit Cost Relationship of Levee Maintenance

(a) Annual Benefit and Cost



(b) Maintenance Quality by Tract Income



Notes: Annual levee maintenance benefit is measured by the reduced levee failure probability and the property damages during levee failure. Property value measured in replacement costs within each levee and depth damage function for floods of different severities are from USACE. Annual levee maintenance cost is estimated in proportion to the initial levee construction cost measured on a per mile basis from Bradt and Aldy (2022). Household income is from the 2019 American Community Survey at the census tract level. Income deciles are calculated within each state.

post-disaster aid. Federal and state involvement on any of these margins can amplify moral hazard by encouraging development in high-risk areas (Hsiao, 2023; Henkel et al., 2022). A full welfare analysis must weigh these moral hazard effects against the efficiency and equity benefits from alleviating local fiscal constraints. It also needs to consider the tradeoffs between defending high-risk areas and pursuing managed retreat strategies like property buyouts. Given the political challenges of large-scale retreat and the path dependency in infrastructure investment, the maintenance margin will remain critical for climate adaptation. While this paper highlights the feedback dynamics that arise under decentralized maintenance, future research is needed to study the optimal state and federal subsidies taking into account moral hazard effects and broader adaptation policies.

6 Conclusion

Climate infrastructure maintenance is a critical but understudied component of climate adaptation. Despite growing attention to climate resilience, policy has focused predominantly on

new capital investment, with limited attention to the long-run maintenance of existing infrastructure. This paper shows that when maintenance is decentralized and financed through local revenue, it can produce a self-reinforcing feedback loop between housing markets and infrastructure quality—deepening climate risk and economic inequality over time.

Using novel data on levee failures and maintenance, I document that low-income neighborhoods are more likely to be protected by levees with poor maintenance and are more vulnerable to levee failure. These disparities are particularly pronounced when levees are managed by municipalities or special districts that rely heavily on local property tax revenue. I show that underlying this coupled economic and climate inequality is a bidirectional feedback loop: Exogenous shocks to local housing values causally affect maintenance quality, while levee failures—which are more likely when maintenance is inadequate—in turn depress housing values and local budgets for future maintenance investment.

These findings have important policy implications. First, current infrastructure programs, such as the Inflation Reduction Act and the Bipartisan Infrastructure Law, primarily emphasize new construction. Greater attention is needed on strengthening long-term maintenance capacity. In contexts where local fiscal capacity is limited, alternative resilience strategies that require less ongoing maintenance may offer more sustainable protection than large-scale infrastructure projects.

Second, most climate policies and infrastructure investments adopt a static framework to evaluate costs and benefits. In reality, behavioral responses in the real estate market to climate risk can generate feedback loops through public finance. This paper identifies the presence of such feedback dynamics and underscores the need to account for system dynamics in policy evaluation. This has implications beyond infrastructure policy, as identifying the tipping points that shift communities into different equilibria can fundamentally alter the optimal allocation of investments.

Finally, while this paper highlights how decentralized financing can entrench fiscal and climate vulnerability through feedback loops, it does not advocate a centralized financing model as the optimal solution. Expanded state or federal support may alleviate local fiscal constraints, but could also create incentive distortions, particularly moral hazard in land use and development decisions in high-risk areas. Future research should formally assess the welfare implications of alternative financing models that balance resilience investments against risks of over development in high-risk areas.

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Supplementary Tables

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.

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.

Table S3: Manual and AI validations of levee failure

	All Tracts (1)	Filtered Tracts (2)	All Tracts (AI) (3)	Filtered Tracts (AI) (4)
Confirmed	140 (50.4%)	129 (73.3%)	227 (81.7%)	159 (90.3%)
Likely/Uncertain	100 (35.9%)	39 (22.2%)	37 (13.3%)	9 (5.1%)
Unlikely	38 (13.7%)	8 (4.5%)	14 (5.0%)	8 (4.5%)
Total	278	176	278	176

Note: Only cases when flood inundation within the levee exceeded 25% of a census tract's area, as determined by satellite imagery, have been inspected. Filtered tracts refer to those located within FEMA flood zones and outside of Florida. Census tracts not included in the FEMA flood map are typically rural and lack infrastructure. Florida tracts, despite having high levels of levee protection, are vulnerable to hurricane-induced flooding, which increases the likelihood of misclassifying levee failures. "Confirmed" denotes cases consistent with USACE riverine levee loading and incidence database records (Flynn et al., 2025) or confirmed by news reports with specific location details. "Likely/Uncertain" refers to cases absent from the USACE records and where news reports mention significant flooding but do not specify exact locations of levee failures. "Unlikely" refers to no evidence of levee failure in any sources. Both manual classification (conducted by the researcher through online searches) and AI classification (Sonnet 4.6) are included.

Table S4: Income and history of flood inundation within levees for the full sample

	Times flooded behind levee since 2000			
	(1)	(2)	(3)	(4)
Log(Per Capita Income)	-0.326***	-0.308**	-0.203	-0.218
	(0.126)	(0.127)	(0.138)	(0.138)
Floodzone Ratio	0.700***	0.742***	0.572***	0.610***
	(0.177)	(0.178)	(0.191)	(0.193)
Log(Protection Level)		-0.311***	-0.209***	
		(0.054)	(0.072)	
Acceptable Quality			-1.122***	-1.177***
			(0.166)	(0.171)
State FE	Yes	Yes	Yes	Yes
Protection level FE	No	No	No	Yes
Observations	2,089	2,062	1,700	1,700
Adjusted R^2	0.261	0.273	0.284	0.287

Note: *p<0.1; **p<0.05; ***p<0.01. Census tract is the unit of observation. Income indicates per capita income from the 2019 American Community Survey. Only levee-reliant census tracts (i.e., with at least 25% land area protected by levee systems) and have data for maintenance quality are included in the analysis. Floodzone ratio indicates share of land area of the census tract within the 100-year flood zone of FEMA. Protection level is measured in the highest level of flood this levee is designed to protect, with 500 indicates withstanding floods of 500 year return period. Acceptable quality is a dummy variable indicating whether a levee is acceptable or minimally acceptable maintenance quality from inspection rating of USACE. State fixed effects and levee ownership (federal or nonfederal) fixed effects are controlled. Flood inundation within levees with area larger than 10 grid cells (i.e., 0.625 square kilometers) are considered as flood inundation within levees to reduce measurement errors.

Table S5: Levee quality and neighbourhood socio-economic conditions without restricting to complete maintenance quality data

	Log(Protection Level)		(Minimally) Acceptable Quality	
	(1)	(2)	(3)	(4)
Log(Per Capita Income)	0.159***		0.084***	
	(0.040)		(0.016)	
Log(Housing Value)		0.181***		0.146***
		(0.034)		(0.014)
Log(Levee Population)	0.122***	0.124***	0.038***	0.035***
	(0.014)	(0.014)	(0.005)	(0.005)
State FE	Yes	Yes	Yes	Yes
Protection level FE	No	No	Yes	Yes
Floodzone Ratio Control	Yes	Yes	Yes	Yes
Observations	2,915	2,870	2,340	2,300
Adjusted R^2	0.506	0.511	0.535	0.553

Notes: *p<0.1; **p<0.05; ***p<0.01. Census tract is the unit of observation. Levee quality is measured in protection level (e.g., 500-year protection) and maintenance quality (i.e., a dummy variable indicating "Acceptable" or "Minimally Acceptable" maintenance quality). Per capita income and median housing value are from the 2019 American Community Survey. Population indicates the population behind levees from National Levee Database. The sample focuses on levee-reliant communities (i.e., more than 25% areas protected by levee) with flood risk (i.e., non-zero area within the FEMA flood zone without considering levee protection).

Table S6: Technology shock IV on pre-treatment socio-economic variables.

	Pre-Treatment Characteristics			
	Income 1980	Homeownership 1980	Home Value 1970	Home Value 1960
	(1)	(2)	(3)	(4)
Routine Occupation	-0.140	0.338	0.499	2.162
	(0.603)	(0.354)	(0.382)	(1.727)
1980 home value	Yes	Yes	Yes	Yes
Floodzone share	Yes	Yes	Yes	Yes
Levee population	Yes	Yes	Yes	Yes
Levee protection FE	Yes	Yes	Yes	Yes
State FE	Yes	Yes	Yes	Yes
Observations	1,902	1,900	1,784	1,351
Adjusted R^2	0.604	0.037	0.797	0.146

Notes: *p<0.1; **p<0.05; ***p<0.01. Census tract is the unit of observation. Standard errors are clustered at the commuting zone level. Income and home value are log transformed. The technology shock IV is defined as routine occupation intensity following Autor and Dorn (2013).

Table S7: Impact of Housing Value on Levee Maintenance: Newly Constructed Levees.

	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)
First Stage				
Routine Occupation	13.777***		84.326***	
	(3.556)		(14.028)	
First-stage F-statistic	15.013		36.136	
TSLS				
Housing value change		0.976***		0.159***
		(0.319)		(0.028)
Controls				
1980 home value	Yes	Yes	Yes	Yes
1980 population	Yes	Yes	Yes	Yes
Floodzone share	Yes	Yes	Yes	Yes
Levee protection FE	Yes	Yes	Yes	Yes
State FE	Yes	Yes	Yes	Yes
Observations	70	70	70	70
Adjusted R^2	0.854	0.387	0.798	0.442

Notes: *p<0.1; **p<0.05; ***p<0.01. Census tract is the unit of observation. Standard errors are clustered at the commuting zone level. Only levees with construction year data and are constructed between 1970 and 1980 are kept in the sample. The technology shock IV is defined as routine occupation intensity following Autor and Dorn (2013).

Table S8: Impact of Housing Value on Levee Maintenance: State Sponsored Levees.

	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)
First Stage				
Routine Occupation	2.539**		14.338**	
	(1.115)		(5.792)	
TSLS				
Housing value change		0.176		0.031
		(0.857)		(0.150)
Controls				
1980 home value	Yes	Yes	Yes	Yes
1980 population	Yes	Yes	Yes	Yes
Floodzone share	Yes	Yes	Yes	Yes
Levee protection FE	Yes	Yes	Yes	Yes
State FE	Yes	Yes	Yes	Yes
Observations	260	260	260	260
Adjusted R^2	0.326	0.895	0.185	0.892

Notes: *p<0.1; **p<0.05; ***p<0.01. Census tract is the unit of observation. Standard errors are clustered at the commuting zone level. Only levees with state governments involved as local sponsors are kept in the sample. The technology shock IV is defined as routine occupation intensity following Autor and Dorn (2013).

Table S9: Impact of Housing Value on Levee Maintenance: Small Levees.

	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)
First Stage				
Routine Occupation	2.667***		10.720**	
	(1.023)		(4.178)	
TSLS				
Housing value change		-0.180		-0.045
		(1.015)		(0.255)
Controls				
1980 home value	Yes	Yes	Yes	Yes
1980 population	Yes	Yes	Yes	Yes
Floodzone share	Yes	Yes	Yes	Yes
Levee protection FE	Yes	Yes	Yes	Yes
State FE	Yes	Yes	Yes	Yes
Observations	266	266	266	266
Adjusted R^2	0.456	0.389	0.412	0.348

Notes: *p<0.1; **p<0.05; ***p<0.01. Census tract is the unit of observation. Standard errors are clustered at the commuting zone level. Only levees sponsored by municipalities yet only protect less than 25% land areas of the municipality are kept in the sample. The technology shock IV is defined as routine occupation intensity following Autor and Dorn (2013).

Table S10: 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.

Table S11: Municipalities Revenue Source

	Median (thousand $)	Mean (thousand $)	N
Total Revenue	546	17,749	33,816
Property Tax	138	4,078	33,816
Intergovernmental Revenue	107	3,557	33,816
Charges and Fees	69	4,016	33,816
License Tax	2	419	33,816
Income Tax	0	1,180	33,816
Sales Tax	0	1,849	33,816
Utility Revenue	0	2,626	33,816

Note: The table reports the median and mean revenue by source across municipalities and towns in 2017, based on data from the U.S. Census of Governments. Zero medians reflect that most municipalities do not levy income, sales, license, or utility taxes.

Table S12: Share of Zero-Valued Observations in Municipal Finance Data

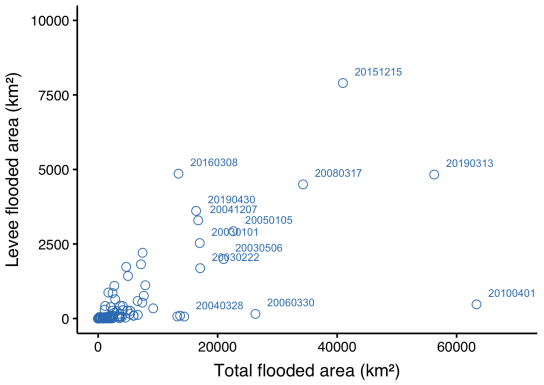
Outcome	Specification	Total Obs.	Zero Count	Zero Share
Population	Levee	3,036	0	0.0000
Property Tax	Levee	3,036	218	0.0718
Intergovernmental Revenue	Levee	3,036	103	0.0339
Total Revenue	Levee	3,036	10	0.0033
Total Expenditure	Levee	3,036	10	0.0033
Capital Outlays	Levee	3,036	980	0.3228
Population	No Levee	21,356	5	0.0002
Property Tax	No Levee	21,357	1,320	0.0618
Intergovernmental Revenue	No Levee	21,357	658	0.0308
Total Revenue	No Levee	21,357	60	0.0028
Total Expenditure	No Levee	21,357	62	0.0029
Capital Outlays	No Levee	21,357	4,946	0.2316

Notes: Zero share is calculated as the proportion of municipality–period observations with outcome equal to zero within each estimation sample. The levee sample includes municipalities with at least 10 percent of area protected by levees used in the levee-failure analysis. The no-levee sample includes municipalities without levee protection used in the flooding analysis.

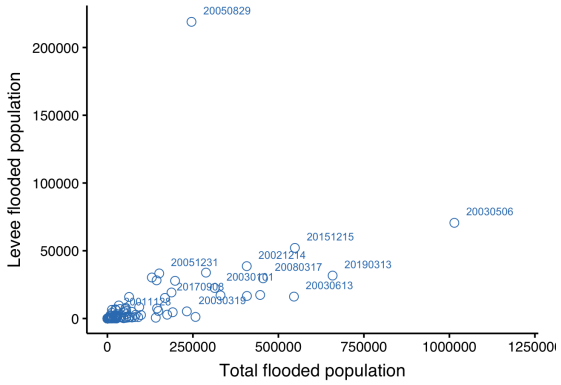
Supplementary Figures

Figure S1: Satellite imagery identified flooding areas and population.

(a) Flooded Area



(b) Affected Population



Notes: Affected population for each census tract is calculated by the proportion of census tract getting flooded times the census tract population.

Figure S2: Example levee project cost-benefit analysis

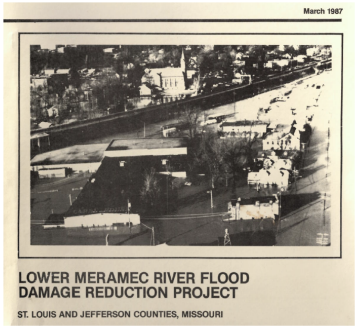


TABLE 3

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.

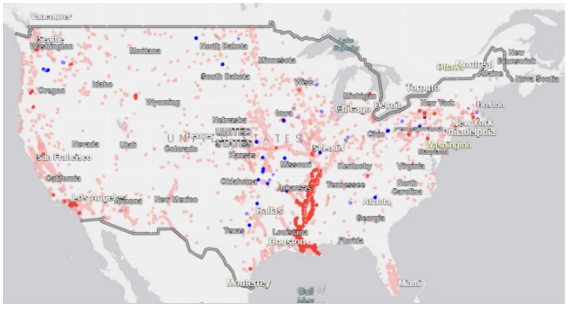
TABLE 11
VALLEY PARK LEVEE
HEIGHT OPTIMIZATION

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

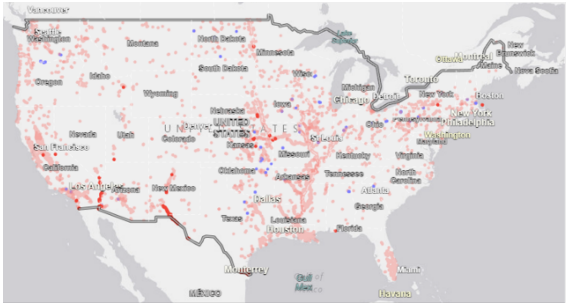
Notes: Figure sources from USACE 1987 plan formulation document.

Figure S3: Distribution of federal and local maintained levees

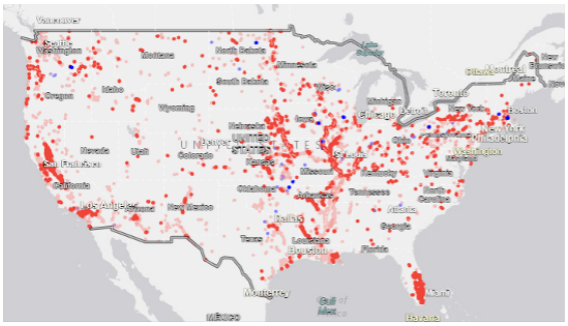
(a) USACE constructed and maintained



(b) Other Federal Agency



(c) USACE constructed and locally maintained



(d) Locally constructed and locally maintained

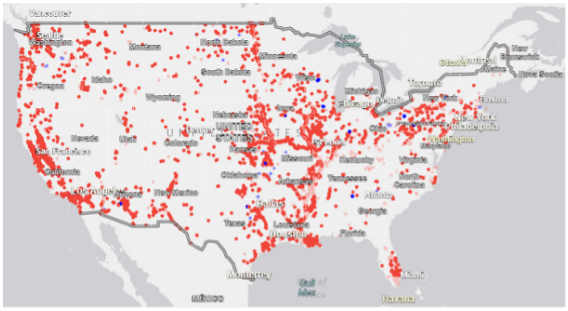
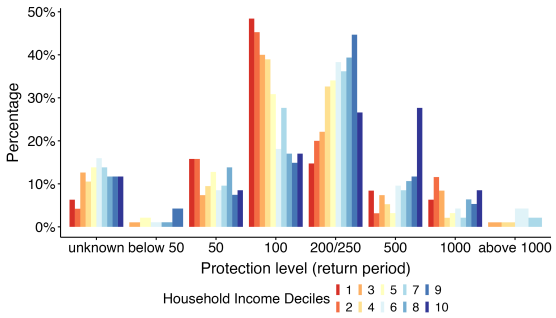
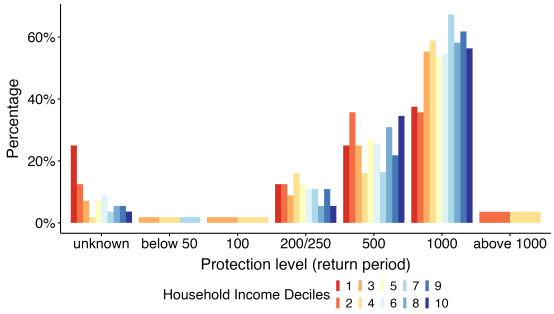


Figure S4: Income distribution in levee-dependent flood zone communities

(a) California

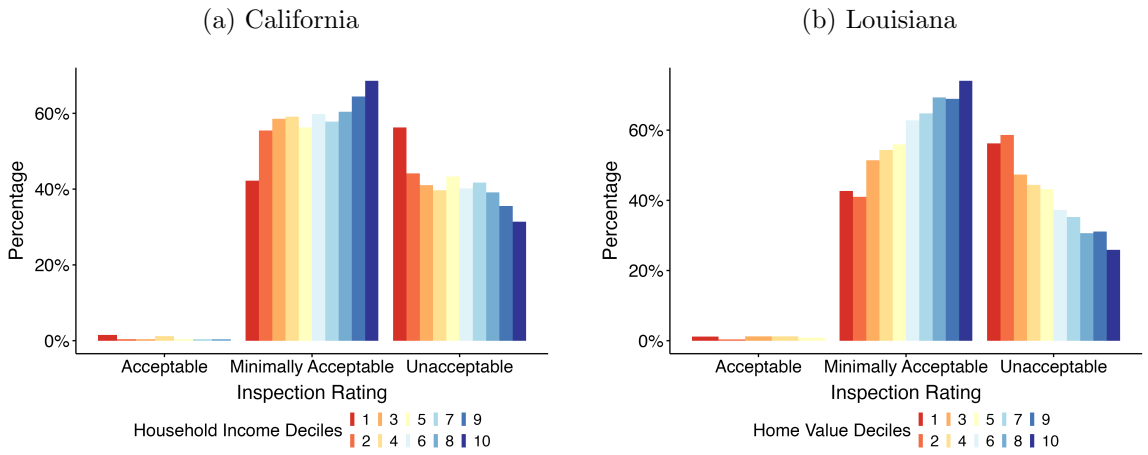


(b) Louisiana



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.

Figure S5: Maintenance rating and income/ home value



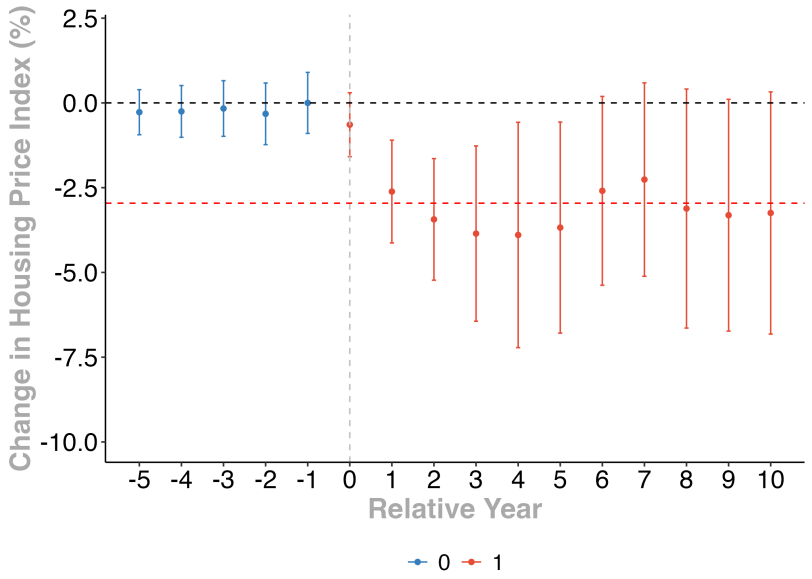
Notes: Sample includes levee-reliant census tracts, defined as more than 25% of land protected by levee. Maintenance quality is based on the most recent inspection ratings from the USACE National Levee Database. Census tracts are grouped into within-state deciles of income or housing value. For each decile, I report the share of tracts rated as "Acceptable", "Minimally Acceptable", and "Unacceptable", with proportions summing to 100%.

Figure S6: Levee construction timeline



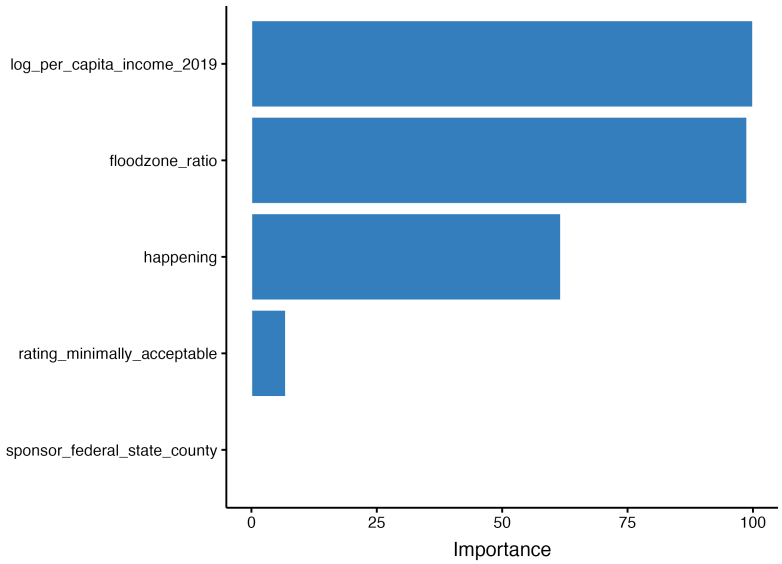
Notes: Construction year information is incomplete. The figure reports the distribution of construction years for levees with non-missing data.

Figure S7: Effects of flooding within levee on housing price for extended period



Notes: Treatment is defined as any flood inundation (flooded area above 0). Housing price index (HPI) changes are scaled to percentage terms using the average tract-level HPI. Event study estimates are based on the Callaway Sant'Anna estimators (Callaway and Sant'Anna, 2021), which allows for dynamic treatment effects and corrects for bias in staggered adoption designs by estimating pseudo-treatment effects in pre-periods.

Figure S8: Random forest feature importance selection

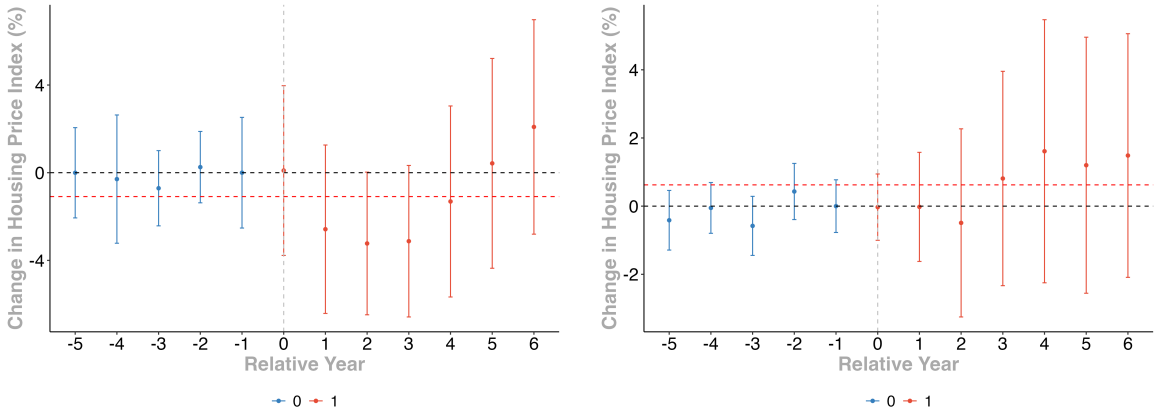


Notes: The figure reports variable importance from a random forest model predicting tract-level treatment effects of levee failure. Predictors correspond to the main heterogeneity dimensions considered in Figure 6. Importance is measured using permutation-based metrics from a cross-validated random forest. All predictors are standardized prior to estimation. The sample is restricted to tracts with non-missing covariates.

Figure S9: Effect of nearby flooding on neighbourhood housing price

(a) Nearby flooding for tracts with levee

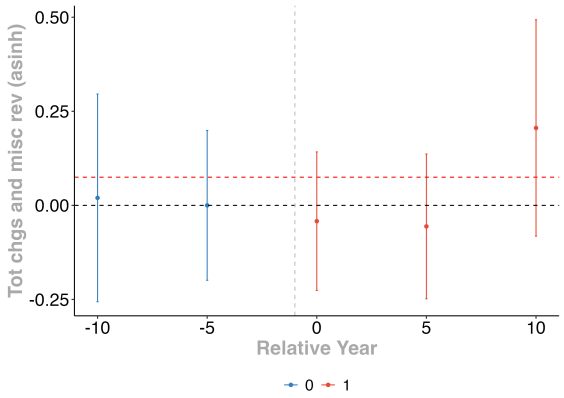
(b) Nearby flooding for tracts without levee



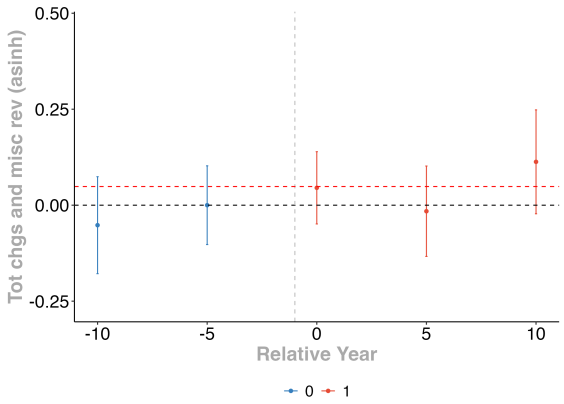
Note: Treatment of nearby flooding defined as flooded area above 10% within the county of the census tract. The census tract of interest does not experience flooding itself. The event study plots use Callaway & Sant'Anna estimators (Callaway and Sant'Anna, 2021), which dynamically computes pseudo-treatment estimates of the average treatment effect in pre-treatment periods.

Figure S10: Effect of flooding on other revenue

(a) Charges and Fees: Levee Failure



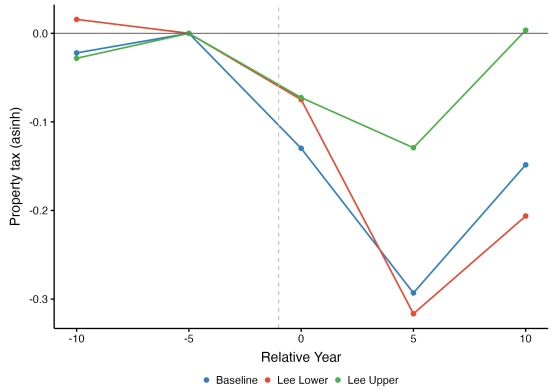
(b) Charges and Fees: Flooding Outside Levees



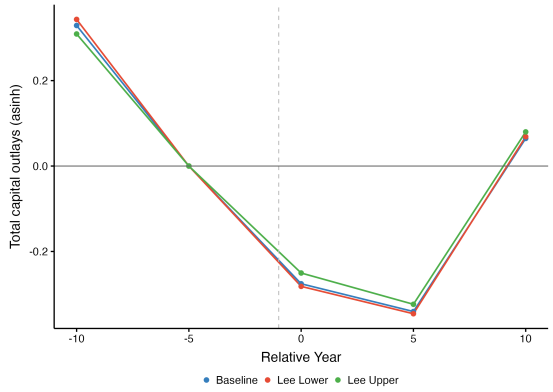
Note: Treatment is defined as flooding affecting tracts containing at least 10% of the municipal population. Coefficients at 0, 5, and 10 represent effects observed 0–4, 5–9, and 10–14 years after the event, respectively. All outcome variables are transformed using the inverse hyperbolic sine; percentage effects are computed as $\Delta Y\% = e^{\hat{\beta} - 0.5\,\mathrm{var}(\hat{\beta})} - 1$ (Kennedy, 1981; Bellemare and Wichman, 2020). For levee failure estimates, both treatment and control groups include levee-protected municipalities. For flooding outside levees, both groups consist of municipalities without levees. Estimates use Callaway & Sant'Anna estimators (Callaway and Sant'Anna, 2021), which dynamically compute pseudo-treatment estimates of the average treatment effect in pre-treatment periods.

Figure S11: Lee bound intensive margin estimates of levee failure effects.

(a) Property Tax: Levee Failure



(b) Capital Outlay: Levee Failure



Note: Treatment is defined as flooding affecting tracts containing at least 10% of the municipal population. Coefficients at 0, 5, and 10 represent effects observed 0–4, 5–9, and 10–14 years after the event, respectively. All outcome variables are transformed using the inverse hyperbolic sine; percentage effects are computed as $\Delta Y\% = e^{\hat{\beta} - 0.5\,\mathrm{var}(\hat{\beta})} - 1$ (Kennedy, 1981; Bellemare and Wichman, 2020). Both treatment and control groups include levee-protected municipalities. Lee bound estimates are used to estimate the effect of levee failure for "always-takers" who would have positive revenue and expenditure regardless of treatment ($Y(1) > 0$, $Y(0) > 0$) (Lee, 2009; Chen and Roth, 2024).

Supplementary Notes

A. NPV of levee maintenance

Annual maintenance cost

The maintenance cost is estimated as a proportion of the initial construction cost as comprehensive maintenance investment reports are not available. Bradt and Aldy (2022) collected construction costs from congress reports and estimated average levee construction cost per mile as \$60.781 Million (in 2019 USD) (Figure S12a). Maintenance cost is not reported as it is not federal responsibility. I obtain the maintenance cost estimate from the plan formulation of Valley Park Levee and assume a fixed ratio between construction and maintenance cost as $26,900/11,579,200 = 0.232\%$ (Figure S12b). The formula for annual maintenance cost in 2019 USD is $LeveeMile \times 60.781M \times 0.232\%$, with levee length data coming from the National Levee Database and differs for each levee system.

Figure S12: Levee Maintenance Cost Data Source

(a) Construction Cost Per Mile

	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

(b) Maintenance Cost Ratio

COST DATA:	Flood Control	Recreation	Total
Initial Cost:	\$11,579,200	\$220,800	\$11,800,000
Annual O&M&R 1/ :	\$26,900	\$26,800	\$ 53,700
Total Annualized Cost 2/ :			\$ 1,077,000

Notes: Figure (a) sources from Bradt and Aldy (2022). Figure (b) sources from 1987 USACE Valley Park Levee Plan Formulation.

Levee failure damages

Maintenance benefit is estimated as the avoided levee failure damages. I first estimate the expected property damages during levee failures. I obtain the total property value protected by each levee system from 2019 national property inventory of USACE, which measures the replacement cost value for both residential and non-residential structures from county appraisal tax databases. The appraisers for each county use the dimensions of the building and the square footage, the interior and exterior materials used to build the structure, the

function of the building, and the HVAC and plumbing makeup for the structure, to determine a new replacement cost for each structure. It is thus not subject to the strategic reports of property owners. From this replacement cost, a depreciation scheme is applied based on the age and condition of the structure(See USACE (2014) for detailed discussion).

Flooding events with different severity (measured in return period) have different probability of triggering levee failure. I obtain estimates of structural failure probability at different flood severity from the USACE Manhattan Local Protection Project Feasibility Study (Figure S13a). Given levee failure happens, the conditional probability of flood severity is as below:

Flood Type	50%	20%	10%	4%	2%	1%	0.2%	0.1%
Failure Probability	0%	0%	1.32%	17.96%	36.44%	41.19%	3.09%	0%

Note: The calculation takes into account both flood frequency and the structural failure probability. For example, although levee failure probability is very high at a flood of 500 year return period, the probability of such an event happening is low each year, resulting in a low conditional probability.

I then estimate the expected property damage ratio for flood events with varying severity based on residential damages estimated for the Valley Park Levee plan formulation (Figure S13b).

Flood Type	50%	20%	10%	4%	2%	1%	0.2%	0.1%
Property Damages	0.13%	0.66%	2.63%	6.92%	11.28%	16.20%	26.31%	35.77%

Using statistics in both tables, conditional on levee failure happens, the estimate of the expected damage is 12.87% of protected property value. The formula for levee failure damages in 2019 USD is as $ProjectedPropertyValue \times 12.87\%$, with property value from 2019 USACE property inventory and veries by levee systems.

Reduced levee failure risk

I then estimate how maintaining levees to (minimally) acceptable maintenance quality would reduce the probability of levee failures. Although maintenance deficiency could lead to repeated levee failure events, it is difficult to quantify property damages in the second or third failure events within 1-2 decades because buildings might not have been rebuilt yet. I thus focus on the calculation of the first levee failure event to provide a conservative estimate. Using satellite imagery to construct the probability of flooding at least once from 2000 to 2021, I find that having levees of maintenance deficiency increases levee failure probability by 11% (Table S13), equivalent to 0.49% increase in annual levee failure risk.

Annual Maintenance Benefit

Synthesizing levee failure damages and reduced levee failure risk due to maintenance, the

Table S13: Levee maintenance and levee failure risk

	Flood in leveed area since 2000 (indicator)	
	(1)	(2)
Log(Protection Level)	-0.043***	
	(0.012)	
Acceptable Quality	-0.106***	-0.112***
	(0.031)	(0.032)
State FE	Yes	Yes
Protection level FE	No	Yes
Floor Zone Control	Yes	Yes
Observations	1,700	1,700
Adjusted R^2	0.250	0.253

Note: *p<0.1; **p<0.05; ***p<0.01. Census tract is the unit of observation. Protection level is measured in the highest level of flood this levee is designed to protect, with 500 indicates withstanding floods of 500 year return period. Acceptable quality is a dummy variable indicating whether a levee is acceptable or minimally acceptable maintenance quality from the inspection rating of USACE.

annual maintenance benefit for each levee is calculated as $ProtectedValue \times 0.49\% \times 12.87\%$. This is a very conservative estimate of maintenance benefits as it only considers property damages under historical climate conditions. In reality, levee failures also lead to life losses, infrastructure damages, and other economic losses, and these damages will be worsened by climate change. Under this calculation, the extra annual flood damages due to levee maintenance deficiency are 317 Million USD, which is about 5.8% of annual US flood damages (NOAA, 2024).

Figure S13: Expected Levee Failure Damages Data Source

(a) Structural Failure Risk by Flood

Table 21: HEC-FDA Manhattan Levee Assurance - Existing Condition Overtopping and Levee Failure

Manhattan Levee	Confluence Reach	Kansas Reach	Big Blue Reach
Assurance (Conditional Non-Exceedance Probability)			
10% event	100.0%	99.9%	99.7%
4% event	97.0%	96.6%	94.1%
2% event	86.2%	86.2%	76.9%
1% event	62.4%	62.8%	52.6%
0.4% event	22.5%	22.4%	9.4%
0.2% event	6.4%	6.2%	3.5%
Long-Term Exceedance Probability			
10 years	10.6%	10.8%	14.2%
30 years	28.5%	29.0%	36.8%
50 years	42.9%	43.5%	53.4%
Expected Annual Exceedance Probability	1.1%	1.1%	1.5%
Height Above the Expected 1% Stage to Top of Levee (ft)	3.7	4.8	3.7

Table 22 contains information on the levee performance based on overtopping only, without considering any geotechnical or structural deficiencies in the levee. As would be expected, the levee performance is much better when not considering the structural and geotechnical deficiencies in the levee. Assurance (formerly referred to as conditional non-exceedance probability) increases by about 35% for the 1% chance flood (52.6% vs. 88.9%). Assurance in the 0.2% chance flood is 3.5% for overtopping plus deficiencies versus 9.1% for overtopping alone.

Table 22: HEC-FDA Manhattan Levee Assurance – Existing Condition Overtopping Only

Manhattan Levee	Confluence Reach	Kansas Reach	Big Blue Reach
Assurance (Conditional Non-Exceedance Probability)			
1% (100 year)	93.4%	94.0%	88.9%
0.4% (250 year)	51.1%	51.2%	21.8%
0.2% (500 year)	18.5%	17.9%	9.1%
Long-Term Exceedance Probability			
10 years	4.6%	4.5%	6.1%
30 years	13.1%	13.0%	17.3%
50 years	20.8%	20.6%	27.1%
Expected Annual Exceedance Probability	0.5%	0.5%	0.6%

(b) Property Damage Ratio by Flood

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

B. Diagnosis of the Validity of Shift Share IV

To assess whether the identifying variation is driven by a narrow set of industries, I reconstruct the technology-exposure instrument using the original 1950 Census microdata, following Autor and Dorn (2013). The procedure involves: (i) obtaining occupation-level employment shares in 1980 and the Routine Task Intensity (RTI) index from Autor and Dorn (2013), and classifying as routine-intensive those occupations in the top employment-weighted third of the RTI distribution; (ii) constructing commuting-zone–level industry and occupation compositions from the 1-percent sample of the 1950 Census; (iii) computing industry employment shares in 1950 for each commuting zone using the SEA–CZ crosswalk to align geographic units; (iv) calculating leave-one-state-out national routine intensity measures at the industry level; and (v) interacting local industry shares with these leave-one-out measures to form the Bartik-style instrument. The reconstructed instrument has a Pearson correlation of 0.904 with the baseline measure used in Table 5, confirming that the reconstruction closely approximates the original [29].

Using this reconstructed shift–share design, I compute Rotemberg weights following Goldsmith-Pinkham et al. (2020). Because of the leave-one-state-out specification, weights are constructed at the industry–state level and aggregated to industries for presentation. A Herfindahl index of 0.053 indicates that the Rotemberg weights are reasonably dispersed across sectors, implying that the instrument is not excessively concentrated. The top five industries—national security and international affairs, insurance, printing and publishing, aircraft and parts, and banking—account for 31.5 percent of the total positive weight (0.623/1.980), suggesting that the identifying variation is not dominated by any single industry. Table S14 presents the Rotemberg weights by industry.

Table S14: Rotemberg weights and average beta by industry.

Industry	$\hat{\alpha}_k$	g_k	$\hat{\beta}_k$	Ind. share
National security and international affairs	0.328	0.563	-0.030	0.038
Insurance	0.133	0.856	0.081	0.011
Printing, publishing, and allied industries, except newspapers	0.072	0.566	0.074	0.012
Aircraft and parts	0.046	0.316	0.713	0.004
Banking	0.044	0.705	0.083	0.008

Note: Rotemberg weight construction is by industry-state, as leaving one out specification is used in the shift share technology shock IV. The results are aggregated to industry level for presentation.

Although public administration (particularly national security) receives a large Rotemberg weight, its just-identified IV coefficient is close to zero. This likely reflects the distinctive labor-market structure of government employment, which is less responsive to market-driven

[29] Because Autor and Dorn (2013) do not provide the scripts mapping raw Census data to the final instrument, exact replication is not feasible. The high correlation suggests that remaining discrepancies reflect minor sample or processing differences and do not materially affect the decomposition analysis.

automation shocks and characterized by more stable labor demand and institutional rigidities. Excluding national security increases the implied 2SLS estimate from 0.131 to 0.212[30], suggesting that the primary transmission mechanism operates through private-sector routine exposure rather than public employment.

To further assess the identifying assumption, I examine pre-trends in housing values in 1960 and 1970 with respect to the industry shares of the five industries with the largest Rotemberg weights. Table S15 shows little evidence of systematic pre-trends: coefficients are generally insignificant, and the only marginally significant estimate (aircraft and parts in 1970) has a sign opposite to the post-period pattern that would threaten identification. Although pre-trends in levee maintenance quality cannot be directly tested due to data limitations, maintenance quality is likely to have been high when infrastructure was newly constructed.

Table S15: Pre-trend tests of industry share for top five industries.

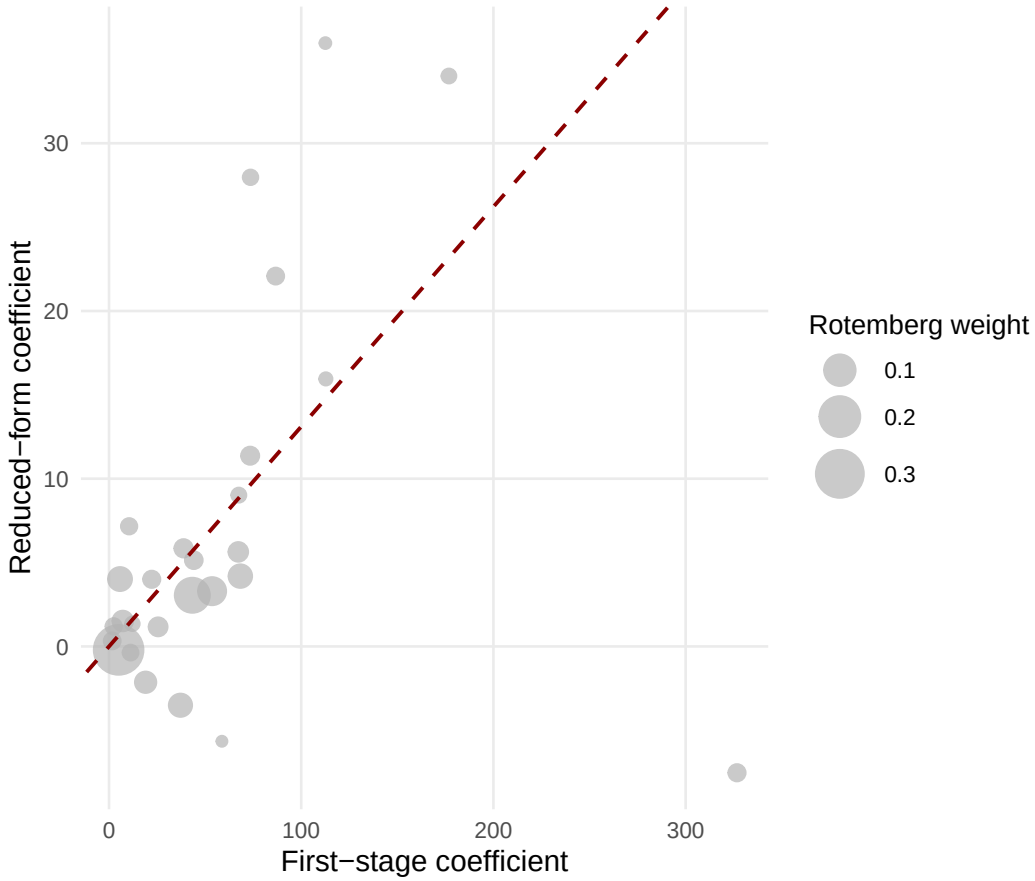
Industry	Share on housing value (1970)	Share on housing value (1960)	Observations
National security and international affairs	-0.628	0.504	1,302
	(0.510)	(1.901)	
Insurance	0.762	5.077	1,302
	(1.682)	(7.336)	
Printing and publishing	1.342	5.737	1,302
	(1.434)	(7.784)	
Aircraft and parts	0.773*	3.029	1,302
	(0.461)	(1.959)	
Banking	1.780	-1.968	1,302
	(3.438)	(14.477)	

Notes: *p<0.1; **p<0.05; ***p<0.01. Census tract is the unit of observation. Standard errors are clustered at the commuting zone level. Housing value is log transformed.

[30]The small discrepancy relative to the baseline estimate reflects the use of reconstructed microdata rather than the original instrument directly from Autor and Dorn (2013).

Finally, to assess sensitivity to the manner in which share instruments are combined, I implement the visual overidentification diagnostic emphasized by Borusyak et al. (2025). Figure S14 plots reduced-form coefficients against the corresponding first-stage coefficients for industries with Rotemberg weights exceeding 0.01. Under the null that all shares identify a common parameter, the points should lie along a ray through the origin with slope equal to the 2SLS estimate. The estimates are broadly aligned with this fitted ray, particularly among industries with larger Rotemberg weights, indicating that the shift-share estimate is not driven by a narrow subset of industries and is not sensitive to the choice of instrument aggregation.

Figure S14: Visual instrument variable for overidentification test



Notes: Reduced form and first stage coefficients using each industry share as the instrument. Bubble size shows the Rotemberg weight. Industries with Rotemberg weights above 0.01 are kept in the sample.