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

Yichun Fan*

March 19, 2026

**Abstract**

Local financing of climate infrastructure links infrastructure quality with housing value through property tax revenue. I examine how this connection shapes long-term neighborhood dynamics. Using novel data on levee quality, I show that lower-income neighborhoods are disproportionately behind levees of maintenance deficiencies, increasing levee failure risk. Exploiting exogenous shocks to local economic conditions and levee failures, I find that weaker housing markets degrade levee maintenance, while levee failures in turn reduce housing values and local revenues. These bi-directional dynamics generate a feedback loop of fiscal stress and climate vulnerability, and contribute to underinvestment in resilience infrastructure.

*Duke University. Email: yichun.fan@duke.edu. I thank Mariana Arcaya, Matthew Kahn, Antoinette Schoar, and Siqi Zheng for valuable advice. I am also grateful to Spencer Banzhaf, Devin Michelle Bunten, Harrison Fell, Amy Finkelstein, Roger von Haefen, Nathaniel Hendren, Mark Jeuland, Bram van der Kroft, Yanjun (Penny) Liao, Andrés de Loera, Jasdeep Mandia, Abigail Ostriker, Juan Palacios, Christopher Palmer, Subhrendu Pattanayak, Albert Saiz, Martin Smith, Charles Taylor, Farshid Vahedifard, Maxence Valentin, Jeffrey Vincent, Zhenxuan Wang, and participants at the ASSA Annual Meeting, ACSP Annual Conference, Triangle Resource and Environmental Economics Seminar, MIT Climate and Real Estate Symposium, Harvard Environmental Economics Workshop, and MIT Public Finance Workshop for helpful comments and suggestions.

# 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 dilemma, 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 that arises when climate infrastructure maintenance is financed through decentralized systems. While the potential moral hazard from federal investments has received growing attention (Henkel et al., 2022), less is known about the consequences of relying on local fiscal capacity to sustain resilience infrastructure. I examine this dynamic 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). Although levee construction is often federally cost-shared, ongoing maintenance falls largely to local sponsors like municipalities and special districts—many of which 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% of levee systems are rated "Unacceptable" by the U.S. Army Corps of Engineers (USACE), indicating a breaching risk before floodwaters reach the designed protection levels. Levee failures, defined as flood inundation within levee-protected areas, can result in property damages and local revenue loss, 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). In resource-constrained neighborhoods, such shocks may further tighten fiscal constraints and perpetuate underinvestment in resilience infrastructure.

Identifying the feedback loop is empirically challenging because infrastructure quality and realized performance are rarely observed jointly at scale. I overcome this constraint by as-

[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).

sembling 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) [2] with the maintenance inspection records from the USACE National Levee Database [3]. I then spatially link these system-level levee quality measures to a newly constructed 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 disparities in levee quality as a function of local economic conditions. A one standard deviation increase in census tract income is associated with an 2.3 percent increase in designed levee protection level and a 6.5 percent (3.8 percentage point) increase in the probability of receiving (minimally) acceptable maintenance ratings. The relationship is even stronger when using housing value as the economic indicator. These disparities are concentrated in areas where municipalities and special districts are responsible for levee maintenance, and are absent when higher levels of government (federal, state, or county) are involved, highlighting the role of local public finance. 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. Controlling for maintenance quality reduces income-based disparities in failure risk by 32 percent and renders them statistically insignificant.

Motivated by the descriptive evidence, I estimate the bidirectional relationship between neighborhood housing values and levee maintenance quality. I address simultaneity by exploiting exogenous variation in housing value growth generated by the national computerization shock in 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 of

[2] While the NLD reports annual exceedance probability 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).

[3] 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.

this technology shock to isolate variation in housing value growth orthogonal to levee quality and flood risk [4]. The 2SLS estimates show that exogenous increases in housing values significantly improve maintenance quality: 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), accounting for the majority of observed cross-sectional variation in maintenance quality.

Second, I estimate the effect of infrastructure quality on housing markets and local fiscal outcomes using event studies around quasi-random levee failure events over the past two decades. Identification relies on exogenous variation from extreme weather shocks, such as heavy rainfall and hurricane paths, conditional on baseline income and flood risk. 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, I find that flooding alone leads to only temporary changes in housing values. In contrast, flooding associated with levee failure results in persistent 3–9 percent reductions in housing prices, with no evidence of recovery. Levee failures also trigger negative income sorting, with post-disaster mortgage buyers having significantly lower incomes.

I find suggestive evidence that declines in neighborhood housing values and income following levee failures have adverse local fiscal impacts. Using municipal budget data in an event study framework, I estimate a 5.6% reduction in total revenue after levee failures, with losses in property tax exceeding post-disaster intergovernmental transfers. The resulting revenue shortfall constrains local expenditures and limits post-disaster capital outlays. While data on special districts are limited, their heavier reliance on property taxes and more limited access to federal funding suggest that they may face even greater fiscal strain, making these estimates a likely lower bound.

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. This paper contributes to the debate by showing that decentralized infrastructure finance can exacerbate climate and economic inequality through a self-reinforcing feedback loop. Beyond equity concerns, the outcomes are far from efficient: I estimate an average

[4]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 S12

benefit-cost ratio of 8.81 for levee maintenance under conservative assumptions, yet 36.4 percent of levees with positive net present value remain under-maintained, disproportionately in low-income, fiscally constrained areas. A back-of-envelope estimate suggests that underinvestment results in annual efficiency losses at least of $272 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, 2023), 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; 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) [5], crowding out private adaptation (Vinnakota and Ziff, 2023; Bradt et al., 2021; Weill,

[5] 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).

2022), or imposing larger post-disaster fiscal burdens for capital outlays (Jerch et al., 2023), thereby magnifying economic impacts when protection systems fail.

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) [6]. 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. Protection levels vary greatly across system, ranging from 50% to 0.02% annual exceedance probability (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).

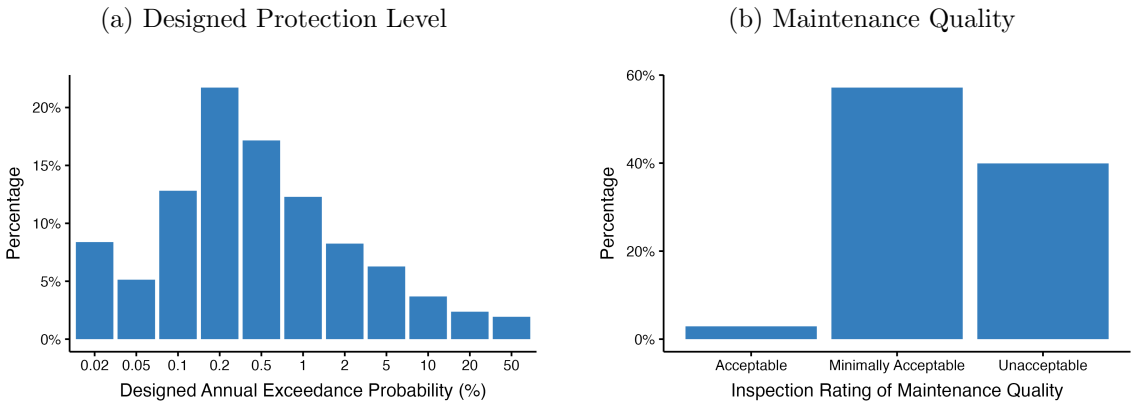
Maintenance quality is assessed through USACE's Rehabilitation and Inspection Program (RIP) [7]. Levees are rated as "Acceptable", "Minimally Acceptable", or "Unacceptable". A rating of "Unacceptable" indicates serious maintenance deficiencies that may cause the system to fail in flood and renders it ineligible for federal assistance unless corrected. As of the most recent data, 57.1 percent of levees are "Minimally Acceptable", 40.0 percent "Unacceptable", and only 2.9 percent "Acceptable" (Figure 3b).

While the NLD includes both federally and locally constructed levees, coverage is limited for the latter. Only 12.7 percent of locally constructed levees 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 systems are less likely to be inspected and generally lower in quality, my estimates likely

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

[7] 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.

understate the true extent of maintenance deficiencies.

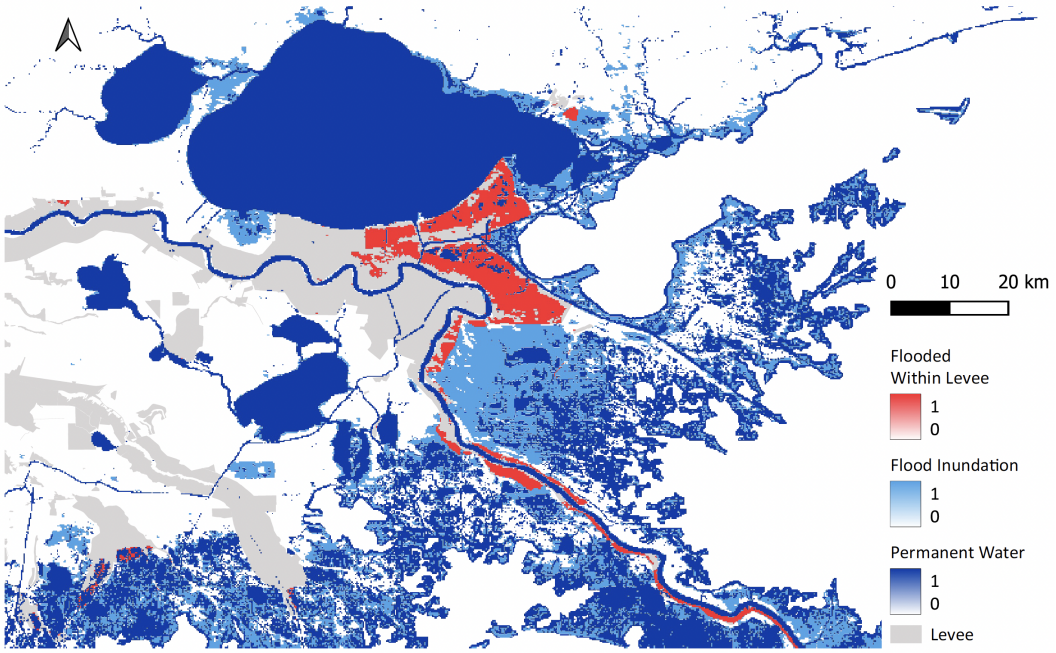
## 2.2 Levee Performance Data

To measure historical levee performance, I construct 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 publicaly 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 [8].

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.

[8]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 only for 4.5% of observations has no supporting evidence.

## 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 [9]. 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 method from Lee and Lin (2018). These variables are used to construct Bartik-style 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 measure 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 [10]. 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.[11] 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

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

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

[11] 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 | 17,656.700 | 73,250 |
| Median housing value | census tract | 271,248.800 | 246,013.500 | 71,958 |
| *Panel B. Levee and flood risk data* | | | | |
| Levee protection | levee system | 304.678 | 734.096 | 6,504 |
| Levee maintenance ((minimally) acceptable quality) | levee system | 0.399 | 0.490 | 1,718 |
| Levee failure experience | levee-dependent tract | 0.138 | 0.345 | 3,402 |
| 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 | 206.612 | 133.057 | 1,926,732 |
| Total revenue | municipality/ town | 20,658,880 | 592,824,600 | 742,497 |
| Property tax revenue | municipality/ town | 4,306,105 | 112,728,100 | 742,497 |
| Intergovernmental transfer revenue | municipality/ town | 4,604,192 | 184,165,100 | 742,497 |
| Total expenditure | municipality/ town | 20,967,750 | 612,178,400 | 742,497 |
| Capital outlay expenditure | municipality/ town | 3,213,985 | 79,612,120 | 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.

# 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) [12]. In contrast, disparities along the maintenance margin remain pronounced. Conditional on designed protection level, higher-income and higher-value neighborhoods are significantly 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 [13]. Housing value exhibits greater explanatory power for both designed protection and maintenance quality.

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 [14]. Maintenance, however, is predominantly the responsibility of local sponsors, except in limited cases involving federal navigation (Figure

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

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

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

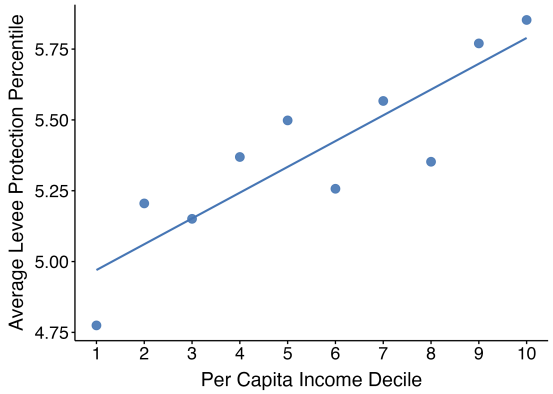
Table 2: Levee quality and neighbourhood socio-economic conditions

| | 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 |

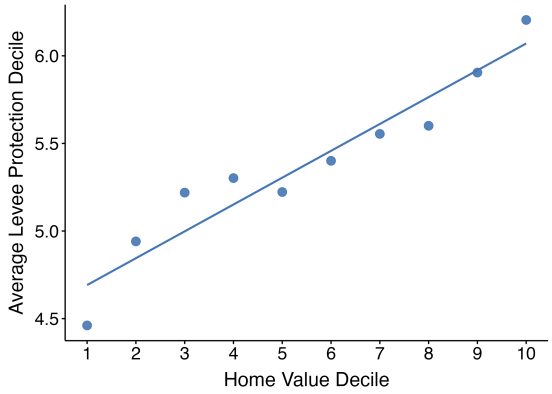
Notes: *p<0.1; **p<0.05; ***p<0.01. The unit of observation is the census tract. Levee protection is measured by return period (e.g., 500-year protection). Maintenance quality is a binary indicator equal to 1 if the levee is rated as "Acceptable" or "Minimally Acceptable". Per capita income and median 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).

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

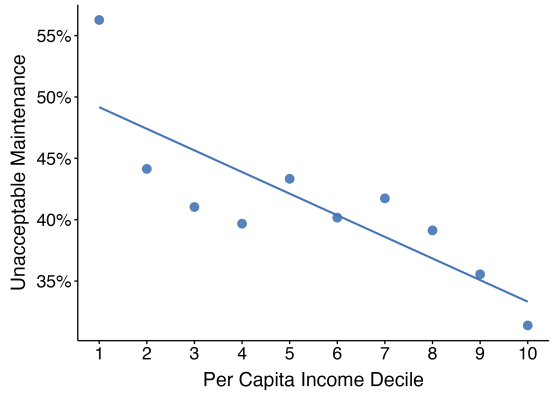
(a) Per Capita Income and Designed Protection



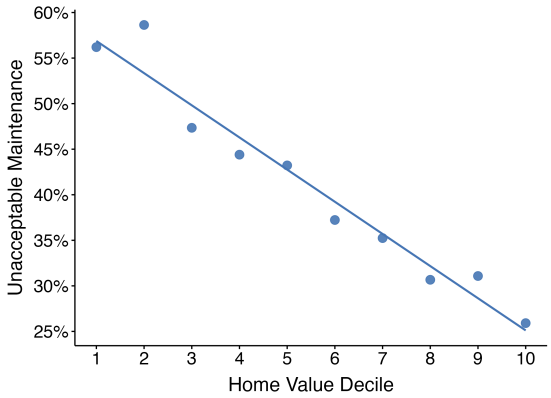

(b) Median Home Value and Designed Protection




(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.

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

income 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 no statistically significant income gradient. These patterns are robust to alternative specifications that use housing values as local economic measure and estimate heterogeneity through interaction terms rather than subgroup analyses (Table S6).

Table 3: Income inequality in levee maintenance quality by sponsorship

| | | (Minimally) Acceptable Quality | | |
|---|---|---|---|---|
| | All | Federal/State/County | Municipality | Special District |
| | (1) | (2) | (3) | (4) |
| Log(Per Capita Income) | 0.086*** | 0.039 | 0.113*** | 0.100*** |
| | (0.017) | (0.032) | (0.025) | (0.023) |
| Log(Levee Population) | 0.038*** | 0.036** | 0.074*** | 0.043*** |
| | (0.006) | (0.017) | (0.027) | (0.006) |
| State FE | Yes | Yes | Yes | Yes |
| Protection level FE | Yes | Yes | Yes | Yes |
| Floodzone ratio control | Yes | Yes | Yes | Yes |
| Observations | 2,300 | 497 | 717 | 1,074 |
| Adjusted $R^2$ | 0.536 | 0.629 | 0.430 | 0.715 |

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.

To assess whether disparities in levee quality translate into differential exposure to failure [15], I examine the relationship between income and levee failure (Table 4). Lower-income com-

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

munities 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.

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.

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

# 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. A central identification challenge is simultaneity. While higher housing values enable greater investment in levee maintenance, levee quality may reversely affect housing values by changing perceived flood risk and residential sorting. Consequently, cross-sectional correlations between housing values and levee quality confound cause and effect.

The ideal experiment would generate exogenous shift in local housing values that is orthogonal to levee maintenance decisions, flood risk, levee design quality, and other unobserved

determinants of levee quality. I approximate this experiment by exploiting the national technology shock associated with the rapid diffusion of computerization beginning in the early 1980s. Rapid declines in the price of computing capital induced widespread automation of routine tasks, differentially affecting local labor markets according to their pre-existing occupational composition. Commuting zones with greater specialization in routine task intensive occupations experienced larger increases in information technology adoption and inflows of high-skill, high-wage workers whose productivity is complementary to computing capital (Autor and Dorn, 2013). These workers exhibit a higher willingness to pay for housing, generating upward pressure on local housing values (Moretti, 2013) [16].

I construct the instrument for local housing value growth based on exposure to the national computerization shock, following the routine employment share approach of Autor and Dorn (2013). Specifically, exposure is measured using the predicted routine employment share in each commuting zone, constructed from 1950 local occupation composition and national occupation-level routine task intensity leaving out the state containing the commuting zone. Fixing both industrial components in 1950—well before the onset of large-scale computerization in the 1980s and prior to the construction of the majority of levee infrastructure (Figure S6)—ensures that variation in exposure reflects predetermined economic structure rather than endogenous responses to local infrastructure quality or flood risk.

The research design investigates the impacts of housing value changes since 1980 on levee maintenance quality, conditional on 1980 housing value and population in the census tract, designed protection of levees, and flood zone share. This specification enables comparisons across neighborhoods with similar initial economic conditions and flood exposure in 1980 but differing housing value trajectories driven by differential exposure to the technology shock. Because most levees were newly constructed as of 1980 and therefore likely had high baseline maintenance quality[17], observed cross-sectional outcomes in maintenance quality today can be interpreted as reflecting changes in maintenance quality since 1980. In this sense, the empirical strategy is analogous to an instrumented difference-in-differences design.

[16] Although the computerization shock also displaced middle-skill routine occupations and increased low-skill service employment (Autor and Dorn, 2013), low-skill workers are disproportionately renters and therefore unlikely to be marginal bidders in local housing markets. By contrast, the inflows of high-skill, high-wage workers increase willingness to pay at the margin, raising equilibrium housing prices. Thus greater adoption of information technology is expected to generate net positive capitalization into housing prices, despite polarized labor-market impacts.

[17] Even if some levees exhibited maintenance deterioration by 1980, such early wear is unlikely to be systematically correlated with commuting-zone routine-work industry composition in 1950, which determines exposure to the computerization shock.

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 changes (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. Consistent with this assumption, the routine occupation instrument is as if random conditional on controls. The instrument is not correlated with other uncontrolled neighborhood socioeconomic characteristics measured in 1980, such as income or homeownership rates (Column 1-2 of Table S7). Moreover, there is no systematic relationship between the instrument and housing values measured in 1960 and 1970 (Column 3-4 of Table S7), eliminating concerns that the housing trajectories diverged prior to the onset of the computerization shock. Rotemberg weights (Table S15), instrument overidentification diagnostics (Figure S14), and balance tests of individual industry shares (Table S16) collectively support that the results are not driven by a narrow subset of industries and the validity of the exogenous share assumption (Supplementary Note C).

Table 5 reports the IV results. The first-stage estimates indicate that occupation exposure to computerization has a strong effect on housing value growth between 1980 and 2019. The two-stage least squares (2SLS) estimates show that census tracts experiencing greater housing value growth—due to higher exposure to computerization in their commuting zone occupations—are significantly more likely to receive "Acceptable" or "Minimally Acceptable" maintenance ratings (Columns 2 and 4). Interpreting magnitudes using percentage changes in housing values (Column 4), a 100 percent increase in housing values is associated with a 15 percentage point increase in the probability of acceptable maintenance, corresponding to a 26 percent increase relative to the sample mean.

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.

The results are quantitatively similar in a restricted sample of levees with non-missing construction year data that were built between 1970 and 1980 (Table S8). 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 more cleanly as reflecting subsequent changes in maintenance quality rather than pre-existing differences in levels.

Several mechanisms could explain why increases in housing values lead to improved levee maintenance. The most direct channel operates through local public finance: higher housing values expand the property tax base, thereby increasing the fiscal capacity of local levee sponsors to fund maintenance. This revenue channel is particularly salient in this setting because levee districts rely almost exclusively on property taxes, and municipalities also have limited access to alternative tax instruments (Table S12).

To assess whether property taxation is the primary revenue channel through which economic growth affects levee maintenance, I link the technology shock instrument to municipal finance data for municipalities that rely heavily on levee protection (defined as having more than 25 percent of land area protected by levees). Table 6 shows that exposure to the technology shock significantly increases total municipal revenue, with the effect driven primarily by higher property tax revenue (Columns 1–2). By contrast, there is no evidence of economically meaningful effects on income tax (Column 3), which play only a minimal role in municipal revenue structures. If anything, improved local economic condition leads to lower intergovernmental transfers from the federal government (Column 4), suggesting that enhanced political leverage for state or federal funding is not a dominant revenue channel. Although comprehensive public finance data are unavailable for levee districts, these entities derive more than 90 percent of their revenue from property taxes and cover only levee-protected neighborhoods, making property tax revenue from leveed areas directly relevant for maintenance budget.

Beyond revenue channel, the technology shock instrument could also alter population composition, raising the possibility that inflows of high-skill, highly educated residents increase political pressure for levee maintenance independent of fiscal effects. If such preference-based mechanism were central, one would expect maintenance improvements even when local sponsor's revenue capacity is largely insulated from housing values. I examine this possibility by focusing on neighborhoods protected by state-sponsored levees, whose maintenance budgets

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.

are determined at the state level and are weakly linked to commuting zone exposure to computerization. In these areas, exposure to the technology shock continues to raise housing values, yet the relationship between housing values and maintenance quality disappears (Table S9). This pattern is difficult to reconcile with a purely preference-driven mechanism.

Another alternative explanation is resource allocation. One allocation-based channel is that richer municipalities may direct additional resources toward levee-protected areas even when those areas do not experience increases in housing values or contribute significantly to the property tax base, for example for equity or political considerations. Because the technology shock instrument varies at the commuting zone level, it does not by itself distinguish revenue generated by levee protected areas from allocation decisions made at the municipality level when the entire municipality gets richer. However, if such within jurisdiction resource allocation is the key mechanism, increases in overall municipal fiscal capacity would lead to improved maintenance even for levees that protect only a small share of the municipality. I find no evidence that housing value growth improves maintenance for municipality-sponsored levees that protect less than 25 percent of municipal land area (Table S10).

A second allocation channel is that increases in housing values raise the perceived importance of protecting high-value areas. Sponsors may therefore allocate more maintenance resources toward levees that protect valuable property, independent of those areas' direct revenue contributions. While this value-based allocation mechanism cannot be ruled out in the current empirical framework, it is fully consistent the feedback loop between housing values and levee maintenance. However, the value-based allocation alone cannot explain the differences in maintenance inequality across sponsor types (Table 3), nor the absence of maintenance impacts when housing value increases contribute little to sponsor revenues (Table S9). Taken together with institutional background that local levee sponsors frequently operate under binding resource constraints (ASCE, 2021; Benson, 2022), these results suggest that local fiscal capacity, even if not the sole mechanism, plays an important role in shaping levee maintenance outcomes.

Overall, the evidence indicates a causal effect of housing values on levee maintenance quality. The IV estimates yield magnitudes comparable to those obtained in the cross-sectional regressions. Specifically, both Column 4 of Table 2 (cross-sectional) and Column 4 of Table 5 (IV) imply that a 10 percent increase in housing value raises the probability of receiving a (minimally) acceptable maintenance rating by approximately 1.5 percentage points. The similarity of these estimates suggests that the majority of the observed inequality in main-

tenance quality today can be attributed to the causal effect of local economic conditions, rather than the reserve capitalization from the infrequent levee failure events. The relative contribution of the two directions in this bi-directional relationship may evolve over time as climate change and infrastructure aging increase the probability of levee failures. Nonetheless, the results underscore that weakening the link between local economic conditions and levee maintenance could play a critical role in mitigating inequality in infrastructure quality.

## 4.2 Impact of Levee Failures on Local Housing Value

Levee maintenance disparities driven by differences in local housing value and public finance capacity can generate long-lasting impacts if maintenance deficiencies further reduce neighborhood housing values, residents' income, and local fiscal capacity for future investments. This feedback loop, in which infrastructure degradation and neighborhood economic decline reinforce one another, echoes the theoretical literature on "urban doom loops" and "cumulative urban decline". Despite its strong theoretical foundation, empirically identifying such dynamics is difficult. 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)[18]. Due to this ex-ante information gap, households mainly update their beliefs about levee quality after performance failures occur in the flood events. I thus 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

[18] 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"".*

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 S11, 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 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 $\delta_i$ 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 [19]. 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'Haultfoeuille, 2022), I follow Callaway and Sant'Anna (2021) and estimate cohort-specific group–time average treatment effects after partialling out fixed effects and

[19] 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.

controls. For each cohort $g$ and period $t$,

$$ATT(g,t) = \mathbb{E}[Y_{it}(1) - Y_{it}(0) \mid G_i = g] \tag{2}$$

where treated tracts are compared to not-yet-treated tracts. Dynamic effects are obtained by aggregating $ATT(g,t)$ over event time. 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 [20].

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 [21]. 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 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.

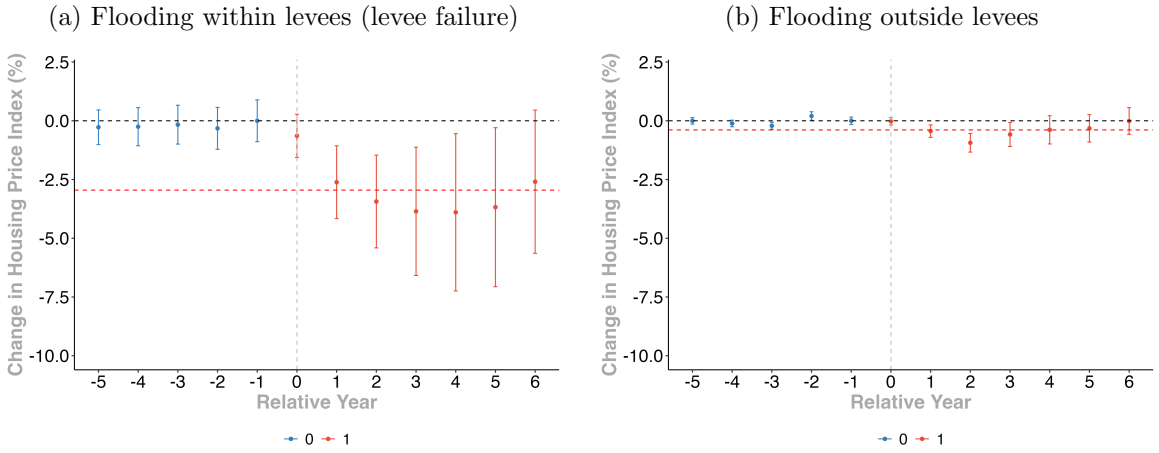
Figure 4 presents event study estimates for all flooding events, comparing the effects of levee failures and flooding outside levee systems on a common scale. Both treatment and control tracts exhibit parallel pre-trends in housing prices, supporting the identifying assumptions. Following the event, census tracts that experienced levee failure exhibit a persistent 2.6% decline in housing prices, with no evidence of recovery. In contrast, tracts affected by flooding

[20] 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.

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

outside levees experience a modest 0.42% decline in prices, followed by a full recovery within six years.

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

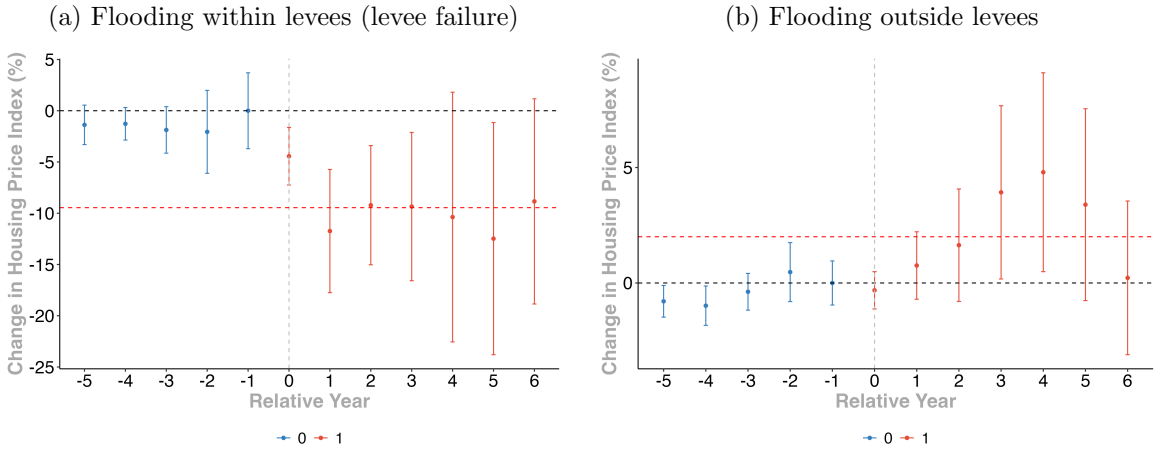



Notes: Treatment is defined as any flood inundation (flooded area above 0). For levee failure effects, both treatment and control tracts are protected by levees; treatment tracts experience flooding within the levee system. For flooding outside levees, both treatment and control tracts lack levee protection; 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.

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). Interestingly, the divergence in outcomes becomes more pronounced. 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. 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).

While prior research has documented strong post-disaster economic recoveries in the US

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.

housing market (Gallagher and Hartley, 2017; Liao and Kousky, 2022; Graff Zivin et al., 2023), my findings suggest that recovery trajectories differ markedly for flood zone communities reliant on low-quality infrastructure. To explore potential sources of this divergence, I conduct heterogeneity analyses across several dimensions (Figure 6) [22].

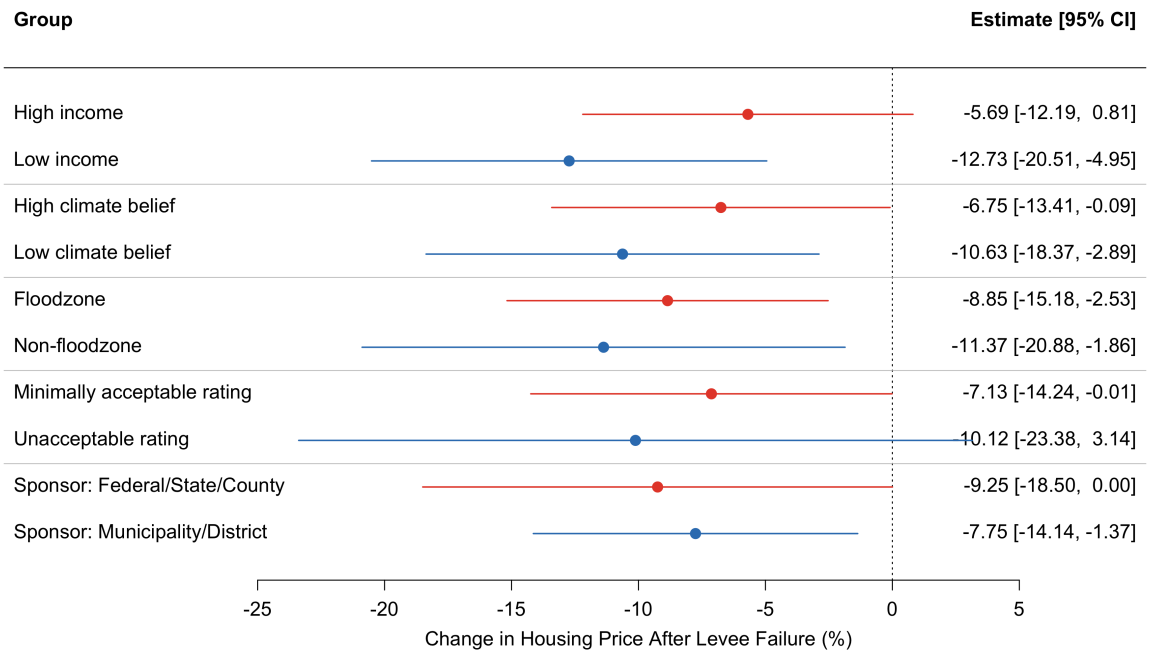
Point estimates indicate some economically meaningful variations. Housing price declines appear larger in lower income tracts, consistent with credit constraints and regressive disaster aid allocation (Billings et al., 2022). Effects are also larger in areas with lower climate concern and outside FEMA flood zones, where flood risk may be undercapitalized and insurance coverage limited (Gourevitch et al., 2023; Bradt et al., 2021). Additionally, impacts are greater in events without federal disaster declarations, underscoring the importance of intergovernmental transfer in post-disaster recovery Costa et al. (2024) [23].

However, while levee failure has significantly negative housing market impacts for all subgroups, none of the subgroup differences are statistically significant. This suggests that the

[22] To address the concerns about multiple hypothesis testing, I also implement a random forest model to assess the relative importance the heterogeneity covariates (Figure S8).

[23] Disaster declarations depend on the depth and breadth of the disaster. While the likelihood of declaration increases with the proportion of a tract inundated (Figure S7a-b), it also depends on the number of affected tracts within a county (Figure S7c-d), potentially excluding certain areas from disaster declarations even when they experience severe local flooding.

Figure 6: Heterogeneous housing price responses to levee failure



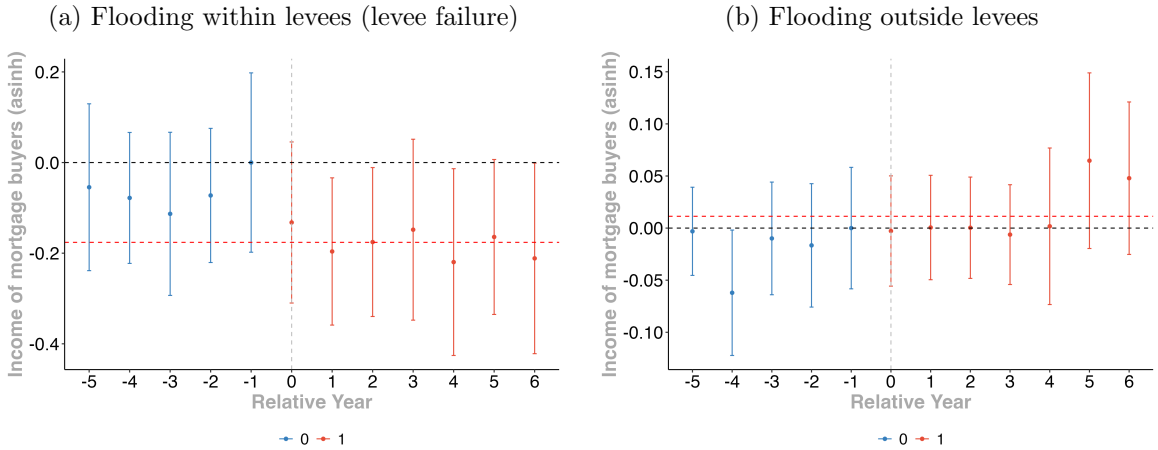

Notes: Estimates are based on subgroup event study analyses, following the specification in Figure 5. Points represent the average housing price effect over the six years following levee failure; lines indicate 95% confidence intervals. Subgroups are defines using median splits. Climate belief data are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

economic consequences of levee failure are broadly distributed and not confined to specific vulnerable groups. This pattern suggests that the sharp housing market response to levee failure is unlikely to reflect differences in baseline income or flood risk exposure. Instead, it is more consistent with a "new news" interpretation, in which infrastructure failure serves as an unexpected signal of unpriced risk and prompts a stronger market reassessment than flooding alone.

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 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.

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 [24]. 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:

$$Y_{mt} = \sum_{\ell \in \{-10,-5,0,5,10\}} \beta_\ell \mathbf{1}\{t - G_m = \ell\} + \delta_m + \theta_t + (X_m \times \lambda_t)\gamma + \varepsilon_{mt}, \tag{3}$$

where $\delta_m$ and $\theta_t$ 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 $\beta_5$ captures outcomes 5–9 years after exposure, and $\beta_{10}$ 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 the fixed effects and controls:

$$ATT_m(g,t) = \mathbb{E}[Y_{mt}(1) - Y_{mt}(0) \mid G_m = g] \tag{4}$$

[24] 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.

where treated municipalities are compared wo to not-yet-treated municipalities. Dynamic effects are obtained by aggregating these cohort-specific estimates over event time $\tau = t - g$, where each unit of $\tau$ corresponds to one five-year period.

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 more likely to be captured in the data. 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 groups receive increased intergovernmental transfers, 21.8% for levee failures and 16.2% for other floods, disbursements to leveed municipalities are more delayed, likely reflecting the longer federal approval process for levee repair assistance.

Despite substantial intergovernmental transfers, the decline in property tax revenue following levee failures more than offsets these gains (Figure 8b). Municipalities experiencing levee failure see a 22.1% drop in property tax revenue, with the largest decline occurring 5-9 years after the event—consistent with the timing of property value reassessments. Some recovery is observed 10–14 years post-disaster, potentially reflecting rebuilding activity. In contrast, municipalities affected by flooding outside levees experience a more modest decline (8.7%), which fully dissipates within a decade. There are no significant changes in other charges and miscellaneous revenues, key sources that municipalities rely on alongside intergovernmental transfers and property taxes (Figure S10) [25]. As a results, the losses in property tax revenue lead to a 5.8% decline in total municipal revenue in levee-reliant areas, even after accounting for intergovernmental transfers (Figure 8d).

Revenue losses following levee failures lead to spending cuts. Municipalities affected by levee failures reduce total expenditures by 12.1% after disaster, precisely when fiscal demand for reconstruction and public service delivery needs are elevated (Figure 8d). Unlike the typical post-disaster pattern of increased capital investment to rebuild, these municipalities also show limited rise in capital outlays (Figure 8e). This suggests that binding fiscal constraints may have limited local capacity to recover and reinvest, potentially exacerbating long-term infrastructure deterioration.

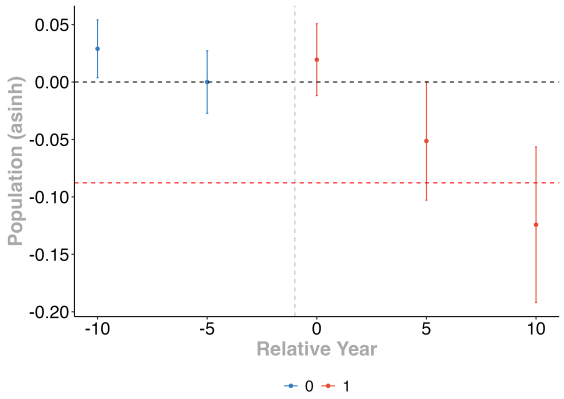
[25] If anything, there is an insignificant increase in charges and fees as revenue after levee failure events. As fines and forfeits are included in this category, an increase in revenues from charges and fees may reflect not just expanded service provision, but also malfunctioning, extractive revenue practices under fiscal constraints (Davis et al., 2023).

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 S13 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 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.

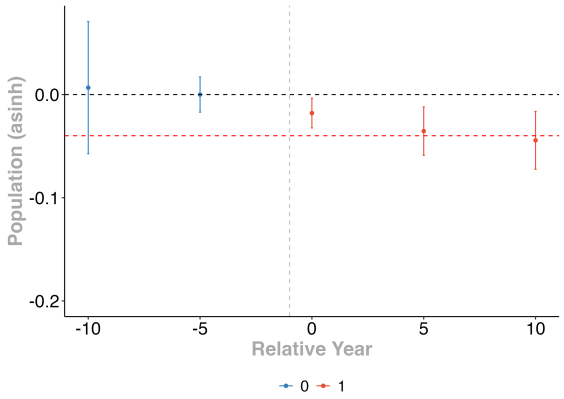
Because fiscal outcomes are observed only at five-year intervals, the analysis cannot fully disentangle post-disaster responses from slower-moving structural changes (e.g., economic decline, outmigration) or other confounding shocks within the same time window. As a result, the fiscal impact estimates should be interpreted as descriptive rather than causal. 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 neighbourhood housing price

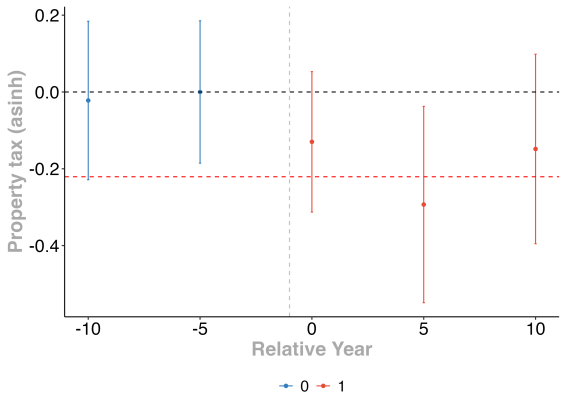
(a-1) Population: Levee Failure



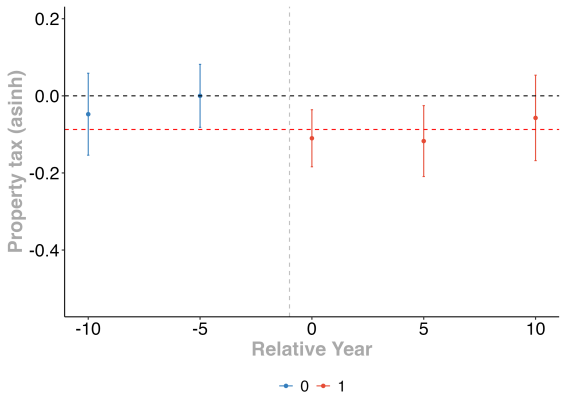

(a-2) Population: Flooding Outside Levees



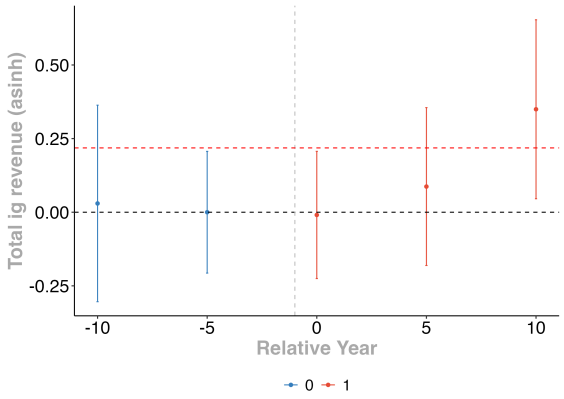

(b-1) Property Tax: Levee Failure



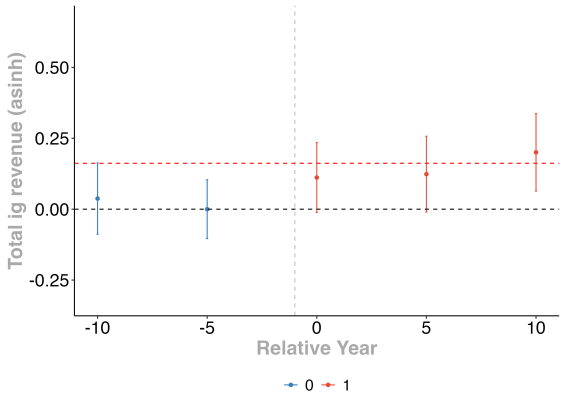

(b-2) Property Tax: Flooding Outside Levees



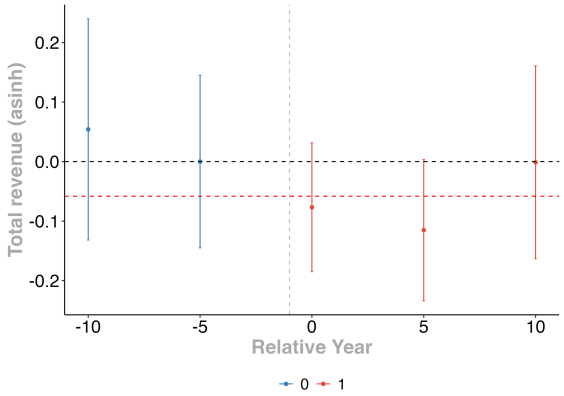

(c-1) IG Revenue: Levee Failure



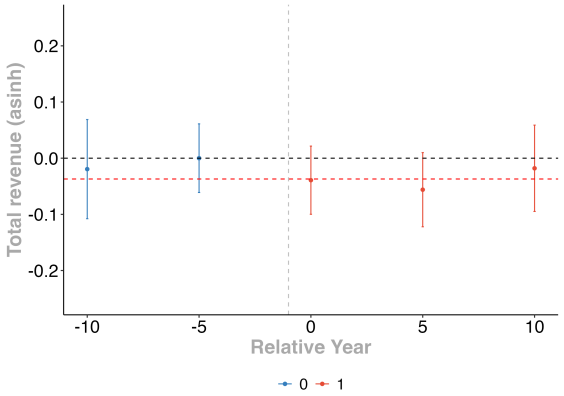

(c-2) IG Revenue: Flooding Outside Levees



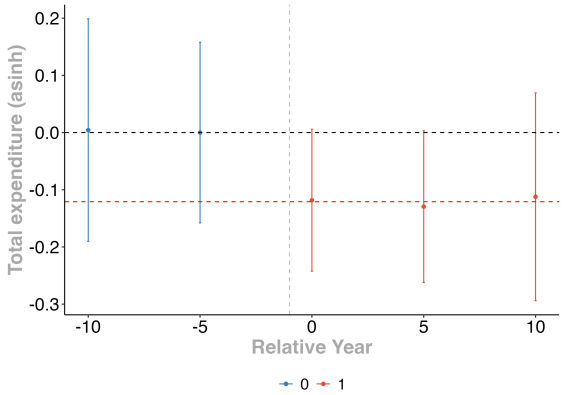
(d-1) Total Revenue: Levee Failure



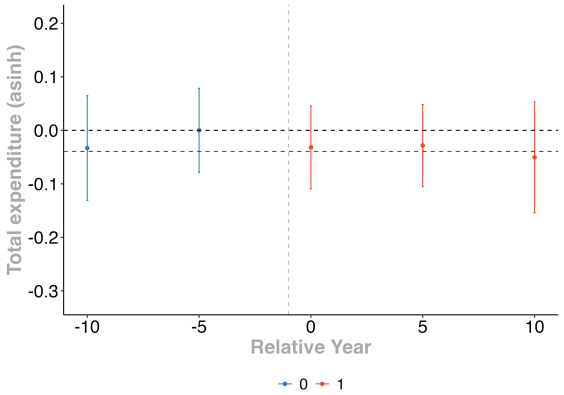

(d-2) Total Revenue: Flooding Outside Levees



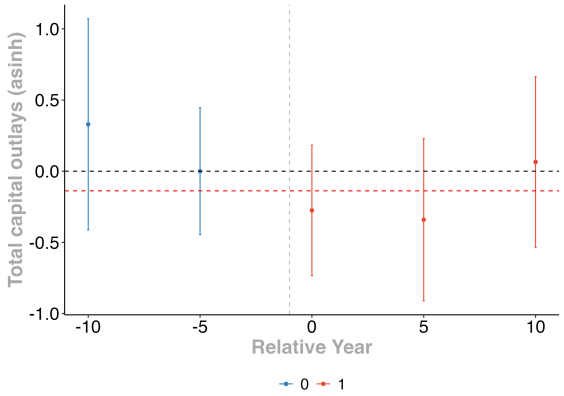

(e-1) Total Expenditure: Levee Failure



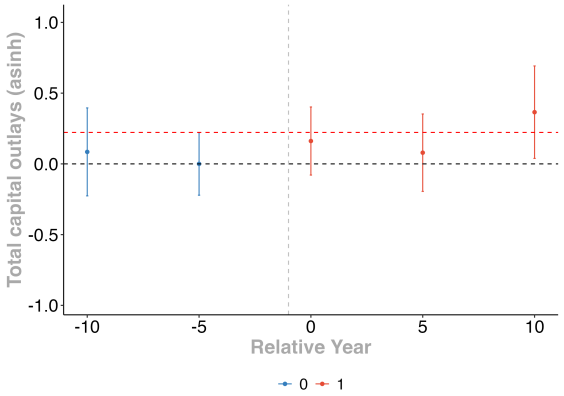

(d-2) Total Expenditure: Flooding Outside Levees




(f-1) Capital Outlay: Levee Failure




(e-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.

# 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 [26]. 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 11.0% between 2000 and 2021 (Table S14), corresponding to an annual risk reduction of 0.49% [27]. 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

[26] 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.

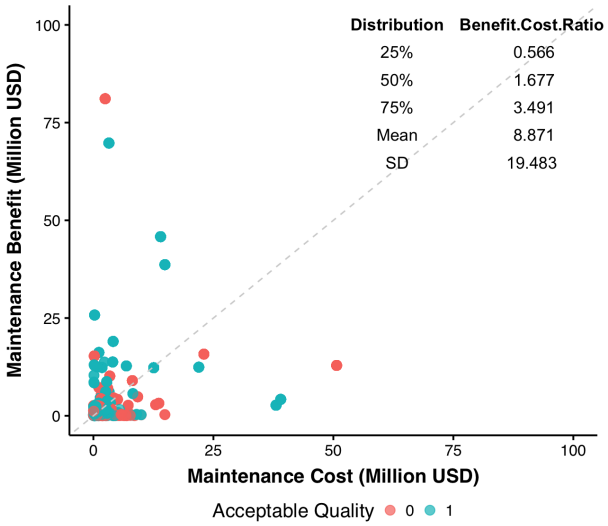
[27] This is a conservative estimate that excludes repeat failures within these 22 years, due to the challenges in calibrating property damage when levees and buildings are not yet fully repaired.

lead to mortality, infrastructure damage, and broader economic costs—all of which are likely to intensify with climate change.

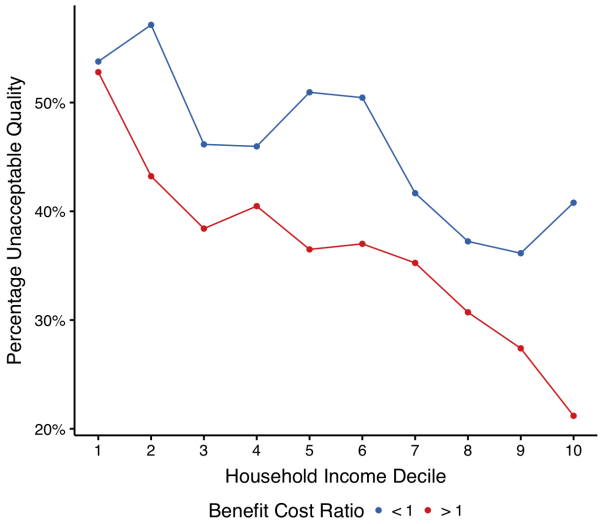
Figure 9a presents estimated annual maintenance benefits and costs for levee-protected tracts. On average, the benefit-cost ratio is 8.87—each dollar invested in maintenance avoids roughly nine dollars in property damage. Despite this high return, 36.4% of levees with benefit-cost ratios above one are 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 $456 million (in 2019 USD), approximately 8.4% of all national flood-related property and crop damages (NOAA, 2024). Net of maintenance costs, this implies an annual efficiency gain of $272 million.

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.

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 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 rising attention to climate resilience, policy remains focused on new capital investment, with limited attention to long-run maintenance. 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 find that underlying this coupled economic and climate inequality is a feedback loop: Exogenous shocks to local housing values causally affect maintenance quality, and that levee failures due to maintenance deficiency in turn depress housing values and local budgets for future levee maintenance.

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.

# References


ASCE (2021). 2021 report card: Levees. Technical report.

ASCE Inter-Institute Levee Committee (2010, January). *So, you live behind a levee!* Reston, VA: American Society of Civil Engineers.

Aschauer, D. (1989, March). IS PUBLIC EXPENDITURE PRODUCTIVE. *Journal of Monetary Economics 23*, 177–200.

Atreya, A., S. Ferreira, and W. Kriesel (2013). Forgetting the flood? an analysis of the flood risk discount over time. *Land Econ. 89*(4), 577–596.

Autor, D., D. Dorn, and G. H. Hanson (2013, October). The china syndrome: Local labor market effects of import competition in the united states. *Am. Econ. Rev. 103*(6), 2121–2168.

Autor, D. H. and D. Dorn (2013, August). The growth of low-skill service jobs and the polarization of the US labor market. *Am. Econ. Rev. 103*(5), 1553–1597.

Baker, A. C., D. F. Larcker, and C. C. Y. Wang (2022, May). How much should we trust staggered difference-in-differences estimates? *J. financ. econ. 144*(2), 370–395.

Bakkensen, L. A. and L. Barrage (2022, July). Going underwater? flood risk belief heterogeneity and coastal home price dynamics. *Rev. Financ. Stud. 35*(8), 3666–3709.

Bakkensen, L. A. and L. Ma (2020, November). Sorting over flood risk and implications for policy reform. *J. Environ. Econ. Manage. 104*, 102362.

Balboni, C. (2025, January). In harm's way? infrastructure investments and the persistence of coastal cities. *Am. Econ. Rev. 115*(1), 77–116.

Baum-Snow, N., M. E. Kahn, and R. Voith (2005). Effects of urban rail transit expansions: Evidence from sixteen cities, 1970-2000. *Brookings-Wharton Papers on Urban Affairs*, 147–206.

Beauregard, R. A. (2006, August). *When America became suburban* (NED - New edition ed.). Minneapolis, MN: University of Minnesota Press.

Beauregard, R. A. (2013, January). *Voices of decline: The postwar fate of us cities: The postwar fate of us cities*. Routledge.

Bellemare, M. F. and C. J. Wichman (2020, February). Elasticities and the inverse hyperbolic sine transformation. *Oxf. Bull. Econ. Stat. 82*(1), 50–61.

Benson, J. (2022). Iowa statewide levee districts study. Technical report, Iowa Department of Homeland Security and Emergency Management.

Bernstein, A., S. B. Billings, M. T. Gustafson, and R. Lewis (2022, December). Partisan residential sorting on climate change risk. *J. financ. econ. 146*(3), 989–1015.

Bernstein, A., M. T. Gustafson, and R. Lewis (2019, November). Disaster on the horizon: The price effect of sea level rise. *J. financ. econ. 134*(2), 253–272.

Bilal, A. and E. Rossi-Hansberg (2023, June). Anticipating climate change across the united states. (31323).

Billings, S. B., E. A. Gallagher, and L. Ricketts (2022, November). Let the rich be flooded: The distribution of financial aid and distress after hurricane harvey. *Journal of Financial Economics 146*(2).

Bin, O. and C. E. Landry (2013, May). Changes in implicit flood risk premiums: Empirical evidence from the housing market. *J. Environ. Econ. Manage. 65*(3), 361–376.

Bock, M. and B. Blemings (2024, January). Road maintenance over the local election cycle. *Public Choice 198*(1-2), 129–151.

Borusyak, K., P. Hull, and X. Jaravel (2025, February). A practical guide to shift-share instruments. *J. Econ. Perspect. 39*(1), 181–204.

Bradt, J. T. and J. E. Aldy (2022). Private benefits from public investment in climate adaptation and resilience. https://www.aeaweb.org/conference/2023/program/paper/6bDTe6eD. Accessed: 2023-9-13.

Bradt, J. T., C. Kousky, and O. E. J. Wing (2021, October). Voluntary purchases and adverse selection in the market for flood insurance. *J. Environ. Econ. Manage. 110*, 102515.

Brueckner, J. K. and R. W. Helsley (2011, March). Sprawl and blight. *J. Urban Econ. 69*(2), 205–213.

Bumgarner, M., J. Martinez-Vazquez, and D. L. Sjoquist (1991). Municipal capital maintenance and fiscal distress. *Rev. Econ. Stat. 73*(1), 33–39.

Bénabou, R. (1996, April). Equity and efficiency in human capital investment: The local connection. *Rev. Econ. Stud. 63*(2), 237–264.

Callaway, B. and P. H. C. Sant'Anna (2021, December). Difference-in-differences with multiple time periods. *J. Econom. 225*(2), 200–230.

Cellini, S. R., F. Ferreira, and J. Rothstein (2010, February). The value of school facility investments: Evidence from a dynamic regression discontinuity design. *Q. J. Econ. 125*(1), 215–261.

Chen, G. (2020, February). Assessing the financial impact of natural disasters on local governments. *Public Budget. Finance 40*(1), 22–44.

Chen, J. and J. Roth (2024, March). Logs with zeros? some problems and solutions. *Q. J. Econ. 139*(2), 891–936.

Chetty, R. and J. N. Friedman (2010). Does local tax financing of public schools perpetuate inequality? *Proceedings. Annual Conference on Taxation and Minutes of the Annual Meeting of the National Tax Association*.

Contat, J., W. Doerner, R. Renner, and M. Rogers (2024). Measuring price effects from disasters using public data: A case study of hurricane ian. *FHFA Working Paper*.

Costa, R., E. Bolte, C. Sharp, and C. Bowers (2024, August). Repeated and localized flooding is an underestimated challenge for urban disaster risk management. *Nat Cities*, 1–10.

Cruz, J.-L. and E. Rossi-Hansberg (2024). The economic geography of global warming. *Rev. Econ. Stud. 91*(2), 899–939.

Currie, J., J. Voorheis, and R. Walker (2023, January). What caused racial disparities in particulate exposure to fall? new evidence from the clean air act and satellite-based measures of air quality. *Am. Econ. Rev. 113*(1), 71–97.

Davis, B. A., M. C. Arcaya, D. R. Williams, and N. Krieger (2023, March). The impact of county-level fees & fines as exploitative revenue generation on US birth outcomes 2011-2015. *Health Place 80*, 102990.

de Chaisemartin, C. and X. d'Haultfoeuille (2022). Difference-in-differences estimators of intertemporal treatment effects. *SSRN Electron. J.*.

Deryugina, T., L. Kawano, and S. Levitt (2018, April). The economic impact of hurricane katrina on its victims: Evidence from individual tax returns. *Am. Econ. J. Appl. Econ. 10*(2), 202–233.

Desmet, K., R. E. Kopp, S. A. Kulp, D. K. Nagy, M. Oppenheimer, E. Rossi-Hansberg, and B. H. Strauss (2021, April). Evaluating the economic cost of coastal flooding. *American Economic Journal: Macroeconomics 13*(2), 444–486.

Ding, M., P. Lin, S. Gao, J. Wang, Z. Zeng, K. Zheng, X. Zhou, D. Yamazaki, Y. Gao, and Y. Liu (2023, August). Reversal of the levee effect towards sustainable floodplain management. *Nature Sustainability*, 1–9.

Durlauf, S. N. (1995, July). Neighborhood feedbacks, endogenous stratification, and income inequality. *Working Papers*.

Durlauf, S. N. (1996). A theory of persistent income inequality. *J. Econ. Growth 1*(1), 75–93.

Fell, H. and C. Kousky (2015, November). The value of levee protection to commercial properties. *Ecol. Econ. 119*, 181–188.

FEMA (2022, February). Levees in risk rating 2.0. Technical report.

Fernandez, R. and R. Rogerson (1996). Income distribution, communities, and the quality of public education. *Q. J. Econ. 111*(1), 135–164.

Filardo, M., J. M. Vincent, and K. Sullivan (2019, May). How crumbling school facilities perpetuate inequality. *Phi Delta Kappan 100*(8), 27–31.

Flavelle, C. (2021, August). Climate in the infrastructure bill: A substantial investment in

resilience. *The New York Times*.

Flynn, S., F. Vahedifard, and D. Schaaf (2025, December). A comprehensive dataset of riverine levee overtopping events for advancing risk assessment. *Sci. Data 13*(1), 36.

Fried, S. (2022, November). Seawalls and stilts: A quantitative macro study of climate adaptation. *Rev. Econ. Stud. 89*(6), 3303–3344.

Gallagher, J. and D. Hartley (2017). Household finance after a natural disaster: The case of hurricane katrina. *American Economic Journal: Economic Policy 9*(3), 199–228.

Galster, G. C., J. Galster, and K. Vachuska (2024, March). The color of water: Racial and income differences in exposure to floods across US neighborhoods. *Real Estate Econ.*.

Gertler, P. J., M. Gonzalez-Navarro, T. Gračner, and A. D. Rothenberg (2024, September). Road maintenance and local economic development: Evidence from indonesia's highways. *J. Urban Econ. 143*(103687), 103687.

Glaeser, E. L. (2013). Urban public finance. In A. J. Auerbach, R. Chetty, M. Feldstein, and E. Saez (Eds.), *handbook of public economics, vol. 5*, Volume 5 of *Handbook of public economics*, pp. 195–256. Elsevier.

Glaeser, E. l. and J. Gyourko (2005). Urban decline and durable housing. *J. Polit. Econ. 113*(2), 345–375.

Goldsmith-Pinkham, P., I. Sorkin, and H. Swift (2020, August). Bartik instruments: What, when, why, and how. *Am. Econ. Rev. 110*(8), 2586–2624.

Goodman-Bacon, A. (2021, June). Difference-in-differences with variation in treatment timing. *J. Econom.*.

Gourevitch, J. D., C. Kousky, Y. p. Liao, C. Nolte, A. B. Pollack, J. R. Porter, and J. A. Weill (2023, February). Unpriced climate risk and the potential consequences of overvaluation in US housing markets. *Nat. Clim. Chang.*, 1–8.

Graff Zivin, J., Y. Liao, and Y. Panassié (2023, March). How hurricanes sweep up housing markets: Evidence from florida. *J. Environ. Econ. Manage. 118*, 102770.

Hamilton, B. W. (1975, June). Zoning and property taxation in a system of local governments. *Urban Stud. 12*(2), 205–211.

Hausman, C. and S. Stolper (2021, October). Inequality, information failures, and air pollution. *J. Environ. Econ. Manage. 110*(102552), 102552.

Henkel, M., E. Kwon, and P. Magontier (2022). The unintended consequences of post-disaster policies for spatial sorting. *SSRN Electron. J.*.

Herold, B. (2024, January). *Disillusioned: Five families and the unraveling of America's suburbs*. New York, NY: Penguin Press.

Hino, M. and M. Burke (2020, March). Does information about climate risk affect property values? Technical Report w26807, National Bureau of Economic Research.

Holtermans, R., D. Niu, and S. Zheng (2024, June). Quantifying the impacts of climate shocks in commercial real estate markets. *J. Reg. Sci.*.

Hornbeck, R. and D. Keniston (2017). Creative destruction: Barriers to urban growth and the great boston fire of 1872. *Am. Econ. Rev. 107*(6), 1365–1398.

Hsiao, A. (2023, April). Sea level rise and urban adaptation in jakarta. https://allanhsiao.com/files/Hsiao_jakarta.pdf. Accessed: –.

Jerch, R., M. E. Kahn, and G. C. Lin (2023, March). Local public finance dynamics and hurricane shocks. *J. Urban Econ. 134*, 103516.

Kahn, M. E. and D. M. Levinson (2011). Fix it first, expand it second, reward it third: A new strategy for america's highways. https://www.hamiltonproject.org/publication/policy-proposal/fix-it-first-expand-it-second-reward-it-third-a-new-strategy-for-americas-highways/. Accessed: 2024-7-9.

Keegan, N., R. O. King, N. T. Carter, and M. Stubbs (2011). Locally operated levees: Issues and federal programs. Technical report, Congressional Research Service.

Kelly, D. L. and R. Molina (2023, November). Adaptation infrastructure and its effects on property values in the face of climate risk. *Journal of the Association of Environmental and Resource Economists 10*(6), 1405–1438.

Kennedy, P. E. (1981). Estimation with correctly interpreted dummy variables in semilogarithmic equations [the interpretation of dummy variables in semilogarithmic equations]. *Am. Econ. Rev. 71*(4), 801–801.

Kim, J. and C. Ebdon (2021, July). Asset maintenance practices and challenges in U.s. counties. *Public Works Manag. Policy 26*(3), 259–278.

Lee, D. S. (2009, July). Training, wages, and sample selection: Estimating sharp bounds on treatment effects. *Rev. Econ. Stud. 76*(3), 1071–1102.

Lee, S. (2023). Adapting to natural disasters through better information: Evidence from the home seller disclosure requirement. *SSRN Electron. J.*.

Lee, S. and J. Lin (2018). Natural amenities, neighbourhood dynamics, and persistence in the spatial distribution of income. *Rev. Econ. Stud. 85*(1 (302)), 663–694.

Liao, Y. p. and C. Kousky (2022, May). The fiscal impacts of wildfires on california municipalities. *Journal of the Association of Environmental and Resource Economists 9*(3), 455–493.

Ludy, J. and G. M. Kondolf (2012, March). Flood risk perception in lands "protected" by 100-year levees. *Nat. Hazards 61*(2), 829–842.

Lundberg, S. and R. Startz (1998, April). On the persistence of racial inequality. *J. Labor Econ. 16*(2), 292–323.

McRae, S. (2015, January). Infrastructure quality and the subsidy trap. *Am. Econ. Rev. 105*(1), 35–66.

Miao, Q., W. Guo, Y. Hou, and M. Davlasheridze (2024, November). Fiscal implications of disasters and the managed retreat thereafter: Evidence from hurricane sandy. *Nat. Hazards Rev. 25*(4), 04024036.

Moretti, E. (2013, January). Real wage inequality. *Am. Econ. J. Appl. Econ. 5*(1), 65–103.

Mulder, P. and C. Kousky (2023, May). Risk rating without information provision. *AEA Papers and Proceedings 113*, 299–303.

Murfin, J. and M. Spiegel (2020, March). Is the risk of sea level rise capitalized in residential real estate? *Rev. Financ. Stud. 33*(3), 1217–1255.

NOAA (2024). Economic damage caused by floods in the united states 1995-2023. https://www.statista.com/statistics/237420/economic-damage-caused-by-floods-and-flash-floods-in-the-us/. Accessed: 2024-10-22.

Nolte, C., K. J. Boyle, A. M. Chaudhry, C. M. Clapp, D. Guignet, H. Hennighausen, I. Kushner, Y. Liao, S. Mamun, A. Pollack, J. Richardson, S. Sundquist, K. Swedberg, and J. H. Uhl (2021, August). Studying the impacts of environmental amenities and hazards with nationwide property data: Best data practices for interpretable and reproducible analyses.

Oates, W. E. (1972). *Fiscal Federalism*. New York: Harcourt Brace Jovanovich.

Oates, W. E. (1999, September). An essay on fiscal federalism. *Journal of Economic Literature 37*(3), 1120–1149.

Ortega, F. and S. Taṣpınar (2018, July). Rising sea levels and sinking property values: Hurricane sandy and new york's housing market. *J. Urban Econ. 106*, 81–100.

Ostriker, A. and A. Russo (2024). The effects of floodplain regulation on housing. *Working Paper*.

Ouazad, A. and M. Kahn (2025). Optimal flood protection policies in spatial equilibrium. *NBER Work. Pap. Ser.*.

Pagano, M. A. (2008). Grading the states infrastructure management performances: The government performance projects process and results. In *Infrastructure reporting and asset management*, pp. 73–80. American Society of Civil Engineers.

Pierson, K., M. L. Hand, and F. Thompson (2015, June). The government finance database: A common resource for quantitative research in public financial analysis. *PLoS One 10*(6), e0130119.

Pruitt, S. (2020, August). How levee failures made hurricane katrina a bigger disaster. *HISTORY*.

Qiang, Y. (2019, February). Disparities of population exposed to flood hazards in the united

states. *J. Environ. Manage. 232*, 295–304.

Rust, S. and I. James (2023, March). Age, drought, rodents and neglect weaken california levees, heightening flood danger. *Los Angeles Times*.

Shavell, S. (1979, November). On moral hazard and insurance. *Q. J. Econ. 93*(4), 541.

Shi, L. and A. M. Varuzzo (2020, May). Surging seas, rising fiscal stress: Exploring municipal fiscal vulnerability to climate change. *Cities 100*, 102658.

Smith, M., J. Schwartz, and T. Gruber (2019, March). 'breaches everywhere': Flooding bursts midwest levees, and tough questions follow. *The New York Times*.

Sun, C., M. E. Kahn, and S. Zheng (2017, January). Self-protection investment exacerbates air pollution exposure inequality in urban china. *Ecol. Econ. 131*, 468–474.

Swanstrom, T., P. Dreier, and J. Mollenkopf (2002, December). Economic inequality and public policy: The power of place. *City Community 1*(4), 349–372.

Taylor, C. A. and H. Druckenmiller (2022, April). Wetlands, flooding, and the clean water act. *Am. Econ. Rev. 112*(4), 1334–1363.

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

Tiebout, C. M. (1956). A pure theory of local expenditures. *J. Polit. Econ. 64*(5), 416–424.

Tran, B. R. and D. J. Wilson (2020, November). The local economic impact of natural disasters. Technical Report 2020-34.

US Army Corps of Engineers (2024). Levee inspections. https://www.mvs.usace.army.mil/Missions/Levee-Safety/Levee-Inspections/. Accessed: 2024-7-12.

U.S. Department of the Interior (2023, March). Inflation reduction act invests over $120 million in proven projects to advance climate resilience, conservation and equity. https://www.doi.gov/pressreleases/inflation-reduction-act-invests-over-120-million-proven-projects-advance-climate. Accessed: 2023-5-1.

USACE (2006). Rehabilitation and inspection program. https://www.mvp.usace.army.mil/Missions/Emergency-Management/Rehabilitation-Inspection/. Accessed: 2024-3-22.

USACE (2014). Manhattan kansas levee feasibility study. https://www.nwk.usace.army.mil/Missions/Civil-Works/Civil-Works-Programs-And-Projects/Manhattan-Kansas/. Accessed: –.

USACE (2023). National levee database. https://levees.sec.usace.army.mil/. Accessed: 2023–.

Vahedifard, F., M. Azhar, and D. C. Brown (2023, September). Overrepresentation of

historically underserved and socially vulnerable communities behind levees in the united states. *Earths Future 11*(9).

Van Nieuwerburgh, S. (2022, November). The remote work revolution: Impact on real estate values and the urban environment. Technical Report w30662, National Bureau of Economic Research, Cambridge, MA.

Vinnakota, M. and A. Ziff (2023, November). Levees: Infrastructure and insurance as adaptation to flood risk.

Weill, J. (2022, June). Perilous flood risk assessments.

Winston, C. (2013, September). On the performance of the U.s. transportation system: Caution ahead. *J. Econ. Lit. 51*(3), 773–824.

Zheng, A. and J. Graham (2022, July). Public education inequality and intergenerational mobility. *American Economic Journal: Macroeconomics 14*(3), 250–282.

# 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 insepction 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: Levee quality and neighbourhood socio-economic conditions: Interactive effects

| | (Minimally) Acceptable Quality | |
|---|---|---|
| | (1) | (2) |
| Log(Home Value) | 0.162*** | 0.121*** |
| | (0.017) | (0.017) |
| Log(Home Value) × Federal/State/County | -0.121*** | -0.073** |
| | (0.033) | (0.030) |
| Log(Levee Population) | 0.012** | 0.022*** |
| | (0.005) | (0.005) |
| Log(Protection Level) | 0.136*** | |
| | (0.014) | |
| State FE | Yes | Yes |
| Floodzone ratio control | Yes | Yes |
| Protection level FE | No | Yes |
| Observations | 1,849 | 1,849 |
| Adjusted $R^2$ | 0.583 | 0.628 |

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" is a dummy variable indicating the levee system is maintained by USACE or locally sponsored levees with involvement from state or county governments. Regressions control for levee protection levels through log or fixed effects to account for variation in initial design standards.

Table S7: 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 S8: 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 S9: 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 S10: 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 S11: 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 S12: 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 S13: Share of Zero-Valued Observations in Municipal Finance Data

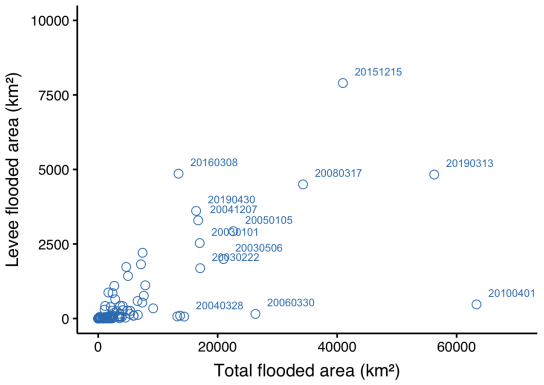
| Outcome | Specification | Total Obs. | Zero Count | Zero Share |
|---|---|---|---|---|
| Population | Levee | 3,036 | 0 | 0.0000 |
| Property Tax | Levee | 3,036 | 218 | 0.0718 |
| Intergovernmental Revenue | Levee | 3,036 | 103 | 0.0339 |
| Total Revenue | Levee | 3,036 | 10 | 0.0033 |
| Total Expenditure | 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.

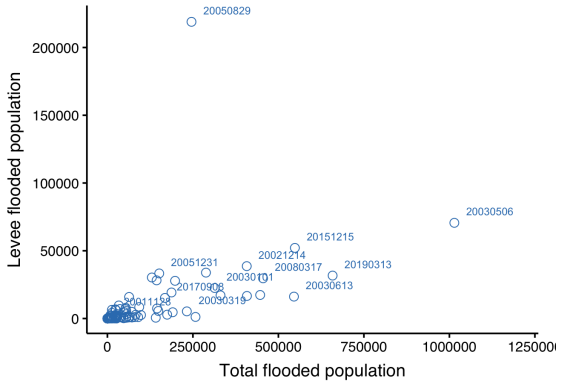
# Supplementary Figures

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

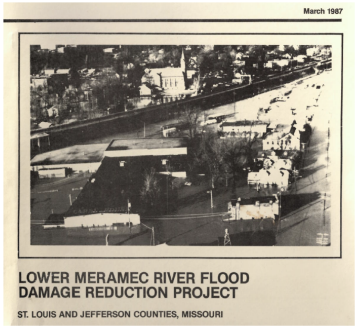



TABLE 3

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.

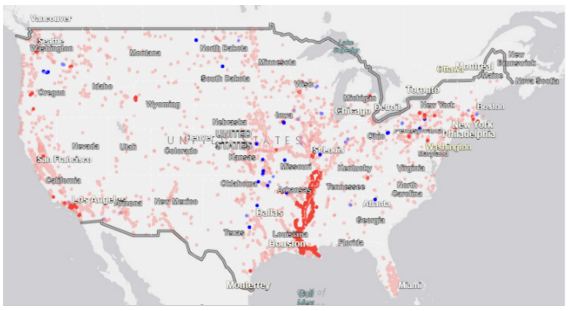
TABLE 11
VALLEY PARK LEVEE
HEIGHT OPTIMIZATION

| 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 |

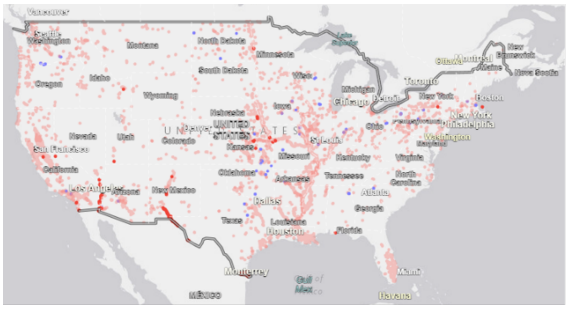
Notes: Figure sources from USACE 1987 plan formulation document.

Figure S3: Distribution of federal and local maintained levees

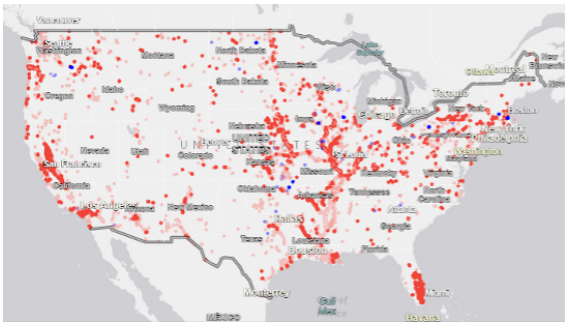
(a) USACE constructed and maintained



(b) Other Federal Agency



(c) USACE constructed and locally maintained



(d) Locally constructed and locally maintained

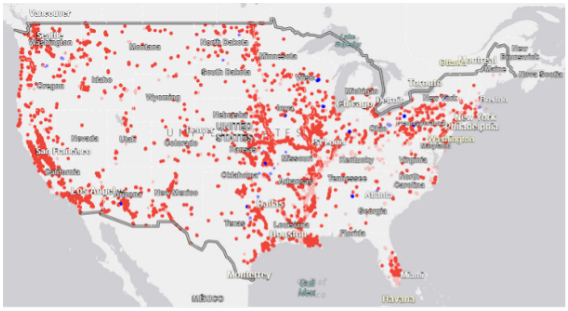
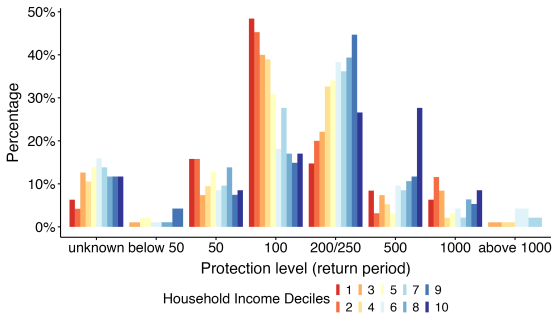
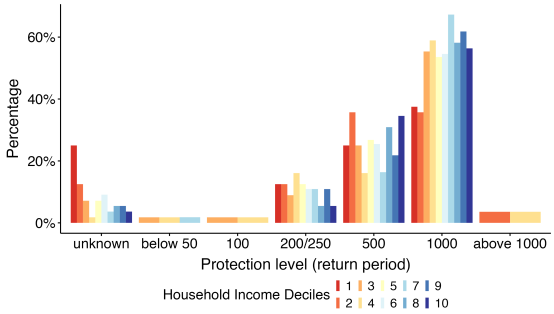


Figure S4: Income distribution in levee-dependent flood zone communities

(a) California

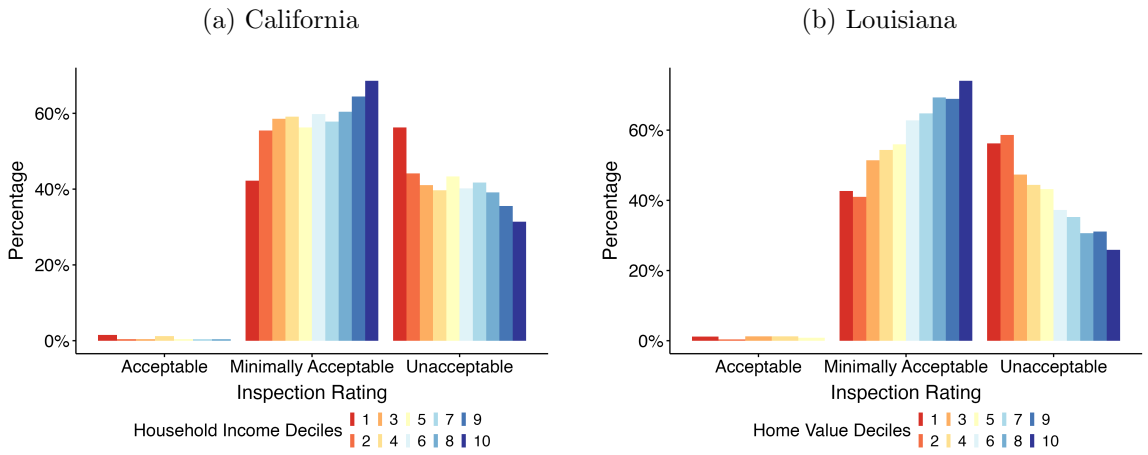



(b) Louisiana




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%.

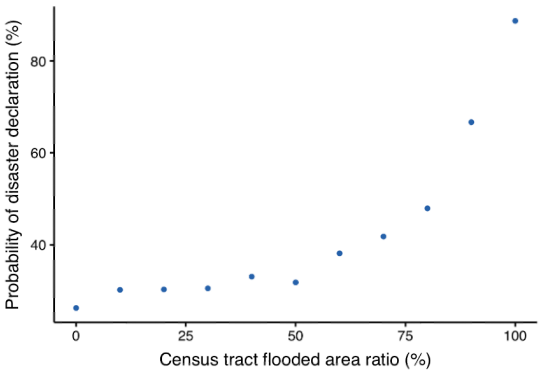
Figure S6: Levee construction timeline



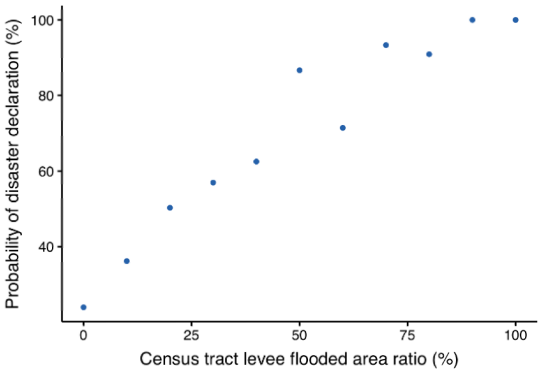

Notes: Construction year information is incomplete. The figure reports the distribution of construction years for levees with non-missing data.

Figure S7: Factors influencing federal disaster declaration

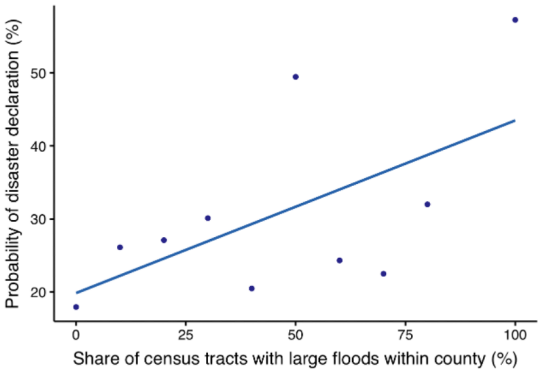
(a) Local flooding extent




(b) Local levee failure extent




(c) County flooding extent




(d) County levee failure extent

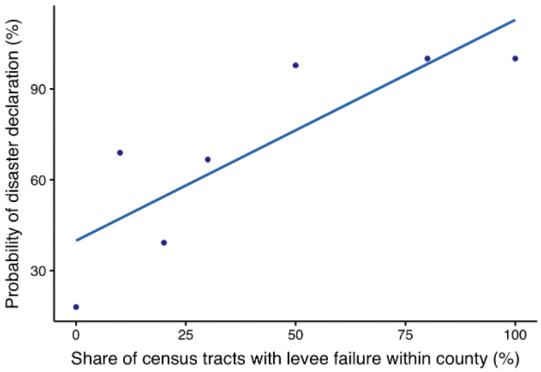
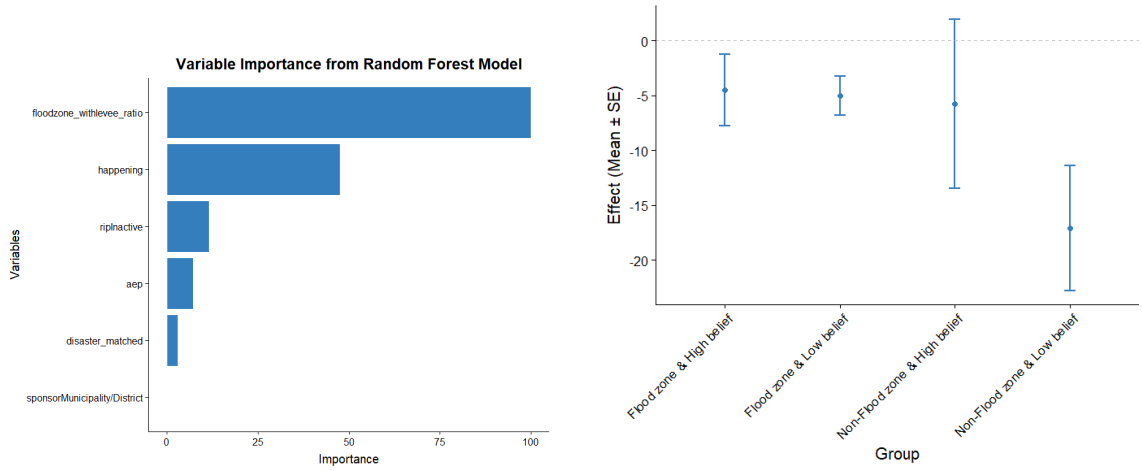


Figure S8: Random forest feature importance selection and sub-group results

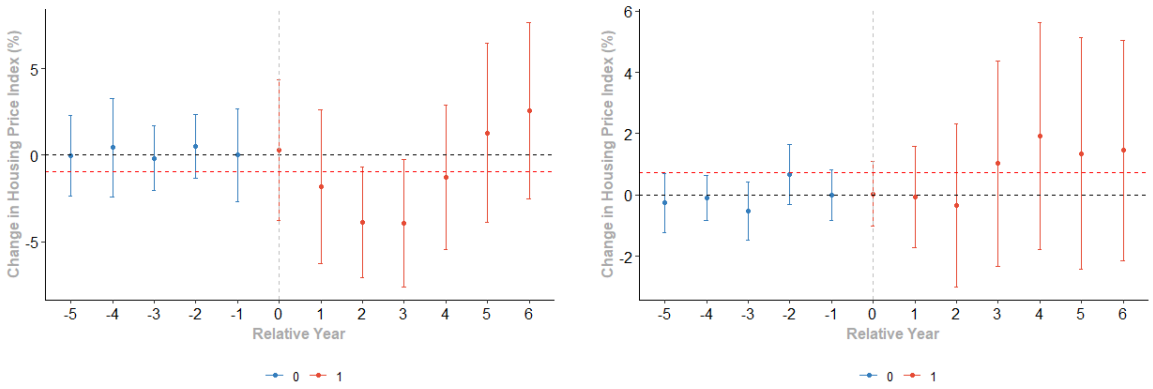
(a) (b)




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.

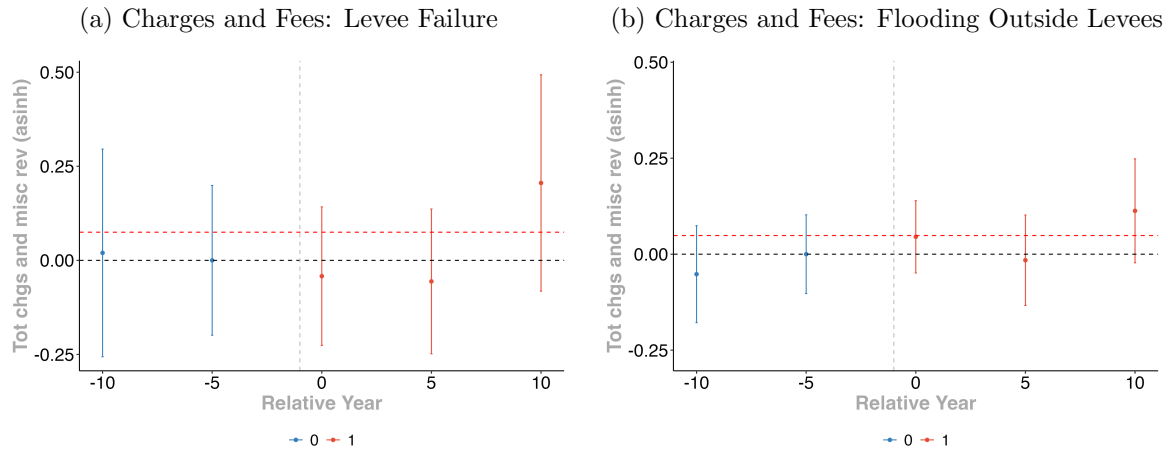
Figure S9: Effect of nearby flooding on neighbourhood housing price

(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.

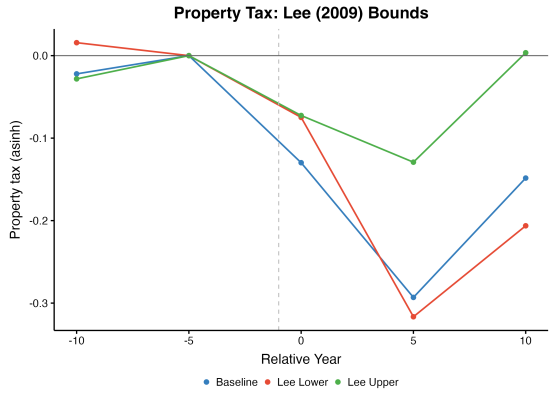
Figure S10: Effect of flooding on other revenue



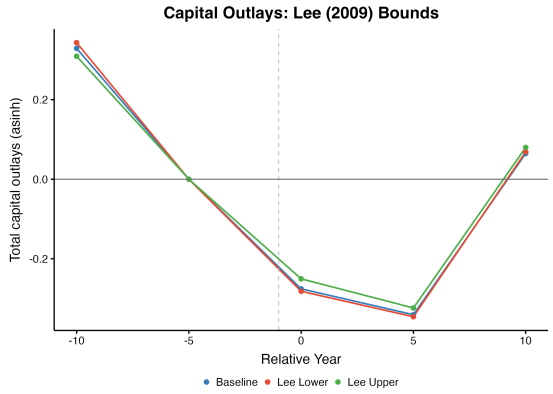

Note: Treatment is defined as flooding affecting tracts containing at least 10% of the municipal population. Coefficients at 0, 5, and 10 represent effects observed 0–4, 5–9, and 10–14 years after the event, respectively. All outcome variables are transformed using the inverse hyperbolic sine; percentage 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%, 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 S14: Levee maintenance and levee failure risk

| | Flooded at least once since 2000 |
|---|---|
| Log(Protection Level) | $-0.044^{***}$ |
| | (0.011) |
| Acceptable Quality | $-0.110^{***}$ |
| | (0.024) |
| State FE | Yes |
| Ownership FE | Yes |
| Floor Zone Control | Yes |
| Observations | 1,700 |
| Adjusted $R^2$ | 0.250 |

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. Geographic and Institutional Units of Analysis

The empirical analysis integrates information measured at three distinct geographic and institutional levels: census tracts, levee sponsorship units, and commuting zones.

### Census tracts (Primary unit of observation)

The primary unit of analysis is the census tract, which approximates a neighborhood-scale housing market. Housing values, income, socio-demographic characteristics, flood zone status, and historical flood exposure are all measured at the census tract level.

Each tract is classified as either levee-protected or not based on its geographic overlap with leveed areas. For protected tracts, I assign the designed protection level and maintenance quality of the levee system providing protection. Census tracts protected by the same levee are assigned identical measures of levee protection and maintenance quality.

Census tracts are used as the main unit of analysis because flood risk, flood exposure, socio-economic outcomes, and housing values are highly localized and can vary substantially within a single levee system. Aggregating to the levee-system level and using average flood exposure or housing values could mask important within-system heterogeneity and attenuate the estimated economic impacts of levee failures.

### Levee sponsorship units (levee decision-making entities)

Levee maintenance is the responsibility of heterogeneous sponsors, including municipal governments, special-purpose levee districts, and, in some cases, county or state governments (see Table S1 and Table S2).

Municipally sponsored levees (including those administered by cities and towns) typically protect large, contiguous areas within a municipality, though in some cases coverage is limited to a subset of high-risk neighborhoods. Levee districts exhibit substantial heterogeneity in scale. Smaller districts may protect only one or a few census tracts, whereas larger districts can span multiple municipalities as components of joint flood control systems.

Levee districts are special-purpose governments whose jurisdictions partially and vertically overlap with municipal and county boundaries. They rely primarily on property taxes and land assessments for revenue and generally face limited authority to levy alternative taxes. In addition, comprehensive and systematically comparable fiscal data for levee districts are often unavailable.

Because there is no within-sponsor variation in revenues and expenditures, analyses related to fiscal outcomes use the levee sponsorship unit as the unit of observation rather than census

tracts. These analyses (such as Table 6 and Figure 8) primarily focus on municipalities that rely heavily on levee protection, given the limited availability of public finance data for levee districts.

### Commuting Zone (technology shock units)

To study the impact of local housing values on levee maintenance, I exploit economic shocks at the level of local labor markets defined by Commuting Zones (CZs) (see Autor et al. (2013) for more detailed commuting zone definition). There are 722 commuting zones in the continental US and more than 80,000 census tracts. Since industry composition is defined at the commuting zone level, economic shocks from computerization are homogeneous within each commuting zone. Accordingly, in Table 5, standard errors are clustered at the CZ level to align with the level of treatment variation. Commuting zones are used exclusively for constructing the technology-shock instrument and are not otherwise employed as units of analysis.

### C. 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. The procedure closely follows Autor and Dorn (2013). First, I obtain occupation-level employment shares in 1980 and the Routine Task Intensity (RTI) index from Autor and Dorn (2013), and classify as routine-intensive those occupations in the top employment-weighted third of the RTI distribution. Second, using the 1 per cent sample of the 1950 Census, I construct commuting-zone–level industry and occupation compositions. Third, I merge these data with the SEA–CZ crosswalk to compute industry employment shares in 1950 for each commuting zone. Fourth, I calculate leave-one-state-out national routine intensity measures at the industry level and merge these with local shares. Finally, I reconstruct the Bartik-style technology exposure instrument by interacting local industry shares with the leave-one-out routine intensity measures. The reconstructed instrument exhibits a Pearson correlation of 0.904 with the baseline measure directly obtained from Autor and Dorn (2013) and used in Table 5, indicating that the reconstruction closely approximates the original instrument.[28]

Using this reconstructed shift–share design, I compute Rotemberg weights following Goldsmith-Pinkham et al. (2020). Owing to the leave-one-state-out specification, the underlying sectors are defined at the industry–state level. A Herfindahl index of 0.053 indicates that the Rotemberg weights are reasonably dispersed across sectors, implying that the instrument is not excessively concentrated. When aggregating the weights to industries for presentation, as shown in Table S15, the top five industries account for 31.5 percent of the total positive weight (0.623/1.980), suggesting that the identifying variation is not dominated by a single industry. The largest weights are associated with national security and international affairs, insurance, printing and publishing, aircraft and parts, and banking.

Table S15: 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 | -0.034 | 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 | 0.692 | 0.004 |
| Banking | 0.044 | 0.705 | 0.084 | 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

[28]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.

labour market structure of government employment, which is less responsive to market-driven automation shocks and characterised by more stable labour demand and institutional rigidities. Consequently, routine exposure in this sector does not transmit through the same skill-complementarity and housing-market channels as in the private sector. Excluding national security increases the implied 2SLS estimate from 0.131 to 0.212[29], 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 top five Rotemberg-weight industries. Table S16 shows little evidence of systematic pre-trends. Across industries, the estimated coefficients are generally insignificant. The only marginally significant estimate arises for aircraft and parts in 1970, but its sign goes opposite to the post-period pattern that would threaten identification. Although pre-trends in levee maintenance quality cannot be directly tested due to the lack of historical maintenance rating, it is reasonable to expect that maintenance quality was high when infrastructure was newly constructed.

Table S16: Pre-trend tests of industry share for top five industries.

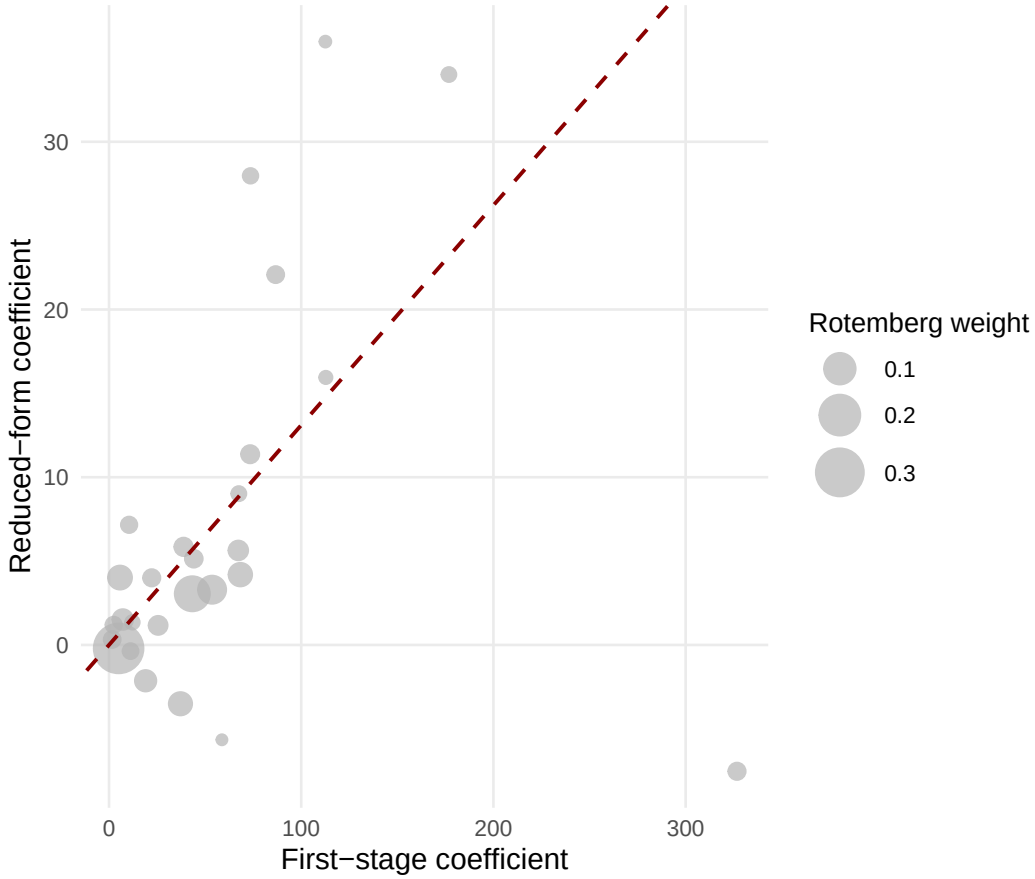
| Industry | Share on housing value (1970) | Share on housing value (1960) | Observations |
|---|---|---|---|
| National security and international affairs | -0.628 | 0.504 | 1,302 |
| | (0.510) | (1.901) | |
| Insurance | 0.762 | 5.077 | 1,302 |
| | (1.682) | (7.336) | |
| Printing and publishing | 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.

[29]The small discrepancy relative to the baseline estimate reflects the use of reconstructed microdata rather than the original instrument.

Finally, to assess the sensitivity of the estimates to the manner in which share instruments are combined, I implement the visual overidentification diagnostic emphasized by Borusyak et al. (2025). Figure S14 plots the 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 figure shows that the estimates are broadly aligned with this fitted ray, particularly among industries with larger Rotemberg weights, indicating that alternative combinations of share instruments yield similar implied effects. This pattern suggests that the shift-share estimate is not driven by a narrow subset of industries and is not very 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.