Private Benefits from Public Investment in Climate Adaptation and Resilience*

Jacob T. Bradt and Joseph E. Aldy†

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Abstract

Flood protection infrastructure investments, such as Army Corps of Engineers levees, can enhance resilience to flood risks amplified by climate change. We estimate levees' benefits by exploiting repeat residential property transactions. In areas protected by levees, home values increase 3-4 percent. Levees impose adverse spillover flood risks that reduce home values in nearby areas by 1-5 percent. Capitalized benefits in protected areas are progressive, but adverse spillover impacts are regressive. Capitalized benefits at levee construction do not vary by race, but racial sorting occurs post-construction. The local political economy of levee construction can explain the distribution of winners and losers.

Keywords: Climate change adaptation, housing markets, hedonic analysis, flood control, environmental gentrification

JEL Codes: Q54, Q58, H23, H22

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†Bradt: The University of Texas at Austin; jacob.bradt@mccombs.utexas.edu. Aldy: Harvard Kennedy School, Resources for the Future, National Bureau of Economic Research, and Center for Strategic and International Studies; joseph_aldy@hks.harvard.edu.

Given the slow pace of greenhouse gas emissions mitigation, governments, businesses, and households face a growing imperative to address the impacts of climate change. In the United States, a changing climate will cause more intense and frequent flooding, resulting in major loss of life and property as illustrated by recent extreme events, including the Mississippi River floods of 2019, Hurricane Ian of 2022, and Hurricane Helene of 2024. The share of properties in the United States at risk of regular flooding will likely increase by 8 percent over the next 30 years (First Street Foundation, 2021). These growing physical risks highlight the importance of both policy and market responses to climate change.

Current climate adaptation policy is likely inadequate. In the face of increasing natural hazard risks, the United Nations Environment Programme estimates global adaptation spending will need to amount to $215-387 billion annually by 2030 (United Nations Environment Programme, 2024). While recent efforts such as the Infrastructure Investment and Jobs Act of 2021, which appropriates tens of billions of dollars for climate adaptation investments in the United States, make progress towards funding these needs, a wide gap remains. As governments consider options for investing in community resiliency, the policy debate will prompt questions about the benefits and costs characterizing these alternatives: how large are the benefits and costs and who receives them?

This paper examines the magnitude and incidence of benefits and costs of public climate adaptation investments. We explore how public investment in adaptation is capitalized in home prices through local property markets. We focus on flood control levee projects, which historically represent one of the largest categories of investment in flood risk reduction in the United States. These public infrastructure projects deliver geographically-specific benefits to nearby properties in the form of reduced risks of flooding. In addition to these flood protection benefits, levee construction results in potential flood risk spillovers to surrounding, unprotected areas. We provide empirical estimates of the magnitude of these housing market effects for a particularly salient subset of US levee projects—those constructed by the US Army Corps of Engineers (USACE)—and leverage these estimates to better understand the distributional, welfare, and political economy impacts of flood adaptation investments.

We analyze the impact of USACE levee construction on residential property values across the continental US by integrating detailed hydrological data on levee-protected areas with comprehensive real estate transaction and assessment records. Our empirical design exploits information on the timing of USACE levee construction and rich geographic data on the proximity of residential transactions to levee protected areas and nearby waterways to estimate a broad set of plausible housing market effects of levee construction. We only have access to housing transaction data since 1990, so we restrict our analysis to levees constructed by the USACE after 1990. Our focus on USACE levees is primarily motivated by our empirical design—we are able to collect information on the date of construction for these projects—however, the scale of this category of public infrastructure projects makes it a useful case study for future investments in climate adaptation: since 1992, the USACE construction account, which includes levees and other flood control projects, has received average annual appropriations of $2.2 billion (nominal dollars; Congressional Budget Office (2022)).

Employing a set of difference-in-differences estimators, we find that the expected net present value of protection benefits from USACE levees ranges from 2.8% to 4.0% of a home's value on average. However, spillovers to surrounding, unprotected properties in the form of increased flood risk reduce home value by 1.1% to 5.4%, depending on the specification and empirical design. This suggests that much of the flood risk reduction accomplished by levees is offset by increased risk elsewhere. We estimate that the total capitalized value of flood protection benefits provided by USACE levees constructed since 1990 amounts to $862 million (2019 USD). In comparison, the total capitalized value of flood risk spillovers from these projects amounts to $631 million (2019 USD).

Our rich, transaction-level data enable us to explore not only the capitalized effects of levee construction, but also the distribution of these effects along key sociodemographic variables. We find that flood protection benefits as a share of income are largest for lower income households; however, the same is true for flood risk spillovers. Thus, while USACE-constructed levees appear at first to reallocate resources towards low-income households, flood risk spillovers work to offset the progressivity of this transfer. We also find suggestive evidence of differential sorting around levee-driven changes in flood risk by different racial and ethnic groups: White and Asian households appear more likely to move into levee protected areas and less likely to move into spillover exposed areas post-levee construction. This is in contrast to Black households, who appear more likely to move into spillover-exposed areas after levee construction, and Hispanic households, who appear less likely to move into protected areas after levee construction.

We contextualize our estimates of the private housing market effects of USACE levee construction using estimates of the net effect of these projects on public expenditures. Though largely financed through federal spending, construction of USACE levees requires cost-sharing from a local, non-federal entity. We manually collect information on construction costs for both federal and non-federal entities for a subset of the USACE-constructed levees in our estimation sample using a broad set of primary sources. Given that we estimate non-trivial housing market impacts from levee construction, we also use property-level information on local real estate tax rates to translate the impacts of levee construction on housing values into changes to local tax revenues.

Calculating the various categories of benefits and costs of USACE levee construction illuminates the local political economy considerations of levee investments. The presence of large flood risk spillovers raises important questions about the extent of internalized impacts by local decision-makers. Many USACE levees in our sample appear to offer minimal returns to aggregate social welfare. If local municipalities which partially fund the construction of USACE constructed levees do not experience the flood risk spillovers and the associated reduction in property tax revenues imposed by the levee, then our estimates clearly indicate that the project will appear far more appealing from their perspective. About one-third of USACE-constructed levee projects in our sample impose spillover effects on counties outside of the county protected by the levee, which suggests that USACE levee construction may indeed represent a classic externality problem.

Despite our focus on USACE flood control levees, our findings extend to other forms of public climate adaptation investment. Any form of public adaptation investment which provides geographically localized benefits—and potentially external costs—is likely to raise similar questions about the distribution of impacts and the associated distortions in incentives to both individuals and policymakers. Sea walls, which feature prominently in discussions about coastal adaptation to storm surge flooding in New York, Miami, Galveston, and more, are a salient form of public investment in climate adaptation that is similar to levees.

These findings underscore the importance of evaluating the impact of existing institutions when considering policies to improve resiliency to climate impacts. A large, growing literature on climate adaptation tends to focus on household- or firm-level adaptation.[1] Recent work examines the implications of policies to mitigate and manage natural hazard risks on household and firm adaptation, including publicly-subsidized flood insurance (Wagner, 2022), sea walls (Hsiao, 2023), wetlands conservation (Taylor and Druckenmiller, 2022), wildfire suppression (Baylis and Boomhower, 2023), and other forms of development incentives (Druckenmiller et al., 2024). Our analysis emphasizes the need to carefully evaluate economic questions surrounding large-scale, public investments in adaptation.

Economists have studied the private benefits from similar investments in flood control infrastructure, including beach nourishment, flood walls, pump systems, and levees, finding that individuals have positive willingness-to-pay for these forms of flood protection (Dundas, 2017; Fell and Kousky, 2015; Gopalakrishnan, Landry and Smith, 2018; Kelly and Molina, 2022; Walsh et al., 2019). These results are a natural extension of a large set of results finding that flood risk is negatively capitalized in housing prices (Beltrán, Maddison and Elliott, 2019; Bernstein, Gustafson and Lewis, 2019; Graff Zivin, Liao and Panassie, 2022).

[1] Examples from this literature include: Balboni, Boehm and Waseem (2024); Barreca et al. (2016); Boustan, Kahn and Rhode (2012); Burke and Emerick (2016); Carleton et al. (2022); Dell, Jones and Olken (2012); Deschênes and Greenstone (2011); Ito and Zhang (2020); Kahn (2016)

While existing work is informative of the magnitude of private benefits from investments in flood risk reduction, they do not model direct spillovers in flood risk and therefore risk misinterpreting the overall impact of these investments. Noteworthy exceptions include is Dundas and Lewis (2020) and Wang (2021). Our results build on this literature by examining the direct spillover effects from large-scale, public adaptation projects using spatially-explicit housing market and levee data.

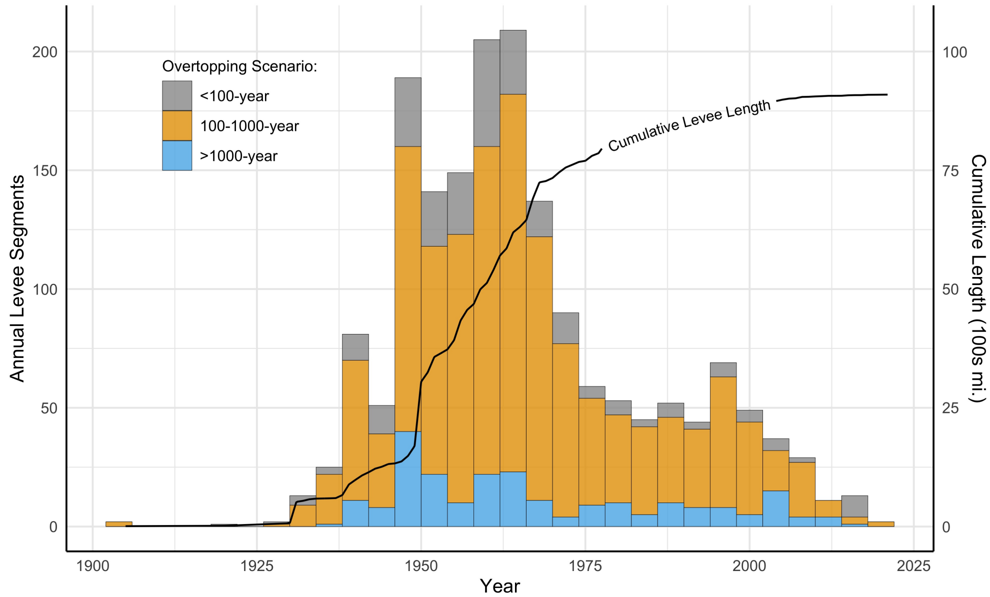
A growing literature examines the public finance implications of climate impacts and adaptation policy. This work emphasizes the imperative for public provision of adaptation infrastructure and other policies to promote resiliency (Balboni, 2024; Barrage, 2020; Fried, 2022). Given the potential for highly localized variation in exposure to natural hazards exacerbated by climate change, this literature highlights the importance of climate adaptation policies at the sub-national level (Goldsmith-Pinkham et al., 2021; Liao and Kousky, 2022). Levees offer one such policy with localized benefits; however, the existence of spillovers underscores the need to consider plausibly strategic interactions between such investments. In this respect, our work relates to the broad literature on place-based policies that examines how strategic interactions can drive both governments' decisions to implement a policy and the policy's outcomes (Busso, Gregory and Kline, 2013; Mast, 2020).

The remainder of the paper proceeds as follows. Section 1 provides detailed background on public policies to address flood risk in the United States. Section 2 provides a high-level description of the data that we use in our analysis (additional detail is provided in Appendix A). Section 3 outlines our empirical design and Section 4 provides our main results. We interpret our primary results and provide additional context in Section 5. Section 6 concludes.

1 Flood Risk Policy in the United States

Responsibility for managing flood risk in the United States is shared by federal, state, and local entities. Historically, US flood policy focused on controlling floodwaters through public investments in large-scale engineered structures such as dams and levees. A levee is a man-made structure, usually an earthen embankment, located along a waterway that diverts water flow during flood stages. Devastating floods in the early 20th century led to the passage of a series of laws authorizing federal involvement in levee building: the Flood Control Acts of 1917, 1928, and 1936 (Arnold, 1988). These Acts established the USACE as the primary federal entity responsible for the design and construction of flood control projects and set precedents around state and local involvement in levee construction and management that continue today (Arnold, 1988). As shown in Figure 1, USACE levee construction accelerated

Figure 1. USACE Levee Construction, 1905-2021.



Note: The histogram (left vertical axis) shows the annual count of levee segments constructed by the USACE and the line (right vertical axis) shows the cumulative number of levee miles constructed by the USACE. The "overtopping scenario" field refers to the level of protection that each levee segment is designed to provide, i.e., the flood level beyond which flood waters exceed the height of the levee and therefore flow over top of the levee structure.

rapidly following the passage of the Flood Control Acts, ultimately peaking in the 1960s.

USACE levee construction activities receive project-level authorization and appropriations by Congress, resulting in substantial interest by individual Members of Congress in the site selection process (Carter and Normand, 2019).[2] The standard project delivery process for individual USACE-constructed levee systems has four steps: pre-construction evaluation through a formal feasibility study, design, construction, and operation and maintenance (O&M). Feasibility studies are required for any potential levee project to be eligible for construction and project-level Congressional authorization and appropriations are required to proceed with both pre-construction feasibility studies and the design and construction stages. All USACE levee projects require a non-federal sponsor, such as state, tribal, territory, county, or local agencies or governments. Since 1986, nonfederal sponsors have been responsible for 50% of pre-construction feasibility study costs, up to 45% of design and construction costs, and all of O&M costs (Carter and Normand, 2019). Given this breakdown of

[2]USACE is a federal agency within the US Department of Defense with substantial engineering expertise and both military and civil works responsibilities. Authorization of USACE civil works activities typically occurs in biennial Water Resource and Development Acts (WRDA) and appropriations for authorized activities are typically provided in annual Energy and Water Development appropriations acts (Carter and Normand, 2019).

O&M costs, USACE transfers ownership of the vast majority of levee systems it constructs to the non-federal, local partners involved.

At the pre-construction feasibility study stage, projects typically target a specific water resource management challenge at a regional or sub-regional level. Authorized and funded feasibility studies then identify and evaluate alternative solutions based on engineering feasibility, cost-benefit analyses, and assessments of environmental impacts. The Flood Control Act of 1936 established the precedent that USACE flood control projects should have benefits that exceed costs, and recent federal policy targets projects with ratios of benefits to costs of 2.5 or more (Carter and Nesbitt, 2016).

In parallel with the slowdown in levee construction shown in Figure 1, US flood policy shifted away from controlling floodwaters to managing the consequences of flooding (Tarlock, 2012). While public policies to manage the consequences of flood related risks are not our focus, they are worth noting given their interactions with levee construction. Specifically, areas protected by levees are eligible for non-trivial reductions in flood insurance premiums under the National Flood Insurance Program (NFIP), a federal program that underwrites 90-95% of residential flood insurance policies in the United States (Kousky, 2018).[3] Areas protected by levees that meet minimum design criteria established by the Federal Emergency Management Agency (FEMA), which oversees the NFIP, are eligible for removal from high-risk areas referred to as Special Flood Hazard Areas (SFHAs). This re-mapping process entitles homes in these areas to lower flood insurance premiums and removes a requirement for all homes with mortgages from federally-backed lenders to acquire flood insurance that would be present in an otherwise higher risk area (Federal Emergency Management Agency, 2021).

Our study focuses on USACE-constructed levees as a case study for understanding where and how private benefits and costs of public investments in adapting to climate related risks are distributed. Despite the slowdown in federal levee construction in recent decades, we believe that there are important lessons to be drawn from this category of investments to future policymaking given that the various categories of impacts that we explore generalize to other types of climate adaptation projects, including forms of built infrastructure which receive substantial attention such as shore hardening and sea walls. In fact, the institutional features of the USACE levee production process are identical to those of several sea walls currently under consideration for construction by USACE. Moreover, given the substantial solvency issues surrounding public programs to manage the consequences of flooding, most notably the NFIP, it is clear that additional efforts to reduce and control risks—including

[3] For a detailed overview of the NFIP, see Kousky (2018).

through additional levee building—are necessary.[4]

2 Data

In this section, we summarize our primary data sources and sample restrictions. A comprehensive discussion of the data used in this analysis can be found in Appendix A. We construct a dataset that combines hydrologically-accurate information on the spatial extent of areas protected by USACE levees with transaction and assessor data for a large subset of residential properties in the continental US. Our dataset also includes information on the income and race of a subset of homeowners obtained from publicly-available mortgage data as well as information on a property's proximity to surface waters.

We collect data on the US housing market from Zillow's Transaction and Assessment Dataset (ZTRAX). As of April 2022, ZTRAX contains detailed information on the price, timing, location, and any associated mortgage loans for more than 400 million residential property transactions obtained from public records across 2,750 US counties.[5] The temporal coverage of transactions contained in ZTRAX varies by state and county, going back as far as 1990 in certain geographies. ZTRAX also contains tax assessor data on property characteristics—including geographic information—for over 150 million parcels in over 3,100 US counties. We exclude residential parcels containing invalid or approximate geographic coordinates and exclude transactions for which the price likely deviates from the property's market value. See Appendix A for a discussion of our sample restrictions.

We obtain novel data on areas protected by USACE-constructed levees through an agreement with the First Street Foundation. First Street aggregates publicly-available information on the infrastructure type, geographic location, and physical characteristics of a large subset of flood adaptation projects throughout the United States. We focus exclusively on USACE-constructed levees, given that they are relatively comparable across projects in terms of siting process, funding sources, and public engagement. Moreover, our focus on this subset of projects allows us to obtain information on the timing of construction via the National Levee Database (NLD), which is critical to our empirical strategies discussed in detail in Section 3. We further subset these data to levees constructed by the USACE after 1990 due to the lack of data on housing transactions prior to this year. This results in a final sample of 80 USACE-constructed levee projects.[6]

[4]For additional information on the NFIP's fiscal issues, see Government Accountability Office (2020).

[5]We deflate all ZTRAX price data to 2019 US dollars using the CPI-Urban deflator.

[6]Levee construction dates are available for about four-fifths of USACE-constructed segments recorded in NLD. Certain large-scale, high-profile levee projects—such as the Lower Mississippi River and New Orleans levees—were originally locally-constructed in the early 1900s. As a result, these salient examples of levees do not appear in our sample.

Since a USACE-constructed levee system, which is the level at which we observe each project in our First Street data, may include several levee segments with possibly differing construction dates, we obtain information on the completion date for all levee segments within USACE-constructed levees in our sample from the NLD. We also obtain geographic data on the location of each levee segment in our sample to allow us to precisely assign levee construction dates to each housing parcel based on its nearest levee segment. We use these data on USACE-constructed levees to subset our housing market data: using valid geographic coordinates for parcel centroids, we identify those residential parcels located either inside of or within relatively close proximity to—in practice, five miles—leveed area boundaries.[7] We assign parcels that are in proximity to multiple leveed areas to their closest levee.

We access demographic information, including income, race, and ethnicity, for the subset of transactions in our sample with valid loan information using successful loan applications for home purchases made publicly-available through the Home Mortgage Disclosure Act (HMDA).[8] HMDA data provide information on the year of origination, property census tract, loan amount, application purpose, lender institution's name, and select applicant demographics and are available for the full period of transactions in our sample. We match approved HMDA loan applications to transactions based on the year of transaction, census tract, approximate loan amount, and lender name. This procedure matches approximately 70% of the original Zillow transactions conditional on the transaction having data on a mortgage. We provide additional information on this matching procedure in Appendix A.

Our final dataset includes over 1.8 million transactions of 1.04 million residential parcels located within or near areas protected by 80 USACE-constructed levee systems, which include a total of 116 unique levee segments. Additional data that we use include authoritative hydrography boundaries from the USGS's National Hydrography Dataset Plus, Version 2.1 (NHD); counts of county-level flooding events from the National Oceanic and Atmospheric Administration (NOAA); and aggregate flood insurance take-up and claims data from the National Flood Insurance Program (NFIP). We provide further information on these data sources in Appendix A, including detailed descriptive statistics in Appendix Table A1.

[7]Given the potential for partial overlap of parcels and leveed areas, our use of parcel centroids may introduce error in our treatment assignment. We therefore omit parcels from our estimation sample that fall within a bandwidth of either side of leveed areas.

[8]The Home Mortgage Disclosure Act of 1975 requires major depository institutions to disclose loan-level information for all of their closed-end home lending activity every year. Estimates suggest that home loans reported through HMDA represent approximately 90% of all home lending nationwide.

3 Empirical Strategy

By estimating the capitalization of levee construction into housing prices, we aim to recover the private costs and benefits of public investments in flood risk adaptation. In our framework, houses are differentiated by proximity to a waterbody and whether or not they are protected by a levee.

3.1 Categorizing Levee Construction Effects

We classify the main impacts of levee construction on the housing market into three categories: protection effects, spillover effects, and macro effects.

Protection Effects—This is the primary intended benefit of levee construction, namely the flood protection benefit that levees provide. Given that construction costs are convex in levee height, levees are constructed to withstand flooding events up to a maximum threshold, often referred to as overtopping scenarios. The modal overtopping scenario—the flood event beyond which a levee will breach—for USACE constructed levees is a 1-in-100 year flood. Thus, capitalized protection benefits should reflect households' expectation of avoided flood damages over the full distribution of flooding scenarios.

Spillover Effects—This category refers to direct effects of levee construction experienced by homes not located inside leveed areas. Engineering and hydrology literatures document that levee construction exacerbates flooding outside of leveed areas using theoretical modeling and observational data (Remo et al., 2018; Remo, Carlson and Pinter, 2012). These negative flood risk spillovers occur both upstream and downstream of levees (Heine and Pinter, 2012).[9] Wang (2021) evaluates the spillover effects of levee heightening and finds non-trivial downstream external costs due to upstream levee building in the Mississippi River basin. In our context, we might expect homes near waterways but not protected by a levee to therefore be exposed to greater flood risk after levee construction. As a result, these homes are likely to experience declines in prices after levee construction.

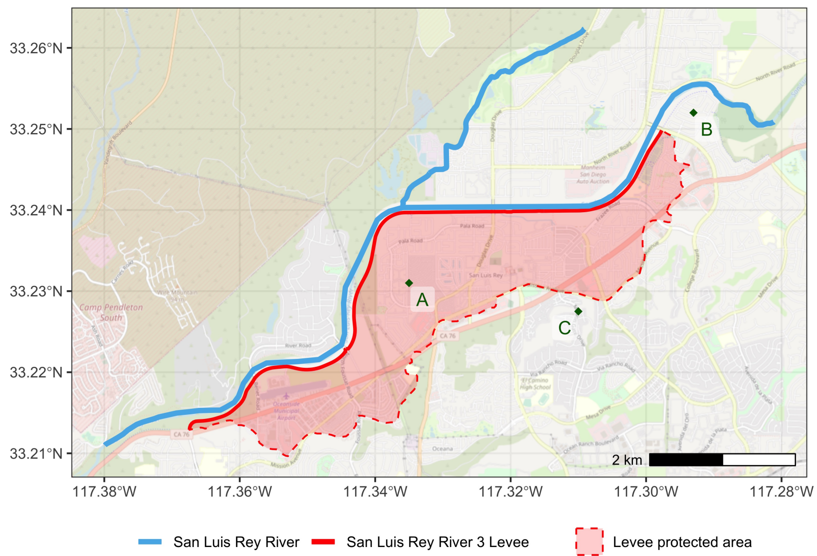
Macro Effects—This broad category refers to effects which are associated with levee construction and common to all homes in the vicinity of levee projects. This category can include effects from indirect economic spillovers due to levee construction—perhaps through increased investment in regions receiving a levee.

Figure 2a illustrates each of the potential housing market effects of levee construction, using as an example the San Luis Rey River 3 Levee, a USACE-constructed levee completed

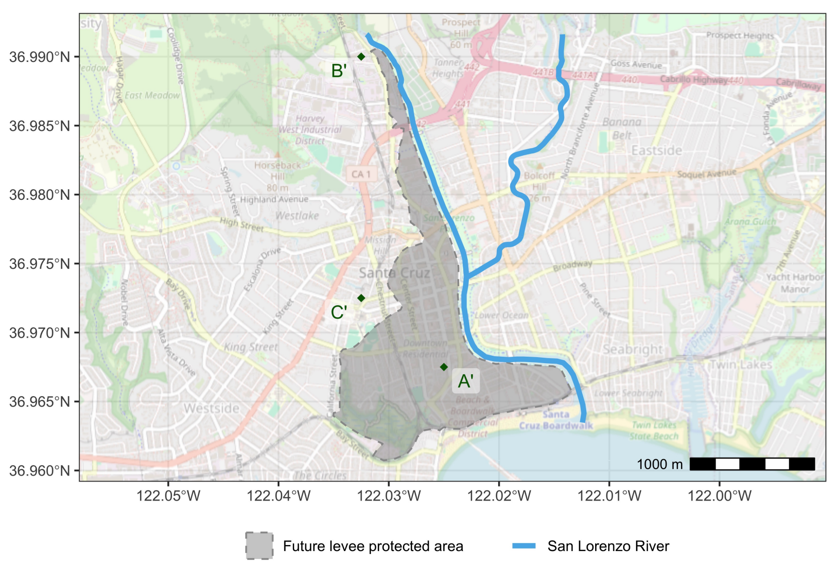
[9] Heine and Pinter (2012) document that flood stage increases downstream are primarily due to the reduction of upstream floodplain areas open to storage of flood waters. Flood stages increase upstream due to backwater effects reducing flood water flow velocities from the levee to all points upstream.

Figure 2. Example Treated and Control Parcels for Estimating Levee Construction Effects.

(a) Example Treated Parcels: San Luis Rey River 3 Levee (Oceanside, CA), Constructed 2000.



(b) Example Control Parcels: San Lorenzo River Right Bank Levee (Santa Cruz, CA), Constructed 2004.



Note: Figure 2a shows three example parcels demonstrating the different types of treatment effects of levee construction in the context of the San Luis Rey River 3 Levee (California, US), a USACE-constructed levee completed in 2000 (see Section 3.1 for a discussion of possible levee construction effects). The empirical design described in Section 3.2.1 uses changes in sale prices of parcels of type C to identify the effects of levee construction on parcels of type A and B. Figure 2b shows three example control parcels using the empirical design described in section 3.2.2 in the context of the San Lorenzo River Right Bank Levee (California, US), a USACE-constructed levee completed in 2004. In this approach, transactions of parcels A', B', and C' before the construction of the San Lorenzo River levee—i.e., not-yet-treated observations of A', B', and C'—serve as controls for parcels A, B, and C, respectively, in Figure 2a.

in 2000. In Figure 2a, parcel A falls within the leveed area and experiences protection effects. Parcel B is not located within the leveed area but is near the relevant surface water and as a result may experience adverse spillover effects from levee construction. All parcels experience macro effects, though this is the only effect to which parcel C is exposed.

3.2 Identifying Levee Construction Effects

We adopt two different approaches to identify levee construction effects: the first leverages local, within-levee changes in transaction prices; the second exploits variation in the timing of construction across levee systems. Each empirical design focuses on within-parcel-type changes in sale prices around levee construction, which accounts for any systematic differences between protected and unprotected homes.

3.2.1 Identifying Levee Construction Effects: Local Variation

Our first approach to identify the capitalized effects of levee construction leverages local, within-levee project changes in transaction prices. We use the example parcels depicted in Figure 2a to illustrate this approach.[10] Consider the price of an example parcel, say P_A, and define the operator Δ_t as the change in a given property's transaction price from before to after construction of a levee, i.e., $\Delta_t P_A = (P_{A,post} - P_{A,pre})$. Then we can decompose the change in each of the example parcel's price around levee construction as follows:

$$\begin{aligned} \Delta_t P_A &= Macro + Protect + \delta_t \\ \Delta_t P_B &= Macro + Spillover + \delta_t \\ \Delta_t P_C &= Macro + \delta_t \end{aligned} \tag{1}$$

where, for example, $Protect$ refers to the change in observed prices attributable to protection benefits from the levee and δ_t is an unobservable change in transaction prices common to all parcels, but not directly related to levee construction. Examples of the latter include macroeconomic factors, labor market trends, or changes in policies. We can therefore identify protection and spillover effects using difference-in-differences estimators:

$$\begin{aligned} (Protect)_{DD} &= \Delta_t P_A - \Delta_t P_C \\ (Spillover)_{DD} &= \Delta_t P_B - \Delta_t P_C \end{aligned} \tag{2}$$

The difference-in-differences estimators (2) implicitly rule out any unobserved, parcel-

[10] This exposition of our approach to identification is inspired by Muehlenbachs, Spiller and Timmins (2015) who employ a similar empirical strategy to identify the capitalized effects of shale gas development.

specific changes in sale price resulting from levee construction. We can interpret this assumption as the stable unit treatment value assumption (SUTVA), which imposes two standard restrictions: first, a given parcel's change in price around levee construction is only a function of that parcel's treatment (i.e., there are no treatment spillovers between parcels not accounted for by our treatment variables) and second, the protection, spillover, and macro effects capture all aspects of the levee construction treatment. A violation of one or both of these restrictions for any of the parcel types would undermine identification of the protection effect, spillover effect, or both effects using the estimators (2).

3.2.2 Identifying Levee Construction Effects: Variation across Levees

Our second approach to identify the capitalized effects of levee construction leverages variation in the timing of construction across levee systems. In particular, this approach exploits admissible comparisons across levees with different construction dates by using not-yet-treated transactions of protection and spillover-exposed parcels as controls when estimating the protection and spillover effect of a given levee.

Figures 2a and 2b illustrate this second identification strategy. Focusing again on identifying the effects of levee construction on parcels A and B in Figure 2a, we now introduce an admissible set of control parcels in Figure 2b, using as an example control project the San Lorenzo River Right Bank Levee, a USACE-constructed levee completed in 2004. Prior to 2004, parcels A', B', and C' in Figure 2b are not-yet-treated analogs to parcels A, B, and C in Figure 2a, respectively. Changes in transaction prices of A', B', and C' from before to after construction of the levee treatment of interest, which is the year 2000 for the San Luis Rey River 3 Levee in Figure 2, can be decomposed as follows if we restrict ourselves to transactions prior to 2004:

$$\Delta_t P_{A'} = \Delta_t P_{B'} = \Delta_t P_{C'} = \delta_t \tag{3}$$

We can then define the following set of difference-in-differences estimators:

$$\begin{aligned} (Protect + Macro)_{DD} &= \Delta_t P_A - \Delta_t P_{A'} \\ (Spillover + Macro)_{DD} &= \Delta_t P_B - \Delta_t P_{B'} \end{aligned} \tag{4}$$

where comparing (1) and (3), we can see that the estimators (4) do not separately identify the protection and spillover effects from the macro effect. Since the local and regional macroeconomic effects of levee construction are likely positive, we should expect results from the difference-in-differences estimators (4) to differ from those from (2).

Despite the fact that the estimators (4) include the macro effects of levee construction, this second identification strategy has two key advantages over the approach that we outline in Section 3.2.1. First, using variation across levee systems is robust to plausible SUTVA violations under the first empirical design. In particular, we may be concerned that the main flood risk effects of levee construction in which we are interested produce general equilibrium impacts in the housing market that influence the prices of unprotected, non-spillover-exposed parcels. For example, levee construction alters the supply of flood-protected and flood-exposed homes in a housing market, which in turn can affect the prices of unprotected, non-spillover-exposed homes in close proximity to the levee.[11] In the context of the example parcels in Figure 2a, this would imply that the change in the price of parcel C around levee construction can be decomposed as follows:

$$\Delta_t P_C = \underbrace{Macro + \Delta_t \xi_C}_{\equiv \text{Total effect of levee construction on C}} + \delta_t$$

where $\Delta_t \xi_C$ is an unobservable change in the transaction price of parcel C due to levee construction that is unique to parcels of this type. When $\Delta_t \xi_C \neq 0$, the difference-in-differences estimators (2) cannot separately identify the protection and spillover effects.

The second advantage of this approach is that it allows us to recover estimates of the total effect of levee construction on parcels of type C. In our first identification strategy, there are no admissible controls for non-protected, non-spillover-exposed parcels. Using changes in prices for not-yet-treated transactions of parcel C', we can identify the total effect of levee construction of parcel C with the following difference-in-differences estimator

$$(Macro + \Delta_t \xi_C)_{DD} = \Delta_t P_C - \Delta_t P_{C'}$$

where the left-hand side gives the sum of the macro effect of levee construction and any unobservable changes in the price of parcel C due to levee construction, perhaps due to general equilibrium effects in the housing market.

3.3 Estimating Capitalized Effects

We take our identification strategies to the data described in Section 2 by first defining a series of indicator variables encoding location relative to leveed areas and waterways for all homes in our final sample. Specifically, let L_i equal 1 if parcel i is located within a leveed area as indicated by the First Street data (protected) and 0 otherwise and W_i equal 1 if

[11] We thank Peter Christensen and Michael Greenstone for raising this concern and Michael Greenstone for suggesting this alternative identification strategy.

parcel i is located adjacent to a waterway and is outside of leveed areas (spillover) and 0 otherwise.[12]

3.3.1 Estimating Capitalized Effects: Local Variation

We implement the identification strategy that we outline in Section 3.2.1 by defining the price of house (parcel) i at time t as a function of a series of interaction terms, a parcel fixed effect (ξ_i), a levee segment-by-year fixed effect ($\mu_{l(i)t}$), and a year-by-month fixed effect (δ_t):

$$\log P_{it} = \alpha_1(T_{it} \times L_i) + \alpha_2(T_{it} \times W_i) + \xi_i + \mu_{l(i)t} + \delta_t + \varepsilon_{it} \tag{5}$$

where $T_{it} = 1$ if the transaction occurs after levee construction and 0 otherwise.

The levee segment-by-year fixed effect, $\mu_{l(i)t}$, accounts for the staggered timing of construction across levee systems—and in certain cases across levee segments within a system—and avoids the biases from standard two-way fixed effects estimators in the presence of heterogeneous treatment effects within-unit over time (de Chaisemartin and D'Haultfœuille, 2020; Goodman-Bacon, 2021). This fixed effect restricts our identifying variation to within treatment groups over time, which implements the identification strategy outlined above based on local variation in housing prices. This is particularly important in our setting given the substantial heterogeneity in treatment effect timing, which spans more than 20 years in our data (see Appendix Figure C2). Implementing a standard two-way fixed effects specification with our highly staggered timing results in a large number of inadmissible comparisons that use early treated transactions as control units for late treated units. Such comparisons can result in later transactions near earlier constructed levee segments having negative weights when aggregating treatment effects by regression estimation (Goodman-Bacon, 2021). Including the levee segment-by-year fixed effect shuts down these inadmissible comparisons, therefore avoiding the issue of negative weights.

Including the parcel fixed effect, ξ_i, helps to account for a large set of unobserved, parcel-level factors which plausibly affect a home's sale price. To implement our estimating equation with a parcel fixed effect, we restrict our estimation sample to parcels for which we observe multiple transactions, which is common in the hedonics literature (Bishop et al., 2020). While this reduces our sample size, it has the advantages of controlling for unobservable property attributes and limiting the extent to which our estimates can be driven by compositional shifts in transacted homes that may occur due to levee construction.

Our double-differencing empirical strategy controls for many unobservables that can affect

[12] Note that the definition of W_i excludes parcels protected by levees, and the definition of L_i excludes parcels in spillover areas.

the estimated capitalized effects of levee construction. In addition to these rich controls, we restrict our sample to properties within a reasonable bandwidth of leveed areas to limit the potential for time-varying unobservables to affect our results. In our main estimates of (5), we restrict our sample to properties within 5 mi of leveed area boundaries, excluding properties that are within 0.1 mi of either side of leveed area boundaries. The logic behind this restriction is that it minimizes unobserved differences between parcels across leveed and non-leveed areas: parcels closer to the leveed area boundary are more likely to have similar neighborhood characteristics and fall within the same effective housing market as parcels within leveed areas. Moreover, we exclude parcels within 0.1 mi of leveed area boundaries to avoid biases introduced due to potential miscoding of the leveed area treatment.[13]

The estimated coefficients α_1 and α_2 are the double-difference measures of protection and spillover effects resulting from levee construction, respectively. In addition to the SUTVA restrictions discussed above, two assumptions about house price counterfactuals are necessary for this causal interpretation to hold. These assumptions are standard from the difference-in-differences literature: parallel trends in outcomes (house prices) for the relevant treatment and control parcels around the time of levee construction. For example, our interpretation of α_1 as capturing protection effects from levee construction requires that absent levee construction, the difference between parcels of type A and C in Figure 2 would remain unchanged. A second, analogous assumption about the house price counterfactuals of parcels of type B and C is necessary to identify spillover effects.

3.3.2 Estimating Capitalized Effects: Variation across Levees

We follow the stacked regression estimator of Cengiz et al. (2019) to implement the identification strategy outlined in Section 3.2.2. To do so, we create event-specific datasets separately for each treatment effect and levee construction event in our data, combining all repeat sales of parcels treated by a particular levee with repeat sales of a set of admissible control parcels. For example, we take repeat sales of all levee-protected parcels for a given levee segment in our data and combine them with repeat sales of not-yet-treated parcels protected by levees constructed after that segment. We restrict the pool of potential levees that can serve as valid controls in each levee segment-specific treatment dataset to those constructed within five years of that levee segment.[14]

[13]Since we use parcel centroids to determine whether a given property falls within or outside of a leveed area, our leveed area treatment is likely to suffer from measurement error near leveed area boundaries. The average lot size for parcels either within 5 mi of a leveed area or within leveed areas is 1.52 acres, which corresponds to a square lot size with a diagonal of 0.07 mi.

[14]This ensures comparability across treatment and control parcels: since the USACE conducts ex-ante benefit-cost analyses of potential levee projects, it is possible that there are diminishing returns to levee

We then stack these levee construction event-specific datasets in relative time to calculate average treatment effects of levee construction across all segments in our data using a single set of treatment indicators. We implement these stacked regressions separately for levee-protected and spillover-exposed parcels:

$$\begin{aligned} &\text{Levee-protected:} \quad && \log P_{it} = \beta_1(T_{it} \times L_i) + \xi_{il(i)} + \mu_{l(i)t} + \varepsilon_{it} \\ &\text{Spillover-exposed:} \quad && \log P_{it} = \beta_2(T_{it} \times W_i) + \xi_{il(i)} + \mu_{l(i)t} + \varepsilon_{it} \end{aligned} \tag{6}$$

where $T_{it} = 1$ if the transaction occurs after levee construction and 0 otherwise. The main difference between the functional form of (6) and that of (5)—apart from the fact that we estimate the protection and spillover effects in separate regressions—is that these specifications fully saturate the parcel and time fixed effects with indicators for each specific stacked dataset (i.e., for each levee segment). These fixed effects are important as they restrict identifying variation for the main target coefficients, β_1 and β_2, to within each event-specific dataset. Given the potential for transactions to appear as both treatment and control units across the different event-specific datasets that we construct—indeed the same transaction can appear as a control for many levee segments—it is important to restrict identifying variation in this way as not doing so can lead to an arbitrary weighting of individual observations when aggregating treatment effects across levee construction events.

While this empirical design relaxes the specific SUTVA restrictions associated with the design that leverages local variation, an analogous set of restrictions must hold: (1) there are no spillovers in treatment across parcels and (2) the modeled effects of levee construction capture all aspects of the levee construction treatment. Moreover, a similar set of parallel trends assumptions are necessary for the estimated coefficients to have a valid interpretation as the causal effects of levee construction. These require parallel trends in outcomes for the relevant treatment and control parcels around the time of levee construction.

3.3.3 Defining Treatment Status

The specifications defined by (5) and (6) implicitly assume that spillover effects decay with distance to the leveed waterway, becoming zero at some distance. A common approach in the literature to determining exposure distance is to flexibly fit a curve between pre- and post-event prices and distance, using the crossing point of the two curves to determine exposure (Linden and Rockoff, 2008; Muehlenbachs, Spiller and Timmins, 2015). We implement this price gradient approach in Appendix Figure C3 and find suggestive evidence that spillovers

construction over our 30 year sample period that could result in time-varying unobservable factors for treated parcels throughout the sample period.

are likely outside of leveed areas between 0 and 0.3 mi of the nearest waterway. We also follow an alternative approach to defining these proximity-based treatment definitions by estimating the adjacency and spillover effects at 0.1 mi distance bins.

3.4 Recovering the Distribution of Capitalized Effects

We recover the distribution of capitalized effects using our estimates of the impacts of levee construction in combination with publicly-available HMDA data on the income and race for a subset of buyers in our transaction sample. In particular, we construct parcel-level demographic information at the time of levee construction using the most recent transaction to the date of construction and use these cross-sectional samples to infer the distribution of capitalized costs and benefits.

4 Results

4.1 Capitalization Estimates

Table 1 reports our main estimates of (5) using different definitions of the proximity-based spillover treatment definition and combinations of fixed effects. The dependent variable in each regression is the log of real sale price. We estimate versions of our main estimating equation that define spillover exposed parcels as those properties located within 0.1, 0.2, and 0.3 mi from the nearest waterbody and report the results in columns 1-2, 3-4, and 5-6 of Table 1, respectively. For each definition of spillover exposed parcels, we report estimates with and without the levee segment-by-year fixed effect in (5) to demonstrate the importance of restricting our identifying variation to within levee segment treatment groups over time. We report standard errors clustered at the census tract level to allow for correlation in the idiosyncratic error terms for transactions occurring in the same tract over the sample period.

We find strong evidence of positive capitalization of protection effects from levee construction: across specifications including segment-by-year fixed effects, we estimate that the protection benefits of levee construction (α_1) range between 2.7 and 2.9% of a homes value, with all estimates statistically significant (Table 1). We also find suggestive evidence of negative spillovers to water-adjacent, unprotected homes, with α_2 estimated to be negative across all specifications. In the three specifications that include the segment-by-year fixed effect, we estimate modest, statistically-significant, and negative spillovers; however, the estimates decrease in magnitude as we increase the distance-to-water bandwidth that we use to define spillover exposure. This pattern validates our assumption that spillover effects decay with distance to the nearest surface water area.

Table 1. Levee Construction Effects: Local Variation

Waterbody Bandwidth:	$k \leq 0.1$ mi		$k \leq 0.2$ mi		$k \leq 0.3$ mi	
	(1)	(2)	(3)	(4)	(5)	(6)
Protection Effect	0.098	0.029	0.095	0.028	0.092	0.027
	(0.015)	(0.009)	(0.015)	(0.009)	(0.015)	(0.009)
Spillover Effect	−0.062	−0.013	−0.062	−0.011	−0.064	−0.008
	(0.012)	(0.007)	(0.009)	(0.005)	(0.008)	(0.005)
Parcel FE	Yes	Yes	Yes	Yes	Yes	Yes
Sale Year-Sale Month FE	Yes	Yes	Yes	Yes	Yes	Yes
Sale Year-Levee Segment FE		Yes		Yes		Yes
Observations	1,244,323	1,244,323	1,244,323	1,244,323	1,244,323	1,244,323
R^2	0.924	0.948	0.924	0.948	0.924	0.948

The dependent variable is the log of real sale price. Data are restricted to parcels for which we observe more than one transaction during our sample period. We further restrict our data to transactions of parcels that either fall within leveed areas or are located within 5 miles of a leveed area boundary, excluding transactions of parcels that are within 0.1 mi on either side of leveed area boundaries (see Section 3). We report estimates of (5) using different waterbody bandwidths, k, that define spillover exposed parcels, namely 0.1, 0.2, and 0.3 mi from the nearest waterbody. Standard errors, clustered at the census tract level, are reported in parentheses.

Our estimates of both the protection and spillover effects of levee construction are substantially larger in magnitude when we exclude the levee segment-by-year fixed effect. As we discuss in Section 3, there are strong conceptual justifications for preferring the specifications that include this fixed effect (Goodman-Bacon, 2021). To explore why the two-way fixed effect estimates that omit the segment-by-year fixed effect produce larger in magnitude estimates, we examine correlations between the regression weights assigned to transactions in these specifications and transaction-specific attributes.[15] Overall, we find that the two-way

[15] The recent literature exploring bias in two-way fixed effects estimates of staggered DD designs suggests that examining the weights placed on different observations in these estimators can help diagnose bias (Baker, Larcker and Wang, 2022; de Chaisemartin and D'Haultfœuille, 2020; Goodman-Bacon, 2021). We estimate treatment weights placed on each observation for each treatment by taking advantage of the Frisch-Waugh-Lovell theorem: each observation's weight for each treatment in the two-way fixed effect specification is equal to its residuals from separate regressions of the treatment status for each treatment on treatment status for the other treatment and the full set of two-way fixed effects, i.e.,

$$\hat{\epsilon}^L_{it} = (T_{it} \times L_i) - \hat{\gamma}_1(T_{it} \times W_i) - \hat{\xi}_i - \hat{\delta}_t \qquad \hat{\epsilon}^W_{it} = (T_{it} \times W_i) - \hat{\gamma}_1(T_{it} \times L_i) - \hat{\xi}_i - \hat{\delta}_t$$

normalized by the sum of these squared residuals, i.e.,

$$\omega^L_{it} = \frac{\hat{\epsilon}^L_{it}}{\sum_{it}(\hat{\epsilon}^L_{it})^2} \qquad \omega^W_{it} = \frac{\hat{\epsilon}^W_{it}}{\sum_{it}(\hat{\epsilon}^W_{it})^2}$$

Thus, each treatment effect estimate in these two-way fixed effects specifications is essentially a weighted sum of the outcome variable with the weights calculated according to the above formula. In the presence of staggered treatment timing and plausibly dynamic treatment effects, the above weights can be negative.

Table 2. Levee Construction Effects: Variation across Levees

	Waterbody Bandwidth:			
	$k \leq 0.1$ mi	$k \leq 0.2$ mi	$k \leq 0.3$ mi	
	(1)	(2)	(3)	(4)	(5)
Protection Effect	0.040				
	(0.017)				
Spillover Effect		−0.081	−0.054	−0.044	
		(0.014)	(0.011)	(0.010)	
Macro Effect					−0.005
					(0.008)
Parcel-by-event FE	Yes	Yes	Yes	Yes	Yes
Sale Year and Month-by-event FE	Yes	Yes	Yes	Yes	Yes
Treatment Events	107	108	108	108	105
Treated Observations	229,727	95,462	251,445	429,962	1,152,158
Observations	683,387	537,683	1,405,865	2,385,282	5,641,680
R^2	0.960	0.959	0.953	0.952	0.951

The dependent variable is the log of real sale price. Data are restricted to parcels for which we observe more than one transaction during our sample period. We further restrict our data to transactions of parcels that either fall within leveed areas or are located within 5 miles of a leveed area boundary, excluding transactions of parcels that are within 0.1 mi on either side of leveed area boundaries (see Section 3 for a discussion). For each treatment, these specifications use not-yet-treated transactions of parcels as controls. We implement this following the stacked differences-in-differences regression estimator of Cengiz et al. (2019) (see Section 3.3). We report estimates of the spillover effect using different waterbody bandwidths, k, that define spillover exposed parcels. Standard errors, clustered at the census tract level, are reported in parentheses.

fixed effect regression weights are positively correlated with purchaser income. Willingness-to-pay to avoid flood exposure may be higher for higher income households (Bakkensen and Ma, 2020), which suggests that greater weight is being placed on transactions with larger price effects from levee construction in the two-way fixed effect specifications. This may reflect an implicit policy objective: policymakers may follow a siting rule that results in higher value areas being selected first, which could produce the observed negative correlation between two-way fixed effects regression weights and income due to the positive correlation between property value and income.[16]

Table 2 presents our main estimates of the second identification strategy that leverages across-levee segment variation, which we implement using (6). The dependent variable in each regression is the log of real sale price. We use this stacked regression design to separately estimate the effect of levee construction for protected parcels (column 1) and

[16]Moreover, weights are negatively correlated with a levee segment's overtopping scenario in the case of protection treatment in these specifications, suggesting that projects providing a higher level of protection to leveed areas receive greater weight when excluding the segment-by-year fixed effect. A similar correlation emerges for elevation and spillover treatment weights.

spillover-exposed parcels (columns 2-4), testing different definitions of spillover exposure based on waterbody proximity. We also estimate the impacts of levee construction on those parcels whose flood risk is plausibly unchanged by levee construction, but may experience indirect impacts from these large-scale investments (represented by parcel C in Figure 2) and report the results in column 5 of Table 2.

The estimates from these stacked regressions are qualitatively consistent with those reported in Table 1: we find evidence of positive capitalization of protection and negative capitalization of spillover effects from levee construction. We find that estimates of the spillover effect decrease in magnitude as we increase the distance-to-water bandwidth that we use to define spillover exposure. Interestingly, we cannot distinguish our estimate of the net effect of levee construction on non-protected, non-spillover-exposed parcels from zero.

While the two identification strategies deliver qualitatively similar results, there are important quantitative differences that are worth noting. In particular, our estimates of the protection and spillover effects of levee construction using across levee variation are larger in magnitude than those that use within levee variation. This is particularly true for our estimates of the spillover effects: while we cannot statistically distinguish estimates of the protection effect from the two strategies, estimates of the spillover effect across the two designs are statistically-different from one another. These differences are likely driven by how we define appropriate control units.[17] Indeed, though we find little evidence of a net effect of levee construction on non-protected, non-spillover-exposed parcels in column 5 of Table 2, this estimate includes both macro effects and any unobserved, indirect impacts of levee construction specific to this category of parcel. If these unobserved, indirect impacts of levee construction exist, they are likely to bias estimates from the first empirical design.

We use estimates from the first approach that leverages within-levee variation in home prices (Table 1) in the discussion that follows, unless stated otherwise. In comparison with the estimates in Table 2, these more conservative estimates arguably offer a plausible lower-bound on the likely capitalized effects of levee construction. Given the strong conceptual arguments against the specifications excluding segment-by-year fixed effect, our preferred specification includes this fixed effect. Furthermore, our preferred definition of the proximity-based spillover treatment sets the waterbody bandwidth at 0.2 mi given that this definition provides us with a more precise spillover effect estimate. We therefore report our preferred specification in Column 4 of Table 1 and use this as our primary result in the discussion

[17]These differences may be due to the fact that this identification strategy that uses not-yet-treated parcels from other levees as controls does not difference away any macro effects of levee construction that are common to all parcels in proximity to a constructed levee. However, since the increase in magnitude of each of these effects work in opposite directions, it is more likely that this is driven by differences in how we define appropriate control units.

that follows. We discuss a number of robustness checks of our main capitalization results in Section 4.5.

4.2 Event Study Estimates of Protection and Spillover Effects

To provide suggestive evidence that differential pre-trends do not drive our results and to examine the effects of levees over time relative to construction, we implement event study specifications of the protection and spillover difference-in-differences estimators, using the within-levee empirical strategy outlined in Section 3.2.1.

In particular, we estimate the following version of the specification given by (5) to estimate event study graphs for protection and spillover effects:

$$\log P_{it} = \sum_{\tau=-5}^{10} \alpha_1^{\tau} \Big(L_i \times Built_{l(i)t}^{\tau} \Big) + \sum_{\tau=-5}^{10} \alpha_2^{\tau} \Big(W_i \times \times Built_{l(i)t}^{\tau} \Big) + \xi_i + \mu_{l(i)t} + \delta_t + \varepsilon_{it} \qquad (7)$$

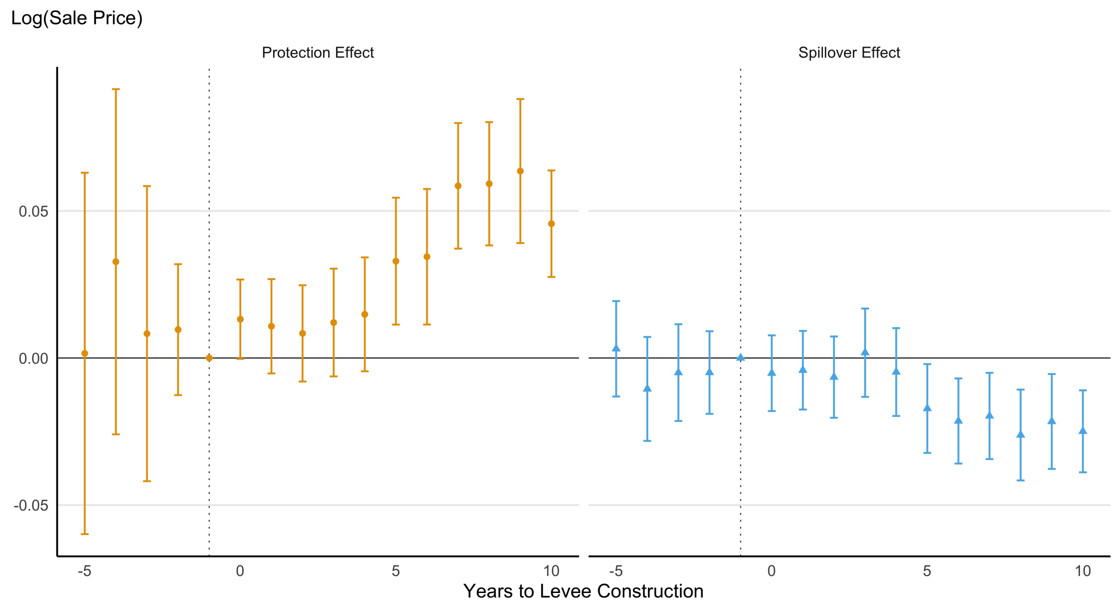
where $LeveeYear_i$ is the construction year of the nearest levee segment, $Built_{l(i)t}^{\tau}$ is an indicator variable that equals 1 if a parcel's transaction year t occurs in event time τ relative to the levee construction year and zero otherwise, and the remaining variables and fixed effects are as defined in (5). We set the coefficients for event time $\tau = -1$ equal to 0, which normalizes the remaining treatment effects relative to the period prior to construction.

We plot the resulting event study estimates from (7), α_1^{τ} and α_2^{τ}, in Figure 3. The figure shows suggestive evidence in favor of the identifying parallel trends assumption. Home prices for levee-protected homes relative to non-levee-protected, non-waterway adjacent homes increase slowly following levee construction: the first year for which we find a statistically-significant, positive post-construction event study estimate is event year $\tau = 5$. Home prices for spillover-exposed homes decrease slowly following levee construction.

4.3 Incidence of Protection and Spillover Effects

We use our preferred estimates of the capitalized effects of levee construction in combination with data on the income and race of a subset of buyers in our transaction sample to recover the distribution of these effects. Using the income distribution from the full matched ZTRAX-HMDA sub-sample to define income quintiles, we estimate average income and home values for all combinations of three racial/ethnic groups—White/Asian, Hispanic, and Black homeowners—and income quintiles for the relevant set of treated households and use these values in combination with our capitalization estimates to construct distributions of protection and spillover effects. Note that we use the income and race/ethnicity of the purchaser from the most recent transaction prior to levee construction when calculating average

Figure 3. Event Study Estimates of Protection and Spillover Effects



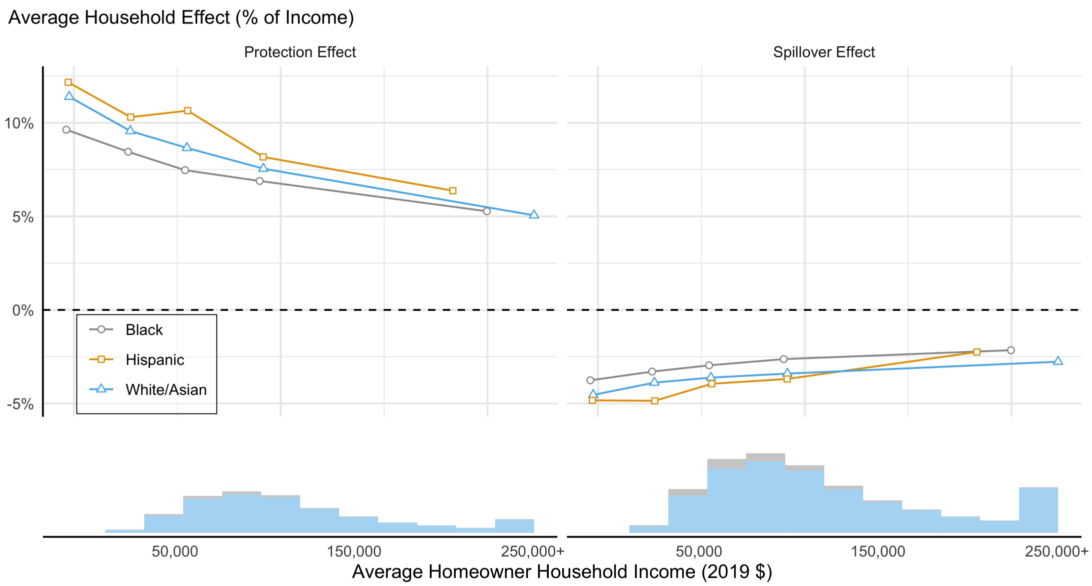
Note: This figure shows the estimated event study coefficients for the the protection effect and spillover effects estimated from (7). Transactions are assigned 1-year event time bins and the coefficients for the year prior to construction are normalized to zero in each regression. Each regression includes parcel, year-by-month, and levee segment-by-year fixed effects and standard errors are clustered at the census tract level.

transfers for each demographic group, since this represents the relevant pool of households for which levee construction operates as a lump sum transfer. We report the resulting distributions of the main capitalized effects of levee construction as a share of average income in Figure 4.

Several striking patterns emerge in Figure 4. First, differences in average incidence across racial and ethnic groups are relatively minor, though as the income distributions suggest, the vast majority of treated households are White or Asian. Second, we find that the flood protection provided by levee construction represents a progressive implicit subsidy to beneficiary households. Among the lowest income quintile households, the protection subsidy provided by USACE-constructed levees ranges from 10 to 12% of average income, whereas in the highest income quintile, the subsidy ranges from 5 to 6% of average income. Finally, we find that the spillover effects of levee construction represent a regressive—or at best, proportional—tax on affected households: this external cost of levee construction ranges from 4% to 5% of income in the first income quintile and from 2 to 3% in the top income quintile. Thus, ignoring the negative spillover effects of levee construction may produce misleading results: spillovers work to offset some of the progressivity of protection benefits produced by USACE-constructed levees.

While this exercise is informative about who gains—and loses—from the windfall benefit

Figure 4. Distribution of Protection and Spillover Effects



Note: This figure shows the estimated distribution of protection and spillover effects of levee construction by race/ethnicity and income quintile. We construct parcel-level demographic information at the time of levee construction using the most recent transaction prior to the date of construction and use these cross-sectional sub-samples to infer the distribution of capitalized protection and spillover effects. We use the estimates from our preferred specification in Column 4 of Table 1 to calculate average household effects. Stacked histograms on the horizontal axis show the in-sample distribution of treated households' income, separately by racial/ethnic groups and treatment type.

or cost of USACE levee construction, it does not give us a full picture of the distributional impacts of these investments. Evidence suggests that low income and minority residents are more likely to move into areas of high flood risk (Bakkensen and Ma, 2020), perhaps due to differences in taste (Banzhaf and Walsh, 2008), beliefs (Bakkensen and Barrage, 2021), information access (Hausman and Stolper, 2021), or housing discrimination (Christensen and Timmins, 2022). Such "environmental gentrification" is certainly of policy relevance in evaluating the distributional impacts of public investments in climate adaptation.

To examine possible differential sorting, we estimate versions of (5) with key demographic variables as outcomes and report the results in Table 3. Overall, we find no evidence of sorting by income; however, we do find suggestive evidence of differential sorting by race and ethnicity. In particular, we find that purchasers in levee protected areas are 4 percentage points more likely to be White or Asian after levee construction compared to before levee construction and that White/Asian households move into spillover exposed areas at lower rates after construction. On the other hand, Hispanic households are 4 percentage points less likely to move into levee protected areas after levee construction, though they also appear less likely to move into spillover exposed areas. Black households appear more likely to move

Table 3. Borrower Demographics on Spatial Treatment Indicators

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

The dependent variables are select household demographic variables from the ZTRAX-HMDA matched sub-sample. Data are restricted to parcels for which we observe more than one transaction during our sample period. We further restrict our data to transactions of parcels that either fall within leveed areas or are located within 5 miles of a leveed area boundary, excluding transactions of parcels that are within 0.1 mi on either side of leveed area boundaries (see Section 3 for a discussion). Standard errors, clustered at the census tract level, are reported in parentheses.

into spillover exposed areas closest to waterways after levee construction relative to before. Overall, these results are in line with past evidence on differential sorting patterns around flood risk across racial and ethnic groups (Bakkensen and Ma, 2020).

4.4 Additional Responses to Levee Construction

We examine several other plausible margins of behavioral response to levee construction. First, we examine the impact of levee construction on private risk management as measured by households' take-up of flood insurance. Unfortunately, we are unable to link flood insurance purchases to individual properties; however, we do have access to annual take-up rates for flood insurance through the National Flood Insurance Program (NFIP) at the census-tract-level.[18] We assign treatment status to each census tract that either intersects leveed areas or is within 5 miles of a leveed area boundary for USACE-constructed levees in our sample based on whether they contain any parcels with the relevant treatment. We report

[18] See Appendix A and Bradt, Kousky and Wing (2021) for details on aggregate NFIP take-up rates.

the census tract-level analog to (5) in Appendix Table C1. We find that census tract-level NFIP take-up rates decline by three percentage points after levee construction for tracts containing levee-protected parcels. Thus, it appears as though the public provision of flood risk protection reduces private investment in risk management.

We also explore the impact of levee construction on the extensive margin by estimating the effect of levee protection and flood risk spillovers on new construction. We construct a panel of all parcels in the ZTRAX tax assessment database that either fall within leveed areas or are located within 5 miles of a leveed area boundary and for which we observe valid information on the date of construction. We then implement a difference-in-differences estimator that leverages within-project variation to estimate the impact of levee construction on new construction. As shown in Table C2, we find minimal impact of levee protection, but a modest, negative impact of spillovers on construction behavior: levee construction decreases the annual probability that a spillover-exposed parcel experiences new construction of a primary structure by nearly 1 percentage point, a substantial reduction given the baseline probability of 1% in our data.

Finally, we explore the impact of levee construction on the intensive margin by examining renovation behavior. Changes in households' flood risk may influence decisions to undertake capital investments. We estimate the impact of levee construction on observed renovations using the same panel data that we use to examine new construction. As shown in Table C3, we find minimal impact of levee protection, but a modest, negative impact of spillovers on renovation behavior. The latter result suggests that part of the capitalized spillover cost could operate through a decrease in capital investment.

4.5 Robustness

We explore the potential for other forms of capitalized housing market effects of levee construction alongside the protection, spillover, and macro effects outlined in Section 3. In particular, we identify two additional categories of potential levee construction effects: adjacency effects and salience effects. The former refers to the full set of housing market effects associated with close proximity to a levee (e.g., positive recreational amenity or negative aesthetic disamenity). The latter refers to differences in the salience of flood protected effects induced by proximity to the levee itself. Appendix Section B provides further descriptions of these additional effects and develops alternative estimators necessary to identify them. Appendix Table B1 reports the results from this supplementary analysis: overall the estimated protection and spillover effects are similar to those reported in Table 1 and we find minimal evidence of adjacency effects and statistically significant and negative salience effects.

The evidence of differential sorting by race and ethnicity post-levee construction raises potential concerns around the inter-temporal variation in price that we use to identify protection and spillover effects in our main estimates. As described by Kuminoff and Pope (2014) and Banzhaf (2021), our estimates would be biased away from the true welfare effects of levee construction if the hedonic gradient shifts over time: using panel variation, while appealing for the purposes of accounting for unobserved attributes, will fail to estimate the slope of the hedonic price function if the composition of households changes over time. Such changes are likely to shift the hedonic price function, which would imply that our main estimates conflate shifts in the price function and movement along the price gradient.

Banzhaf (2021) shows that a change in price along the ex-post price gradient for a specific attribute serves as a lower bound on the Hicksian equivalent surplus for a change in that attribute. Given that our preferred specifications allow the estimated price gradient to vary over time (pre- and post- levee construction) as well as over space, our preferred estimates should provide reasonable lower-bound estimates of welfare changes associated with levee construction.[19] However, given that we document non-trivial ex-post sorting, we test the robustness of our estimates to an alternative approach to accounting for changes in the price gradient over time.

Following Muehlenbachs, Spiller and Timmins (2015), we employ a nearest-neighbor matching estimator to test the robustness of our main results to these concerns. We match each transaction of protected and spillover-exposed parcels in our main estimation sample with two transactions from the first empirical strategy's group of control parcels using nearest-neighbor matching, with exact matching on the year of sale.[20] Exact matching by year of sale restricts identifying variation within a year, a period over which large shifts in hedonic price functions are unlikely. We report the results from this nearest-neighbor matching estimator, which are qualitatively similar to our preferred estimates, in Table C4.

To explore the robustness of our definition of spillover exposure based on a parcel's proximity to surface waters, we estimate a version of (5) that uses FEMA-mapped floodplains to define spillover-exposed parcels. The spillover estimate that results from this definition is similar in both sign and magnitude to the analogous results using our distance-to-water spillover exposure definition. We compare the estimates from these different definitions of spillover exposure in Appendix Table C5.

Given that levee segments within the same levee system can be constructed at different points in time, we may be concerned with potential treatment contamination within the same levee system. We test the robustness of our preferred capitalization estimates to potential

[19]We thank Spencer Banzhaf for suggesting this interpretation of our primary results.

[20]Within each sale year, nearest-neighbor matching is based on detailed house attributes, including the log of square footage, the number of bedrooms, the number of bathrooms, lot acreage, and quadratic polynomials in latitude and longitude.

anticipation effects by replacing the levee segment-by-year fixed effect with a levee system-by-year fixed effect and report the resulting estimates in Table C6. Overall, we estimate slightly larger protection effects with the system-by-year fixed effect compared with the segment-by-year fixed effect, suggesting potential anticipation of protection benefits. We also find that our results are robust to re-weighting by household income in Table C6. We explore the robustness of our main capitalization results to alternative proximity-based sample restrictions and report the results in Table C7.

5 Discussion

5.1 Potential Mechanisms

We explore two potential mechanisms through which our estimated capitalized effects of levee construction may operate: changes in flood insurance premiums resulting from levee construction and household learning from flooding events.

5.1.1 NFIP Premium Reductions

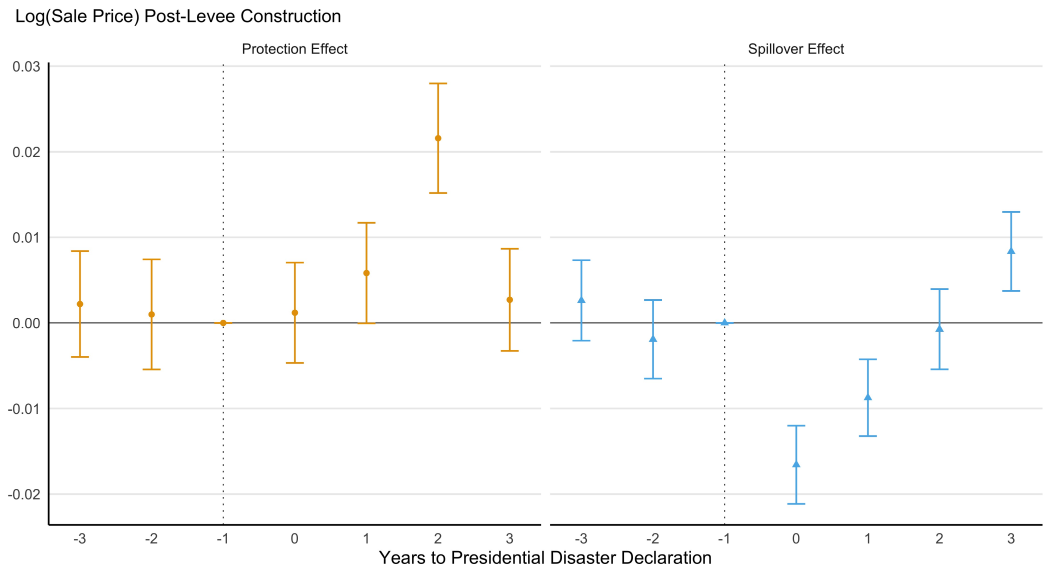
Households that are protected by a levee and fall within a FEMA floodplain are eligible for re-mapping out of so-called Special Flood Hazard Areas (SFHA) post-levee construction. For this re-mapping to occur, the levee must be accredited by FEMA as satisfying certain safety and protection requirements. Re-mapping out of SFHAs entails lower flood insurance premiums through the NFIP and a removal of the mandatory flood insurance purchase requirement for homes with mortgages from federally-backed lenders. We therefore might expect our estimate of the capitalized flood protection benefit to reflect the potential savings from lower NFIP premiums and the removal of the insurance mandate.

To evaluate this potential mechanism, we first examine the differential capitalization of protection effects for levees that are FEMA-accredited and therefore eligible for re-mapping and those that are not. Results reported in Appendix Table C8 indicate that capitalized protection benefits are, on average, greater for FEMA-accredited levees than non-FEMA-accredited levees. However, this may reflect other differences between FEMA-accredited and non-FEMA-accredited levees, particularly given that the accreditation likely implies a greater level of protection or better construction and maintenance practices.

We explore this mechanism further by using observed premiums to estimate the present discounted value of NFIP insurance costs as a share of home value for all levee-protected homes in our sample.[21] As shown in Appendix Figure C4, we estimate that average NFIP

[21] Specifically, we use policy-level observations of NFIP premiums for 2009-2020 to estimates the average

Figure 5. Household Learning from Exposure to Floods



Note: The figure shows the estimated event study coefficients for the effect of experiencing a Presidential Disaster Declaration (PDD) post levee construction on the price effect of falling within a leveed area and falling within a spillover area. Data are restricted to transactions that occur after levee construction. The pooled regression includes parcel, year-by-month, and levee segment-by-year fixed effects and standard errors are clustered at the census tract level.

insurance costs are 2.1% of home value for levee-protected homes in our sample, conditional on the property owner holding a NFIP insurance policy. With NFIP take-up within SFHAs at about 48% nationwide in 2019 (Bradt, Kousky and Wing, 2021), the expected reduction in insurance expenditures associated with lower NFIP premiums and the removal of the mandatory purchase requirement would be no more than about 1% of home value after levee construction.

5.1.2 Households Learning from Floods

The finding of gradual capitalization shown in Figure 3 suggests that households learn about the flood risk implications of levee construction over time, perhaps as a result of accumulated experience with flood related events. This potential mechanism is in line with existing evidence on consumer learning about flood risk in housing markets (Bakkensen and Barrage, 2021; Bin and Landry, 2013; Gallagher, 2014; Hallstrom and Smith, 2005).

premium per dollar of coverage for each census tract-year in this period. We then assume that all levee-protected households take-up insurance under the NFIP in perpetuity at a coverage level equal to the lower of the value of their home or the $250,000 NFIP coverage limit and use a 4.09% annual discount rate to calculate the present value of the stream of future insurance costs as a share of home value. This annual discount rate corresponds to the average interest rate on a 30-year fixed rate mortgage for 2009-2020 according to Freddie Mac (retrieved from https://www.freddiemac.com/pmms/pmms_archives on 10/11/2024).

We test this mechanism using county-level data on the occurrence of major flood-related storm events. We collect information on approved Presidential Disaster Declarations (PDD) at a county-level and use these data to construct county-year counts of the number of flood-related disaster declarations.[22] We then estimate the following specification using only repeat transactions that occur after levee construction in order to identify the causal effect of learning about levee's effects on flood risks through large regional flood events:

$$\log P_{it} = \sum_{\tau=-3}^{3} \alpha_1^{\tau}\Big(L_i \times PDD^{\tau}_{c(i)t}\Big) + \sum_{\tau=-3}^{3} \alpha_2^{\tau}\Big(W_i \times PDD^{\tau}_{c(i)t}\Big) + \xi_i + \nu_{c(i)t} + \delta_t + \varepsilon_{it} \tag{8}$$

where $PDD^{\tau}_{c(i)t}$ is a binary variable that equals 1 if the transaction of parcel i occurs in a county c that experiences a federal disaster declaration τ years relative to sale year t and 0 otherwise and $\nu_{c(i)t}$ is a county-by-year fixed effect. The remaining variables and fixed effects are as defined in (5).[23]

We find suggestive evidence of a differential effect of high exposure to flood-related storm events on the capitalization of protection and spillover effects. As shown in Figure 5, there is a statistically-significant, positive, and large in magnitude difference in sale price between protected parcels that experience a PDD and those that do not in the years immediately following the event. A similar pattern emerges when examining the dynamic effects of flood exposure on spillover effects: spillover exposed parcels that experience a PDD sell at a discount relative to spillover exposed parcels that do not experience a PDD in the years immediately following the disaster. Interestingly, the differential effect of experiencing a PDD event appears stronger for spillover exposed parcels than those in levee protected areas, suggesting that the information contained in these events may come in the form of realized damage to a household's property or nearby properties. The gradual effect of a PDD on levee-protected homes may be driven by the expiration of federal disaster aid post-disaster, at which point there could plausibly be an increase demand for levee-protected housing.[24] In addition, the learning lag among those in leveed areas may reflect a weaker, less salient signal of protection than signal extracted by spillover area homeowners after flooding.

These results suggest that households learn about the impact of USACE-levee construc-

[22] The Presidential Disaster Declaration (PDD) system, established in the Disaster Relief Act of 1950, is a process by which state governor's make formal requests for federal assistance in specific counties following major natural disasters (Carter et al., 2019).

[23] We only estimate event study coefficients for the periods $\tau = -3, ..., 3$ given the potential for contamination from other PDD events within a given county outside of that window: the average transaction in our estimation sample experiences 3 years with at least 1 PDD in the 10 years leading up to the transaction.

[24] For example, FEMA's Individual and Households Program, which provides financial assistance to individuals and households affected by a PDD with uninsured or underinsured losses and is one of the largest sources of federal disaster aid, is limited to 18 months following the date of a PDD (Carter et al., 2019).

tion on properties' flood risks based on recent experience with floods, which is in line with existing literature (Bakkensen and Barrage, 2021; Gallagher, 2014).[25] The fact that households appear to update their valuation of changes in flood risk following exposure to floods raises the question of to what extent the flood risk effects of levee construction are fully capitalized in housing markets. Appendix Figure C5 compares the expected damages from a 100-year flood for protected parcels in our sample, which we calculate using property attributes and USACE estimates of expected damages ("depth-damage" curves), with our estimate of the protection benefit. This exercise finds suggestive evidence of incomplete capitalization of flood protection benefits in housing prices.

5.2 Aggregate Benefits and Costs

We contextualize our main capitalization findings in the broader public finance setting of USACE levee investments. We translate our preferred capitalization estimates into aggregate private welfare effects using two different estimates of the total value of treated housing stocks: the tax assessment data included in ZTRAX and data on structure values from the USACE's National Structure Inventory.[26] We then multiply these measures of the value of treated property stocks by our preferred estimates of the protection and spillover effects.

We explicitly model two other categories of benefits and costs. The first include upfront levee construction costs. Unfortunately, construction cost information is not consistently available for USACE civil works projects. We therefore manually scrape information on federal and non-federal partner construction costs for USACE-constructed levees in our sample from a disparate set of primary sources, including federal budget requests, appropriations bills, and USACE annual reporting. We are able to construct estimates of construction costs for a total of 37 projects, which include 53 separate levee systems.[27]

The final category of benefits and costs for which we account are local fiscal externalities (i.e., the impact on local tax revenues). We do so using the tax assessment database from ZTRAX. Specifically, we estimate effective property tax rates for each treatment group by

[25] Given the potential political factors that play into the declaration of federal disaster declarations, we report results that are consistent with Figure 5 using alternative data in Appendix Table C9.

[26] Each source allows us to identify the universe of treated residential parcels for each levee project. We subset data from each source to structures constructed prior to levee construction and use county-level annual housing price indices from the Federal Housing Finance Agency (Bogin, Doerner and Larson, 2019) to deflate current assessed fair market values to the year of levee construction, which we then convert to 2019 dollars using the consumer price index for all urban consumers. The USACE NSI data are not directly comparable to the ZTRAX-derived estimates as they include non-residential real estate values; however, they produce a similar distribution of total capitalized effects of protection benefits across projects, with a correlation coefficient of 0.7. See Appendix Figure C6.

[27] In many cases, projects referred to in source materials includes a collection of several NLD levee systems. For additional information, see Appendix A.

Table 4. Average Benefits and Costs (Million 2019 USD) per Levee Mile Constructed

	Mean	Std. Dev.	Min.	Med.	Max.	N
Protection Benefits						
ZTRAX Housing Stock Estimate	1.066	2.136	0.007	0.264	10.930	37
USACE Housing Stock Estimate	10.743	14.820	0.026	5.729	71.202	37
Costs:						
Construction Costs						
Total	60.782	157.655	0.189	8.313	852.182	37
Federal	49.009	130.030	0.003	7.055	664.114	29
Non-Federal	15.385	38.061	0.005	2.281	188.068	27
Spillover Effects	13.799	40.799	0.008	1.565	238.268	37
Fiscal Externalities						
Protection Benefits (ZTRAX Housing Stock)						
2% real interest rate	0.955	1.709	0.000	0.309	6.628	37
3.5% real interest rate	0.546	0.977	0.000	0.177	3.788	37
Protection Benefits (USACE Housing Stock)						
2% real interest rate	22.448	75.666	0.000	3.946	460.965	37
3.5% real interest rate	12.827	43.238	0.000	2.255	263.409	37
Spillover Effects						
2% real interest rate	35.404	147.909	0.000	0.973	880.430	37
3.5% real interest rate	20.231	84.520	0.000	0.556	503.103	37

This table presents average benefits, costs, and fiscal externalities across 37 USACE-constructed levee projects. We calculate protection benefits using our preferred estimate of protection effects from Table 1 and estimates of the value of the protected housing stock for each project. Fiscal externalities refer to the long-run impacts on local property tax revenues. To estimate fiscal externalities, we calculate effective property tax rates separately for the relevant treated parcels—protection and spillover exposed homes—from ZTRAX assessment data.

dividing the total property tax revenue by the total assessed value and averaging across all parcels in each treatment group within each levee project. We then multiply this effective annual tax rate by the relevant total capitalized effect of levee construction to get an estimate of the annual effect of each change in property value on property tax revenues. We assume that these annual property tax revenue effects occur in perpetuity and calculate the present discounted value of each using two separate long-term interest rates, 2% and 3.5%.[28] Our assessment of long-run fiscal externalities should consider municipalities' long-run costs of capital, which motivates our chosen interest rates.

Table 4 describes the resulting estimated benefits, costs, and fiscal externalities across 37 USACE-constructed levee projects for which we are able to scrape construction cost data. We normalize each category of total impacts by the levee length of each project to account for any effects of project scale on total magnitudes. Several interesting findings emerge from

[28]The latter discount rate approximately corresponds to Bloomberg's index rate of return on 30-year municipal bond yields as of December 2022. Source: Bloomberg Finance L.P., retrieved from `https://www.bloomberg.com/quote/BVMB30Y:IND` on 12/7/2022.

Table 4: first, the residential property protection benefits of levee construction—inclusive of positive fiscal externalities—are smaller in magnitude than the direct costs of construction. Second, there is substantial heterogeneity in the magnitude of aggregate costs and benefits across projects, as indicated by the large standard deviation in many categories. As a result, we focus our interpretation on the median values from each category.

We note that there are a number of important categories of levee construction impacts which we omit in Table 4. On the cost side, we omit operations and maintenance costs, which are 100% borne by non-federal partners, as well as other fiscal externalities, such as the impact of levee construction on the federal National Flood Insurance Program (NFIP).[29] There are also categories of plausible benefits that we omit, such as protection of commercial and industrial properties and the indirect economic impacts of levee construction.

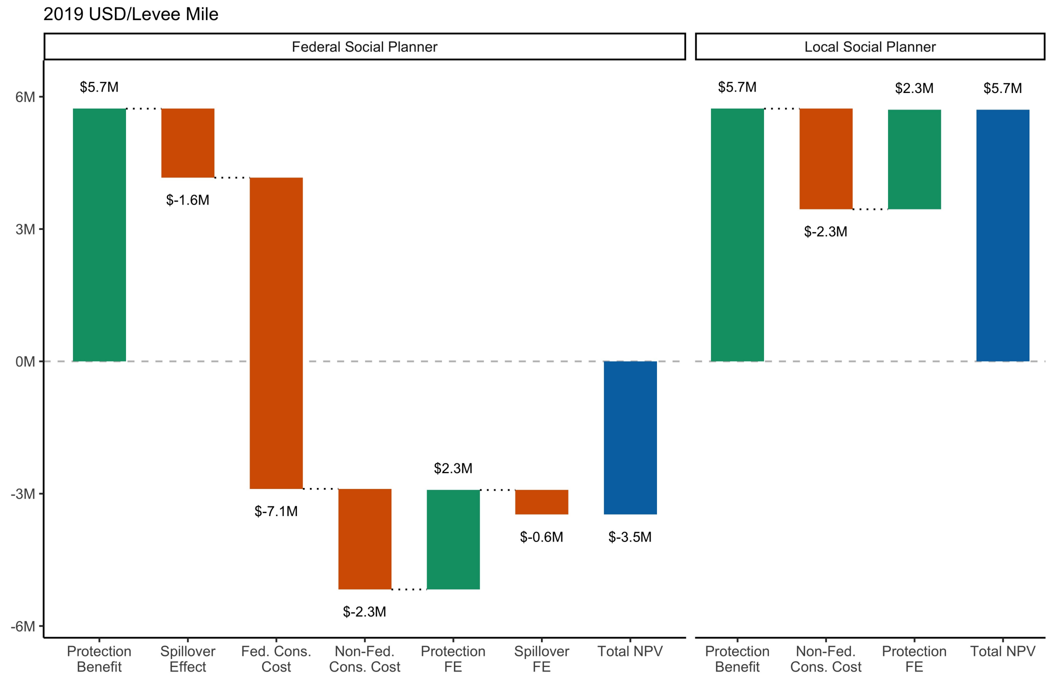
5.3 Local Political Economy Considerations

Given the requirement for non-federal partner cost share, we examine how median values of each of the cost and benefit categories compare from two perspectives: a federal social planner (i.e., USACE) and a local social planner (i.e., non-federal partner). The federal social planner internalizes all categories of benefits and costs that we model, whereas the local social planner only considers the effects of levee protection and non-federal construction costs. While it is likely that some local municipalities experience both protection benefits and spillover costs, the geographically-differentiated nature of levee construction impacts raises the potential for these costs to be external from the local perspective. Of the 80 USACE-constructed levee systems in our final estimation data, 24 impose spillover effects on counties outside of the county protected by the levee. This potentially results in a classic externality problem.

If the local, non-federal sponsor for a USACE levee project does not internalize the flood risk spillover effects of levee construction then the project will have a net present value of \$5.7 million per levee mile from their perspective (Figure 6). This is in stark contrast to the social planner or federal perspective: considering the full suite of impacts that we model, the net present value of USACE levee construction amounts to $-\$3.5$ million per levee mile. Comparing median benefit and cost components from these two perspectives may help to explain, at least in part, the fact that we find USACE-constructed levee projects to have relatively low benefits relative to costs ex-post.

[29] USACE levee construction likely reduces NFIP premium revenue while also reducing claims payments for an ambiguous net budgetary impact. However, the presence of flood risk spillovers perhaps increases NFIP budget outlays through increased claims payments. We examine these potential fiscal externalities on the NFIP in Appendix Table C1, which validates the hypothesized effects.

Figure 6. Net Present Value (NPV) of USACE Levees from Federal and Local Perspective



Note: This figure decomposes the median NPV of USACE levees for the subset of 37 USACE-constructed levee projects for which we are able to collect construction cost data from two distinct perspectives: a federal social planner (e.g., USACE) and a local social planner (e.g., non-federal project sponsor/partner). The protection benefits shown in the figure use estimate of the protected housing stock taken from USACE's National Levee Database (NLD). We use a long term interest rate of 3.5% to calculate the effects of annual changes in property tax revenue in perpetuity.

The possibility of this externality problem and the distorted incentives it presents introduces a natural policy prescription, namely a corrective Pigouvian tax. This could take the form of a policy requiring households or communities that benefit from levee protection to internalize the external spillover costs of the levee through a fee that in aggregate totals the net present value of expected damages to spillover exposed communities. Our empirical exercise provides a blueprint for how to best calculate this spatially-explicit corrective tax.

Another possible policy to address the issue of external costs in levee building from the local perspective is to enhance centralized planning in levee construction at the watershed level. Wang (2021) discusses this as a policy prescription to address spillover effects from levee heightening. In fact, the policy architecture already exists for this approach: USACE's involvement in the ex-ante feasibility assessment phase should hedge against fully ignoring external costs; however, it is unclear the extent to which spillover costs are considered ex-ante and the continued role of Congress in authorizing and funding levee construction does not eliminate incentives to prioritize internal benefits over external costs.

Examining states represented on the Congressional committees with authorizing and appropriating jurisdiction for USACE civil works projects in recent decades, we find a positive correlation between the degree of representation and amount of USACE levee construction.[30] Appendix Figure C7 shows the correlation between state-level measures of cumulative Congressional committee membership and USACE levee construction for the 103rd to 115th Congresses (1993-2018), finding a consistent, positive association. While these state-level relationships may not speak directly to the incentives Congress faces to consider external costs of levee construction, they are suggestive of Representatives prioritizing funding levee construction in their own state.

6 Conclusion

Recent trends in natural disasters place the costs of a changing climate in stark relief. According to data collected by the National Centers for Environmental Information, the US experienced 102 separate natural disasters with individual costs exceeding $1 billion over the 5-year period ending in 2023.[31] These trends are driven by a combination of factors, including the effects of anthropogenic climate change on the frequency and intensity of natural disasters and increasing exposure and vulnerability to these events. Current policies to control risks and manage impacts are struggling to keep pace with these trends: for example, the NFIP currently carries a debt exceeding $20 billion despite congressional approval for $16 billion in debt forgiveness after Hurricane Harvey in 2017 (Horn and Webel, 2021). Policymakers face a growing imperative to redesign and expand existing efforts to provide public goods that will enhance communities resilience and adaptability to these risks.

Our results provide important insights into the difficulties that policymakers face in using existing institutions for climate adaptation. We find that levees provide substantial flood protection benefits; however, decisions by federal, state, and local entities about the placement of such investments generate large cost externalities by increasing flood risks elsewhere. Ignoring these external costs in analyzing this particular form of adaptation investment may yield errors in interpretation: for example, taking advantage of our rich, transaction-level data to explore the distribution of capitalized effects of levee construction, we find that any redistribution towards lower income households accomplished by the construction of levees is potentially offset by the regressive nature of spillover costs. Were we to assess the distri-

[30] Committee membership is relevant to USACE civil works projects since committee members exercise substantial discretion in the early drafting of the relevant authorizing and appropriating legislation. Since USACE levees are funded at the project-level, committee members have input into the site selection process.

[31] See: NOAA National Centers for Environmental Information (NCEI) U.S. Billion-Dollar Weather and Climate Disasters (2023). https://www.ncei.noaa.gov/access/billions/, DOI: 10.25921/stkw-7w73.

butional consequences of levees on flood protection benefits alone, we would draw misleading conclusions about these projects.

Moreover, our accounting of a broad set of aggregate benefits and costs of levee construction illuminates key strategic incentives which may determine policy outcomes under current institutions. The potential for local interests in USACE levee construction to ignore external costs in the project development process results in an externality problem in the production of levee-based public flood risk adaptation. Economists have long studied similar externality problems in other settings. This insight into the local political economy of levee siting introduces a valuable set of potential policy prescriptions to the issue of climate adaptation with a long history of study and application elsewhere.

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Online Appendix for "Private Benefits from Public Investment in Climate Adaptation and Resilience"

Jacob T. Bradt and Joseph E. Aldy

The following appendices are **for online publication only**:
—Appendix Section A: Data Appendix
—Appendix Section B: Additional Levee Construction Effects
—Appendix Section C: Supplemental Figures and Tables

A Data Appendix

A.1 Additional Information on Data Sources

We provide additional information on each of the data sources used in our analysis below.

- *Zillow Transaction and Assessment Dataset (ZTRAX)*: provides data on transactions of residential parcels for over 2,750 counties across the US dating as far back as 1990.[1] ZTRAX consists of two main databases. The property transaction database contains over 400 million public transaction records, including information on sale price, key dates, associated loan information, source document types, and a series of Zillow-generated codes and data quality flags. The second main database, a tax assessment database, stores property-level records extracted from publicly-available property tax roll data. Given that reporting requirements are generally stricter for tax roll data than transaction data, we observe greater coverage in the assessment database: it covers approximately 150 million parcels in over 3,100 US counties. The assessment database includes key information on parcel attributes: lot size, building size, number of bedrooms, number of bathrooms, geographic coordinates, tax valuation, estimated fair market value, and more. Observations are linked across the transaction and assessment databases based on a unique parcel identifier, which allows us to assign property

[1] Nolte et al. (2021) note that there are clear geographic trends in the availability of valid, fair market value transaction price information in ZTRAX: the public disclosure of sales prices is not universal across states, so such data are not universally available nationwide. In particular, Alaska, Idaho, Indiana, Kansas, Louisiana, Mississippi, Montana, New Mexico, North Dakota, South Dakota, Texas, Utah, and Wyoming do not require public disclosure of sales prices, which means that representative sales price information for these states is scarce in ZTRAX and is likely only available in select sub-geographies such as major urban centers where reporting requirements or norms are different.

attributes to a transaction. We acquire ZTRAX data through a data use agreement with Zillow.[2]

- *First Street Foundation (FSF) Adaptation Database*: in an effort to capture major man-made hydrological modifications in their nationwide flood model, the FSF has collected data on the location and key physical and hydrological characteristics of over 20,000 flood adaptation projects in the continental US. FSF collect the data from state, county, and city agencies across the US and digitizes projects by drawing the area for which a structure provides flood protection and assigning a level of protection provided. The FSF adaptation database provides us with shapefiles representing the spatial extent of protected areas for each project in the database as well as key project-level information, including project type, project source, any project source identifiers, and estimates of the level of protection provided.[3] In the case of USACE levees, a levee system appears as a single project in the FSF Adaptation Database. We acquire data from the FSF Adaptation Database through a data use agreement with FSF.[4]

- *US Army Corps of Engineers (USACE) National Levee Database (NLD)*: provides comprehensive information on the near universe of federal, state, and local levees across the US, covering over 6,900 levee systems and 24,000 miles of levees. Data contained in the NLD are provided by USACE on the universe of USACE-constructed levees and by state and local agencies/entities in the case of non-federally constructed levees. As a result, coverage is less exhaustive in the case of non-federal levees. The NLD provides detailed information on the spatial extent, overtopping scenario, construction end date, constructing agency, and operating agency at the levee segment level. A single levee system may consist of one or more levee segments. We are able to link NLD systems to projects in the FSF Adaptation Database using the unique NLD system identifier and we use NLD data on the constructing agency to subset the FSF adaptation projects to all systems with at least one USACE-constructed levee segment. The segment construction dates provide the key field that we use to determine treatment timing

[2]As of 11/20/2022, Zillow plans to end the ZTRAX program and is no longer accepting applications for access to ZTRAX.

[3]These estimates of the level of protection are based on the return period to which it will continue to function. The "return period" can be thought of as the reciprocal of expected frequency: for example, a 100-year flood has a 1/100 = 0.01 or 1% chance of being exceeded in any given year. These estimates of the level of protection are also referred to as the "overtopping scenario" in the context of levees, i.e., the flood level beyond which flood waters exceed the height of the levee and therefore flow over top of the levee structure. FSF takes the overtopping scenario values from the USACE NLD for all USACE-constructed levees.

[4]Additional information on the FSF National Flood Model (FSF-NFM) is available here: https://firststreet.org/research-lab/published-research/flood-model-methodology_overview/ (accessed 11/20/2022).

in our analysis. Unfortunately, levee construction dates are not reliably recorded for all USACE-constructed levee segments; however, they are available for around 79% of USACE-constructed segments recorded in NLD. Moreover, certain large-scale, high-profile levee projects—such as the Lower Mississippi River and New Orleans levees—have been heavily modified over time, with some originally locally-constructed in the early 1900s. As a result, these salient examples of levees on which USACE has provided ongoing maintenance or to which USACE has added do not appear in our sample of USACE-constructed levee segments. We use the spatial data on segment extents to calculate the distance between parcels and their nearest levee. Data from the NLD are publicly available.[5]

- Home Mortgage Disclosure Act (HMDA): HMDA, enacted by Congress in 1975, requires major depository institutions to disclose loan-level information for all of their closed-end home lending activity every year. Data are provided at the level of the loan application under HMDA for the entire period that we study. We harmonize loan application register and transmittal sheet data for the period 1990-2020 in order to observe the following at the loan-level: loan application purpose, loan application result, loan amount, collateralized property census tract, loan application decision date, lender institution name, applicant race, applicant income, and applicant ethnicity. Due to changes in reporting requirements over the period for which we acquire data, we are only able to access data on applicant ethnicity for a subset of later years. HMDA loan application data are publicly available.[6]

- *US Geological Survey (USGS) National Hydrography Dataset (NHD) Plus, Version 2.1*: provides spatially granular, comprehensive information on the location and physical attributes of the water drainage network of the US. Maintained by the USGS, the NHD is the most up-to-date and comprehensive hydrography dataset for the US. We use the NHD's area and waterbody features to calculate proximity between residential parcels in our data and rivers, streams, canals, lakes, ponds, estuaries, wetlands, and coastline. NHD data are publicly available.[7]

- *USGS 3D Elevation Program (3DEP)*: provides access to a national baseline of consistent high-resolution topographic elevation data derived from lidar point cloud data

[5] Additional information on the NLD is available here: https://levees.sec.usace.army.mil/#/ (accessed 11/20/2022).

[6] Additional information on HMDA data is available here: https://www.ffiec.gov/hmda/ (accessed on 11/20/2022).

[7] Additional information on the NHD is available here: https://www.usgs.gov/national-hydrography/national-hydrography-dataset (accessed 11/20/2022).

products. We use 3DEP-derived digital elevation models (DEM) at a 10m resolution to determine the elevation and slope at the coordinates of all parcels in our data. 3DEP data are publicly available.[8]

- *Presidential Disaster Declaration (PDD) Summaries*: provides information on all approved federal disaster declaration requests, including data on the disaster type, disaster event start and end dates, and affected counties.[9]

- *National Oceanic and Atmospheric Administration (NOAA) Storm Events Database*: provides records on storms and other significant weather events having sufficient intensity to cause injury, loss of life, significant property damage, and/or disruption to commerce; rare weather phenomena that generate media attention; and other significant meteorological events, such as record maximum or minimum temperatures or precipitation. The database includes data for the period 1950 through 2022 and indicates all counties affected by a specific event; however, events other than tornadoes, thunderstorms, wind, and hail storms are first recorded in the dataset in January 1996. We use these data to generate measures of recent exposure to flood-related storms over various intervals—specifically, the previous 6-, 12-, 18-, and 24-months—for all transactions in our data to which we can link such storm types over the relevant interval. NOAA Storm Events Database is publicly available.[10]

- *National Flood Insurance Program (NFIP) Redacted Claims and Policies Datasets*: provide nationwide data at the policy-level for all policies issued since 2009 and all claims dating back to 1978 under the NFIP. These NFIP data include information on the term of the policy, the date of the claim, and the location of the policy/claim down to the census tract level, which we use to generate annual counts of the number of policies-in-force, number of claims, and average claim amounts conditional on making a claim at the census tract-year level for all years for which data are available. We combine our estimates of policies-in-force with estimates of the number of residential units at the census tract-year level taken from the Census Bureau's 5-year American Community Survey (ACS) to construct estimates of tract-year take up rates for 2009-2020. NFIP claims and policies data are publicly available.[11]

[8] Additional information on 3DEP is available here: https://www.usgs.gov/3d-elevation-program (accessed 11/20/2022).

[9] Additional information on the PDD data is available here: https://www.fema.gov/openfema-data-page/disaster-declarations-summaries-v2 (accessed 11/20/2022).

[10] Additional information on the NOAA Storm Events Database is available here: https://www.ncdc.noaa.gov/stormevents/ (accessed 11/20/2022).

[11] Additional information on the NFIP policies and claims data are available here: https://www.fema.gov/about/openfema/data-sets (accessed 11/20/2022).

A.2 ZTRAX Data Cleaning

Zillow's ZTRAX database provides unprecedented access to parcel-level information on the near universe of residential properties nationwide and associated transactions for a substantial time period. Zillow sources ZTRAX from a major third-party data provider as well as their own county-level data collection program. While Zillow makes efforts to harmonize the assessment and transaction-level data contained in ZTRAX, given the disparate underlying data sources, there are a number of additional steps that must be taken to ensure the final dataset used in our analysis contains arms-length transactions of residential parcels with valid attributes, most importantly geographic information.

It is important to only include arms-length transactions as our empirical approach—and hedonic pricing methods more broadly—implicitly rely on the assumption that sales prices of property transactions are indicative of the fair market value (FMV) of the parcel. Examples of non-FMV transactions include transfers between family members, foreclosures, or transactions involving public agents. Such deviations from FMV in observed transaction prices would bias our estimates of capitalized effects of levee construction. Moreover, it is important to only include parcels with accurate geographic information in our analysis as we use parcel coordinate information in ZTRAX to assign parcels to different spatial treatment statuses.

Fortunately, a team of researchers with substantial collective experience working with ZTRAX has collected a set of best practices for ensuring ZTRAX-derived data quality and identifying arms-length transactions (Nolte et al., 2021). In order to subset to FMV, arms-length transactions, we implement the following filters based on guidance from Nolte et al. (2021):[12]

1. We drop all transactions with listed sales prices below 1001. Ultimately we drop transactions below the 1st and the 99th percentile in our final, levee-adjacent sample described in Appendix A.5 in order to remove major outliers; however, this step removes a non-trivial number of transactions which are clearly below FMV transactions and are changing hands for nominal amounts.

2. We drop all transactions that are not recorded in ZTRAX as deed transfers, which explicitly excludes mortgage refinancing records, foreclosures, and other transactions which may appear in ZTRAX, but are identified by Zillow as explicitly not involving deed transfer.

[12] Additional information on the filters that Nolte et al. (2021) suggest applying to identify FMV, arms-length transactions is available in their paper and at the following website: https://placeslab.org/ztrax/ (accessed 11/20/22).

3. We drop transactions flagged by Zillow as intra-family transfers, likely based on similarities between buyer and seller names.

4. We keep transactions with sales price sources which Nolte et al. (2021) identify with high confidence as indicative of FMV transactions. For example, Nolte et al. (2021) identify transaction prices listed in a given source document as "cash sale" as indicative of FMV with high confidence; however, a sales price listed in a given source document as derived from the transfer tax amount is indicative of FMV with either low or medium confidence.

5. We keep transactions with document type categories which Nolte et al. (2021) identify with high confidence as indicative of FMV transactions. There are 161 standardized document type categories in ZTRAX, which describe the source of the transaction information recorded in ZTRAX. Nolte et al. (2021) identify which document types in each state tend to reflect FMV transactions best and provide a complete listing of their assessment, which we use to filter out document types which they view as reflecting FMV with low confidence.

A key ZTRAX data quality issue for our analysis involves the accuracy of parcel coordinates. In addition to a non-trivial share of parcels in ZTRAX with missing point locations, some ZTRAX coordinates appear to have been derived from ZIP code area centroids instead of parcel data[13]. In addition, there are certain instances where ZTRAX coordinates fall outside of the boundaries of the county or ZIP code listed for a parcel, which are taken directly from source documentation and should therefore be viewed as authoritative.

To address these issues, we first remove all coordinate data for parcels with duplicated coordinate information, though we do not immediately drop these parcels from our sample. This addresses the concern that many coordinates are likely derived by approximate geocoding to assign ZIP code or other aggregate geographic coordinates. Next we remove all coordinate data for parcels with coordinates falling outside of their listed county boundary, but again we do not immediately drop these parcels. Finally, where possible we take street address information for all resulting parcels with missing coordinate data and use the Census Bureau's Geocoder API to assign coordinates for each of these parcels.[14]

[13] According to Nolte et al. (2021), ignoring such cases can result in geo-location errors exceeding 1km.

[14] Further information about the Census Geocoder is available here: `https://geocoding.geo.census.gov/geocoder/Geocoding_Services_API.pdf` (accessed on 11/03/2022).

A.3 ZTRAX-HMDA Matching Procedure

We are interested in not only estimating the magnitude of capitalized effects of USACE levee construction, but also the distribution of these effects along key socioeconomic variables. Unfortunately, ZTRAX does not contain detailed information on purchaser demographics; however, we are able to make use of loan-specific information to link a subset of transactions in ZTRAX to information on successful loan applications for home purchases made publicly-available through the Home Mortgage Disclosure Act (HMDA).

HMDA data provide information on the year of origination, property census tract, loan amount, application purpose, lender institution's name, and select applicant demographics for all loan applications to major depository institutions. We collect loan application-level data for the years 1990 through 2020 and use available documentation to harmonize key fields across all years of data. We then subset the harmonized HMDA loan applications to those which are ultimately successful and are for the purpose of a home purchase given that the loans we observe in ZTRAX are for that purpose as well. We then follow a procedure to match the HMDA loan-level information to our ZTRAX transaction-level information. Specifically, we:

1. Define all possible matching loan application and transaction pairs from HMDA and ZTRAX as those with the same year, census tract, and loan amount (rounded to the nearest 1000).[15]

2. This results in a non-trivial number of duplicate match candidates: in a non-zero number of cases, lenders make multiple loans of the same amount in a single census tract in a given year. We keep all many-to-one and one-to-many matches in order to potentially narrow these matches down further; however, we discard all many-to-many matches as it is difficult to further refine such matches.

3. For all many-to-one and one-to-many matches, we conduct fuzzy string matching on the lender name information contained in both the HMDA and ZTRAX microdata. Specifically, we calculate the Jaro-Winkler distance between the potential HMDA-ZTRAX matched pairs, which gives us a quantified measure of the proximity of the strings in each pair. We then keep all pairs with a Jaro-Winkler distance satisfying a sufficient similarity criterion, which we validate by examining the resulting matches.

[15] We match loan applications and transactions based on the year of origination as listed in the HMDA data and the year of sale as listed in the ZTRAX data. Given that HMDA data use historical census tract definitions, which can change dramatically after each decennial census, we assign each parcel in our ZTRAX data to their corresponding 1990, 2000, and 2010 census tract boundary using valid geographic coordinates and use the relevant assigned census tract to match to HMDA data depending on the year of sale/origination.

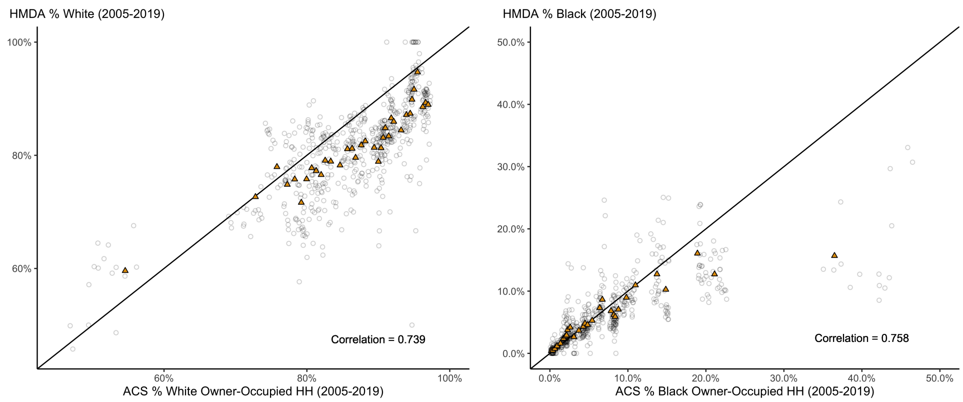
Implementing the above matching procedure on the full set of accepted loans for home purchase from 1990-2020 and the nationwide processed ZTRAX data, we are able to match 41.46% of arms-length transactions in ZTRAX to a unique loan application record in the HMDA data. This is similar to other match rates observed in the literature that employs the above approach: Bayer et al. (2016) match 55% of San Francisco Bay Area sales from 2994 to 2004; Bakkensen and Ma (2020) match 47% of residential property sales from the Miami Dade-Port St. Lucie-Fort Lauderdal CSA from 2009 to 2012; and Graff Zivin, Liao and Panassie (2022) match a little over 50% of sales across the state of Florida from 2000 to 2016. Given that we implement this procedure for the entire continental US for the period 1990-2020, it is unsurprising that we observe a slightly lower match rate. Conditioning on arms-length transactions in ZTRAX for which we observe some non-empty loan information, our match rate is 68.45%.

Since not all transactions in our data contain loan information and we are unable to match HMDA loan data to all those that do, it is worth evaluating how representative our HMDA-ZTRAX matches are of the broader population. Given that we are targeting the population of homeowners, we need external data on analogous demographic variables for the universe of home owning households. We do so by aggregating our income, race, and ethnicity variables for our matched ZTRAX-HMDA sample to the state-by-year level and comparing the resulting aggregates to relevant data obtained from the Census Bureau's 1-year American Community Survey (ACS) for the period for which these data are available, 2005-2019. Figure A1 shows the resulting comparison for a subset of our constructed sociodemographic variables. Compared to the median income for households with a mortgage in the ACS, median household income in our ZTRAX-HMDA matched sample is quite similar across state-years, with an overall correlation of 0.78. Our ZTRAX-HMDA matched sample also has similar shares of white and black households compared to owner-occupied households in the ACS; however, it is worth noting that our ZTRAX-HMDA matched sample seems to under-predict the share of black households in areas where the ACS estimates this figure to be relatively high.

A.4 Constructing USACE Levee Cost Data

To better understand our estimates of the benefits and costs of USACE levee construction, we collect information on upfront construction costs for a subset of projects in our final dataset. Unfortunately, construction cost information is not maintained in a central, consistent, and publicly-available format for USACE Civil Works projects. We therefore have to manually scrape this information from a disparate set of primary sources, including federal budget requests, appropriations bills, and USACE annual reporting.

Figure A1. Comparing select demographic variables from the ZTRAX-HMDA matched sample with estimates from the Census Bureau's 1-year American Community Survey (ACS).



A major challenge in collecting construction cost data that applies to all primary source information that we consult is that there is no clear one-to-one mapping from levee systems as listed in the USACE NLD—and thus how they appear in our data—and projects referenced in these sources. In many cases, a project may be referred to in budgetary, appropriations, and reporting materials that refers to a collection of many NLD levee systems built over several decades. This requires us to manually map NLD levee systems to project names from various stages in the funding process, which we are only able to do with high confidence for a subset of projects.

We collect ex-post information on project costs from several sources, where possible. First, we review annual reports of the Chief of the USACE to Congress (often referred to as "Chief Reports"), which cover the period 1848-2012. These reports include detailed project-level narratives on construction, navigation, and hydropower projects undertaken by USACE using federal funds. Over the relevant period of our analysis, these reports offer a relatively consistent format of ex-post descriptions of activities carried out in a given fiscal year by each USACE District and include tabular information on cumulative spending for a subset of Civil Works projects. Unfortunately, these Chief Reports only provide sufficient project-level information through fiscal year 2012 — USACE appears to have satisfied its annual Congressional reporting requirements in subsequent fiscal years through written committee testimony alone. Where possible, we also collect information on ex-post project construction costs from various public documents, such as press releases, published by the various USACE Districts.

Due to the incomplete coverage of the Chief Reports and the challenge presented by the lack of a one-to-one match with NLD levee systems, we also collect Civil Works project appropriations from regular and supplemental appropriations bills, which provide ex-ante measures of project costs. We also consult budget request information, which also provide ex-ante measures of project costs. These sources are subject to the same challenge of a lack of a one-to-one match with NLD levee systems and are likely only approximations to the true upfront cost of USACE levees, so we only rely on these materials where we find a high confidence match to projects in our data.

A.5 Final Sample Construction and Summary Statistics

As described in Section 2, we use combined data on USACE-constructed levees from the FSF Adaptation Projects Database and the USACE NLD to subset our processed ZTRAX data: using valid parcel-level geogrpahic information, we identify those residential parcels located either inside of or within relatively close proximity to—in practice, five miles—leveed area boundaries, with distance to a leveed area boundary defined as standard Euclidean distance. This assumes that the housing market effects of levee construction are restricted to within five miles of a levee/leveed area boundary.

In addition to filters applied to the raw ZTRAX data described above, we subset our final dataset in several ways. First, we remove price outliers by dropping transactions that are either below the 1st percentile or above the 99th percentile of real transaction price for the entire period. Finally, we remove clear outliers in terms of square footage, number of bedrooms, and number of bathrooms, which are either the result of coding errors or represent parcels which are likely uncomparable to the rest of those in our data. The final dataset is described in Table A1, which shows average values of key variables for both the unmatched and HMDA-matched sub-samples and calculates the differences in means where possible.

Table A1. Summary Statistics

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

Reported standard errors are from a two-sided t-test of the difference in means between the unmatched and HMDA-matched sample.

B Additional Levee Construction Effects

We explore the potential for other forms of housing market effects of levee construction alongside the protection, spillover, and macro effects outlined in Section 3.

B.1 Categorizing Additional Levee Construction Effects

We identify two additional categories of potential levee construction effects: adjacency and salience effects.

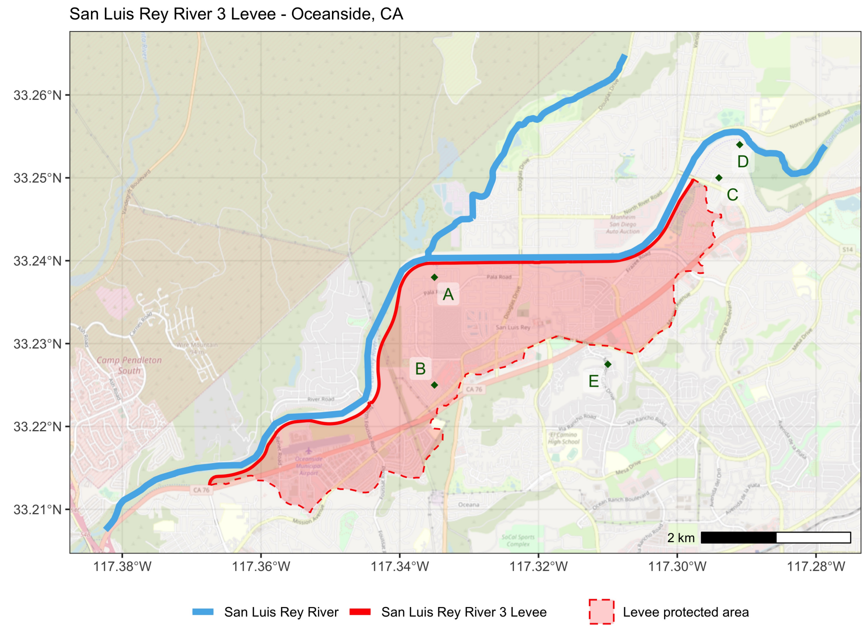
Adjacency Effects.—This category refers to the full set of housing market effects associated with close proximity to a levee. This includes a potential positive amenity effect of adjacency to a levee: households may derive positive utility from residing near a waterway and it is common for levees to be built with combined recreation use in mind, for instance by building a recreation trail on top. It is also possible that there are negative disamenity—or nuisance—effects associated with proximity to a levee: given their size and the scale of construction and maintenance activities, homes near levees may experience noise and light pollution or visual disamenities associated with large built infrastructure around waterways. Given the broad set of effects captured by this category, the net capitalization effect of this category is theoretically ambiguous.

Salience Effects.—This category refers potential differences in the salience of flood protection effects induced by proximity to the levee itself: households may place greater weight on any flood protection effects if they regularly encounter or can see the levee near their home. This category is distinct from adjacency effects in that the latter are experienced by homes near a levee independent of whether or not they are behind the levee. These salience effects account for potential heterogeneity in households' perceptions of the flood protection benefits they receive by being behind a levee based on proximity to the levee itself. Since this category captures differential salience of protection benefits as opposed to disamenity effects associated with levee proximity—which are captured by the adjacency effects category—capitalized salience effects are likely positive.

Figure B1 amends Figure 2 to provide a demonstration of the expanded set of housing market effects of levee construction.[16] Parcels A and B both fall within the leveed area and experience *Protection Effects*. Parcel B is located near the levee itself, experiencing *Adjacency Effects* and *Salience Effects*. Parcels C and D are not located within the leveed area but are near the relevant surface water and as a result may experience *Spillover Effects* from levee construction. Given its proximity to the levee, parcel C also experiences *Adjacency Effects*. All parcels experience *Macro Effects*, though this is the only effect to which parcel

[16]Note that the labeling of different parcel types is different.

Figure B1. Categories of Levee Construction Effects



Note: Five example parcels (labeled A, B, C, D, and E) demonstrating the different types of potential effects of levee construction in the context of the San Luis Rey River 3 Levee (California, US), a USACE-constructed levee completed in 2000.

E is exposed.

B.2 Identifying Additional Levee Construction Effects

Building on this categorization, we can use the example parcels depicted in Figure B1 to illustrate our approach to identifying the capitalized effects of levee construction. This exposition of our approach to identification is inspired by Muehlenbachs, Spiller and Timmins (2015) who employ a similar empirical strategy to identify the capitalized effects of shale gas development. Consider the price of a particular example parcel, say P_A, and define the operator Δ_t as the change in a given property's transaction price from before to after construction of a levee, i.e., $\Delta_t P_A = (P_{A,post} - P_{A,pre})$. Then we can decompose the change in each of the example parcel's price around levee construction as follows:

$$
\begin{aligned}
\Delta_t P_A &= Macro + Protect + Adjacency + Salience \\
\Delta_t P_B &= Macro + Protect \\
\Delta_t P_C &= Macro + Adjacency + Spillover \\
\Delta_t P_D &= Macro + Spillover \\
\Delta_t P_E &= Macro
\end{aligned}
\tag{B1}
$$

where, for example, *Protect* refers to the change in observed prices attributable to protection benefits from the levee. As Equation B1 demonstrates, we can identify protection, spillover, and adjacency effects using difference-in-differences (DD) estimators:

$$(Protect)_{DD} = \Delta_t P_B - \Delta_t P_E$$
$$(Adjacency)_{DD} = \Delta_t P_C - \Delta_t P_D$$
$$(Spillover)_{DD} = \Delta_t P_D - \Delta_t P_E$$

In this framework, the first difference refers to the change in sale prices before and after levee construction for each parcel type. In the case of the protection and spillover effects, identification then comes from comparing this change for homes within leveed areas but not near the levee (i.e., parcel B) and outside of leveed areas and near surface waters (i.e., parcel D) with the change for homes outside of leveed areas and far away from surface waters (i.e., parcel E), respectively. We identify adjacency effects by comparing the pre- and post-levee construction price change for homes outside of leveed areas, adjacent to levees, and adjacent to waterways (i.e., parcel C) with that for homes outside of leveed areas and adjacent to waterways (i.e., Parcel D).

Note that to identify potential salience effects, we must difference away macro, protection, and adjacency effects from the change in sales price for homes within leveed areas and near levees. Thus, we can estimate salience effects using the following triple-difference (DDD) estimator:

$$(Salience)_{DDD} = \underbrace{(\Delta_t P_A - \Delta_t P_B)}_{=(Salience+Adjacency)_{DD}} - \underbrace{(\Delta_t P_C - \Delta_t P_D)}_{=(Adjacency)_{DD}}$$

where the first difference—depicted by Δ_t—is the within home-type change in sale price around construction of a levee. The second difference compares the change in prices between homes adjacent to a levee and comparable homes not adjacent to a levee: in the case of levee-adjacent homes within leveed areas (i.e., parcel A), the relevant difference compares price changes with those for non-levee-adjacent homes within leveed areas (i.e., parcel B). In the case of levee-adjacent homes outside leveed areas (i.e., parcel C), the relevant difference compares price changes with those for non-levee-adjacent, waterway-adjacent homes outside leveed areas (i.e., parcel D). The third difference subtracts these double-differences, removing adjacency effects and leaving only salience effects. Similar to the main design used to identify protection and spillover effects in the text, this design addresses concerns about the endogeneity of levee site selection.

B.3 Estimating Expanded Capitalized Effects

Let L_i equal 1 if parcel i is located within a leveed area as indicated by the First Street data and 0 otherwise; A_i equal 1 if parcel i is located adjacent to a levee and 0 otherwise; and W_i equal 1 if parcel i is located adjacent to a waterway and is outside of leveed areas and 0 otherwise.[17]

We implement our identification strategy for the expanded set of levee construction effects by defining the price of house (parcel) i at time t as a function of a series of interaction terms, a parcel fixed effect (ξ_i), a levee segment-by-year fixed effect ($\mu_{l(i)t}$), and a year-by-month fixed effect (δ_t):

$$\begin{aligned}\log P_{it} = {} & \alpha_1(T_{it} \times L_i) + \alpha_2(T_{it} \times A_i) + \alpha_3(T_{it} \times W_i) \\ & + \alpha_4(T_{it} \times L_i \times A_i) + \alpha_5(T_{it} \times A_i \times W_i) \\ & + \xi_i + \mu_{l(i)t} + \delta_t + \varepsilon_{it}\end{aligned} \tag{B2}$$

where $T_{it} = 1$ if the transaction occurs after levee construction and 0 otherwise. As previously discussed, T_{it} is assigned to transactions based on the construction date of the nearest levee segment to parcel i, which may result in different construction dates for transactions of parcels near the same levee system. Similar to our main specification in the text, we include a levee segment-by-year fixed effect to account for the staggered timing of construction across levee systems—and in certain cases across levee segments within a system—and avoid the biases from standard two-way fixed effects estimators in the presence of heterogeneous treatment effects within-unit over time (de Chaisemartin and D'Haultfœuille, 2020; Goodman-Bacon, 2021). Note that by including this fixed effect, we cannot separately estimate a parameter on T_{it} due to collinearity with $\mu_{l(i)t}$; however, this parameter is not of independent interest.

Similar to our main analysis in the text, to implement our estimating equation with a parcel fixed effect, we restrict our estimation sample to parcels for which we observe multiple transactions, which is common in the hedonics literature (Graff Zivin, Liao and Panassie, 2022; Hallstrom and Smith, 2005). While this reduces our sample size, it has the benefit of limiting the extent to which our estimates can be driven by compositional shifts in transacted homes that may occur due to levee construction by restricting the identifying variation to sales of properties that transact multiple times in our sample period.[18]

[17] Note that the definition of W_i excludes parcels protected by levees (i.e., $W_i = 1 \Leftrightarrow L_i = 0$), which allows us to use transactions of homes for which $W_i = 1$ to identify spillover effects.

[18] Note that L_i, A_i, and W_i do not enter Equation B2 on their own due to the inclusion of the parcel fixed effect, ξ_i. Furthermore, Equation B2 does not include the full suite of interaction terms between all four indicator variables due to the fact that interaction terms that only vary across properties are collinear with

The model specified in Equation B2 implicitly assumes that exposure to various treatments, specifically levee-adjacency (L_i) and waterway-adjacency (W_i) decays with distance to the relevant feature, ultimately becoming zero at some distance. A common approach in the literature to determining exposure distance is to flexibly fit a curve between pre- and post-event prices and distance, using the crossing point of the two curves to determine exposure (Linden and Rockoff, 2008; Muehlenbachs, Spiller and Timmins, 2015). We implement this price gradient approach in Appendix Figure C3 and determine that constraining the effects of levee-adjacency and waterway-adjacency to 0.1 mile is reasonable.

There are several assumptions necessary to use Equation B2 to identify the expanded set of effects outlined above

> ASSUMPTION B1: *the spillover effects of adjacency to a waterway do not vary with distance to a levee, i.e.,* $\alpha_5 = 0$.

Our main estimating equation therefore becomes:

$$\begin{aligned} \log P_{it} = \alpha_1(T_{it} \times L_i) + \alpha_2(T_{it} \times A_i) + \alpha_3(T_{it} \times W_i) \\ + \alpha_4(T_{it} \times L_i \times A_i) + \xi_i + \mu_{l(i)t} + \delta_t + \varepsilon_{it} \end{aligned} \tag{B3}$$

Assumption B1 rules out changes in risk or risk salience for spillover exposed parcels based on proximity to a levee. This assumption aids in identification by ensuring that we are able to fully difference out all spillover effects in our adjacency DD estimator. To see this and to connect Equation B3 to the exposition of our identification strategy in Section 3.2.1, consider the correspondence between the coefficients and parcels A, B, C, D, and E from Figure 2:

$$\begin{aligned} \Delta_t P_A &= \alpha_1 + \alpha_2 + \alpha_4 + \Delta_t \mu_{l(i)t} + \Delta_t \delta_t \\ \Delta_t P_B &= \alpha_1 + \Delta_t \mu_{l(i)t} + \Delta_t \delta_t \\ \Delta_t P_C &= \alpha_2 + \alpha_3 + \Delta_t \mu_{l(i)t} + \Delta_t \delta_t \\ \Delta_t P_D &= \alpha_3 + \Delta_t \mu_{l(i)t} + \Delta_t \delta_t \\ \Delta_t P_E &= \Delta_t \mu_{l(i)t} + \Delta_t \delta_t \end{aligned}$$

where $\Delta_t \mu_{l(i)t}$ and $\Delta_t \delta_t$ denote the change in the time-varying fixed effects for each parcel before and after levee construction.[19] This implies that the four estimators presented above

the parcel fixed effect and by definition $W_i = 1 \Leftrightarrow L_i = 0$. The terms that remain in the above estimating equation are those that are well-defined and not collinear with the fixed effects.

[19]Note that the parcel fixed effects, ξ_i are differenced away through the Δ_t operator.

are as follows:

$$
\begin{aligned}
&(Protect)_{DD} = \Delta_t P_B - \Delta_t P_E = \alpha_1 \\
&(Adjacency)_{DD} = \Delta_t P_C - \Delta_t P_D = \alpha_2 \\
&(Spillover)_{DD} = \Delta_t P_D - \Delta_t P_E = \alpha_3 \\
&(Salience)_{DDD} = (\Delta_t P_A - \Delta_t P_B) - (\Delta_t P_C - \Delta_t P_D) = \alpha_4
\end{aligned}
$$

Thus, α_1, α_2, and α_3 are the double-difference measures of protection effects, adjacency effects, and spillover effects resulting from levee construction, respectively, and α_4 is the estimate of the salience effect of proximity to a levee for a protected home. As the above indicates, if $\alpha_5 \neq 0$ in Equation B2, then $\Delta_t P_C - \Delta_t P_D = \alpha_2 + \alpha_5$ and we are unable to identify any adjacency effects.

Two additional assumptions about house price counterfactuals are necessary for the estimated coefficients $(\alpha_1, \alpha_2, \alpha_3)$ to have the causal interpretations indicated above. The first allows us to identify protection, adjacency, and spillover effects and is standard from the DD literature: parallel trends in outcomes (house prices) for the relevant treatment and control parcels around the time of levee construction. This is analogous to the parallel trends assumption necessary for identification in the main specification in the text.

The second assumption about house price counterfactuals builds on Olden and Møen (2022) and provides a causal interpretation for α_4.

ASSUMPTION B2: *the trend in the price differential between levee-adjacent and non-levee-adjacent parcels is equivalent for levee-protected parcels and non-levee-protected, waterway-adjacent parcels.*

Using the parcel categorization from Figure B1, Assumption B2 states that the price differential for parcels of type A and B must have the same trend as the price differential for parcels of type C and D. In other words, there are no factors beyond levee construction generating a difference in differential trends for levee-adjacent and non-levee adjacent homes in leveed and non-leveed areas.

B.4 Double- and Triple-Difference Results

Table B1 reports our main results estimating Equation B3 using different proximity treatment bandwidths. Overall, the estimated protection and spillover effects are similar to those reported in Table 1 in the text. We find minimal evidence of adjacency effects. Interestingly, there do appear to be non-zero effects associated with proximity to a levee within a leveed area; however, these are estimated to be statistically significant and *negative* when

Table B1. Log Sale Price on Spatial Treatment Indicators

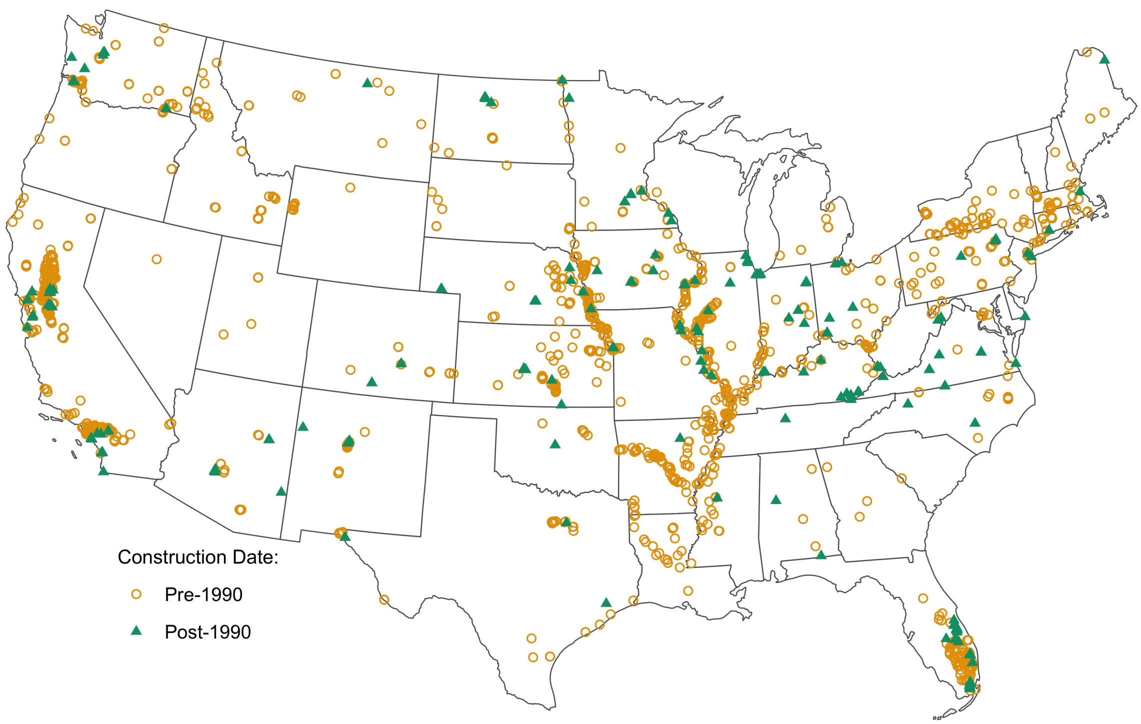
	$k \leq 0.1$ mi.		$k \leq 0.2$ mi.		$k \leq 0.3$ mi.	
	(1)	(2)	(3)	(4)	(5)	(6)
Post x						
Intersects	0.098	0.026	0.097	0.027	0.095	0.027
	(0.015)	(0.008)	(0.015)	(0.009)	(0.015)	(0.009)
k mi. of Levee	−0.0005	−0.019	0.054	0.014	0.070	0.018
	(0.043)	(0.029)	(0.029)	(0.015)	(0.024)	(0.011)
k mi. of Water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

The dependent variable is the log of real sale price. Data are restricted to parcels for which we observe more than one transaction during our sample period. We further restrict our data to transactions of parcels that either fall within leveed areas or are located within 5 miles of a leveed area boundary, excluding transactions of parcels that are within 0.1 mi on either side of leveed area boundaries (see Section 3 for a discussion). We report estimates of Equation B3 using different proximity treatment bandwidths, k, that define spillover, adjacency, and salience exposed parcels, namely 0.1, 0.2, and 0.3 mi from the nearest waterbody or levee. Reported coefficients $(\alpha_1, \alpha_2, \alpha_3, \alpha_4)$ correspond directly to those in Equation B3 and correspond to the protection, adjacency, spillover, and salience effects of levee construction, respectively. Standard errors, clustered at the census tract level, are reported in parentheses.

using larger bandwidths. This may be due to a number of factors, including a differential disamenity effect relative to parcels near levees but outside of leveed areas. It may also be driven by a perception that proximity to a levee entails greater flood risk despite the protection benefits that levees provide. This may be plausible if the levee itself calls attention to the hazard from which it provides protection. Overall, the results of Table B1 validate our treatment of protection and spillover effects as the main housing market impacts of levee construction.

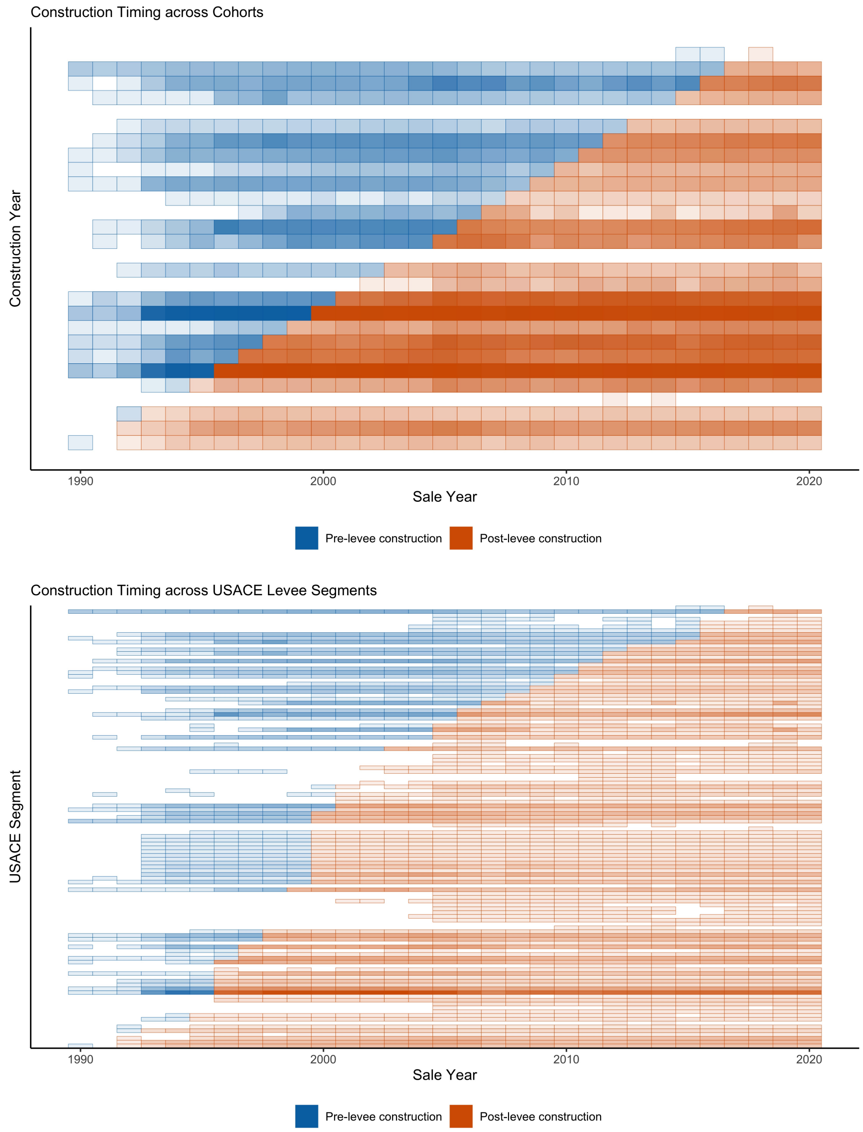
C Supplemental Figures and Tables

Figure C1. Map of USACE Constructed Levee Segments.



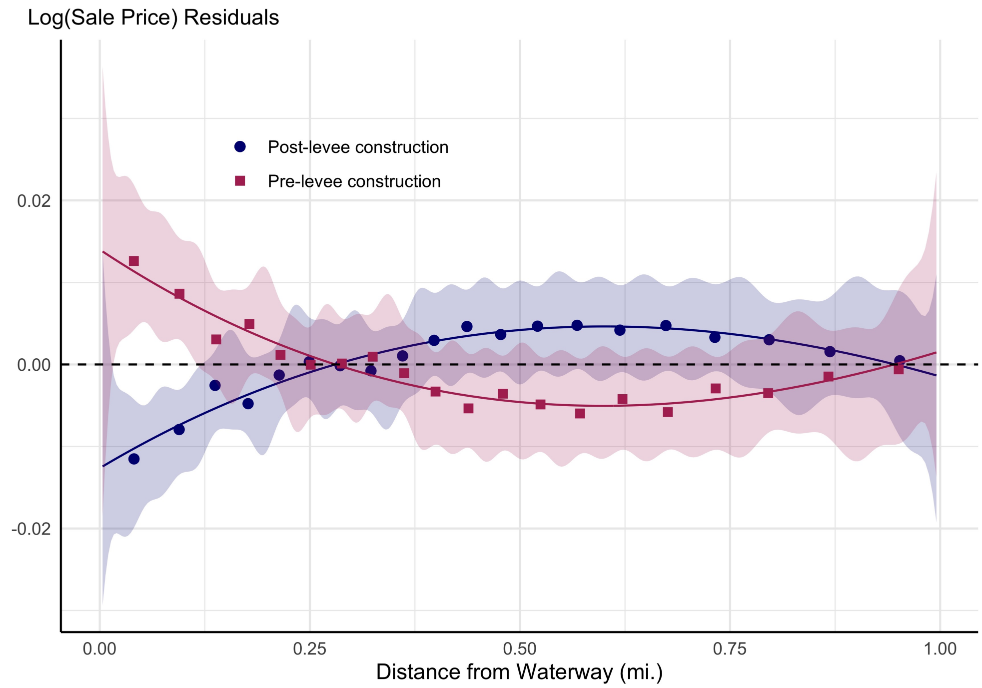
Note: This figure shows the location of US Army Corps of Engineers (USACE) constructed levee segments built pre- and post-1990, the earliest year for which we have residential transaction data. Levee segments that are part of USACE authorized projects, but are entirely constructed by non-federal partners are omitted as are USACE constructed levee segments for which reliable construction year information are unavailable.

Figure C2. Treatment Timing by Construction Year Cohort and Segment.



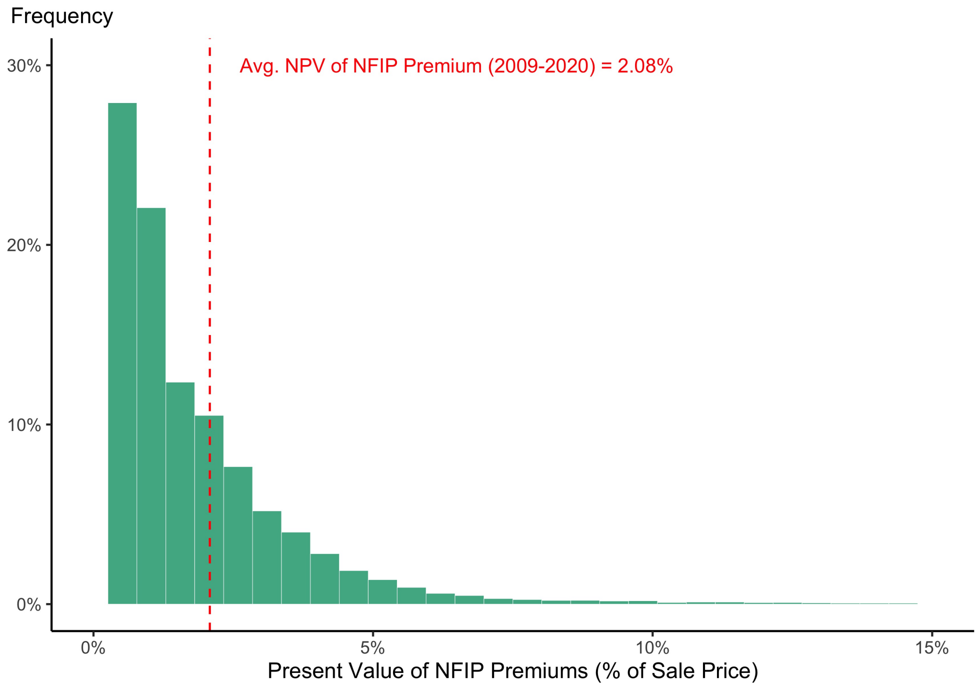
Note: This figure plots the timing of USACE levee segment construction across levee segment construction year cohorts (upper) and across individual USACE levee segments (lower). Vertical axes are ordered in ascending order of construction year. Blue tiles represent pre-construction transaction observations, red tiles represent post-construction observations, and empty tiles represent missing transaction data. The shade of the tile indicates the number of transactions observed in a given year for each levee construction year cohort (upper) and levee segment (lower).

Figure C3. Price Gradient of Distance from Nearest Waterway.



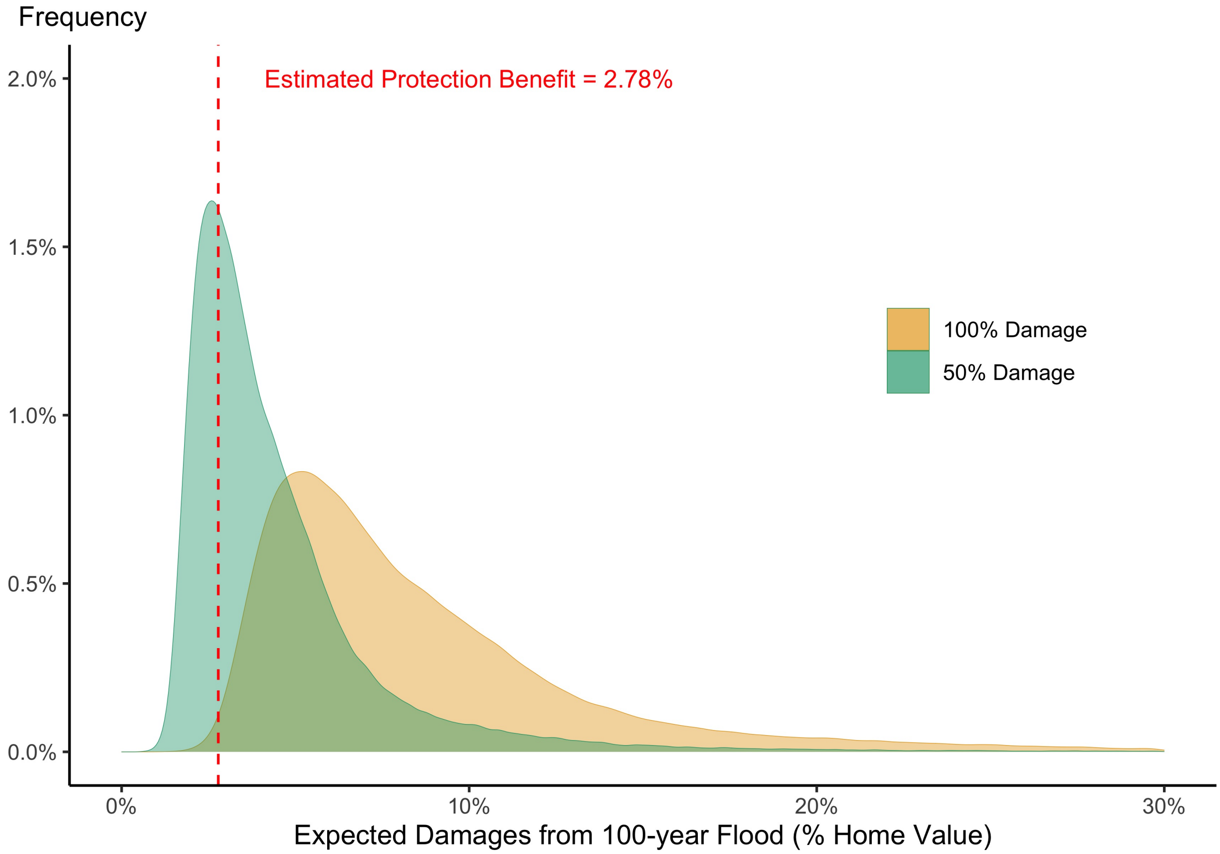
Note: This figure fits cubic spline on the empirical relationship between the residual of house prices from a regression on parcel and time fixed effects on a parcel's distance from the nearest waterway. We use this figure to help identify the distance range over which proximity-based levee construction effects—i.e., spillover effects—are likely relevant. This approach is first used by Linden and Rockoff (2008) and is used elsewhere in the literature (Muehlenbachs, Spiller and Timmins, 2015).

Figure C4. Present discounted value of maximum coverage NFIP premiums for levee protected homes.



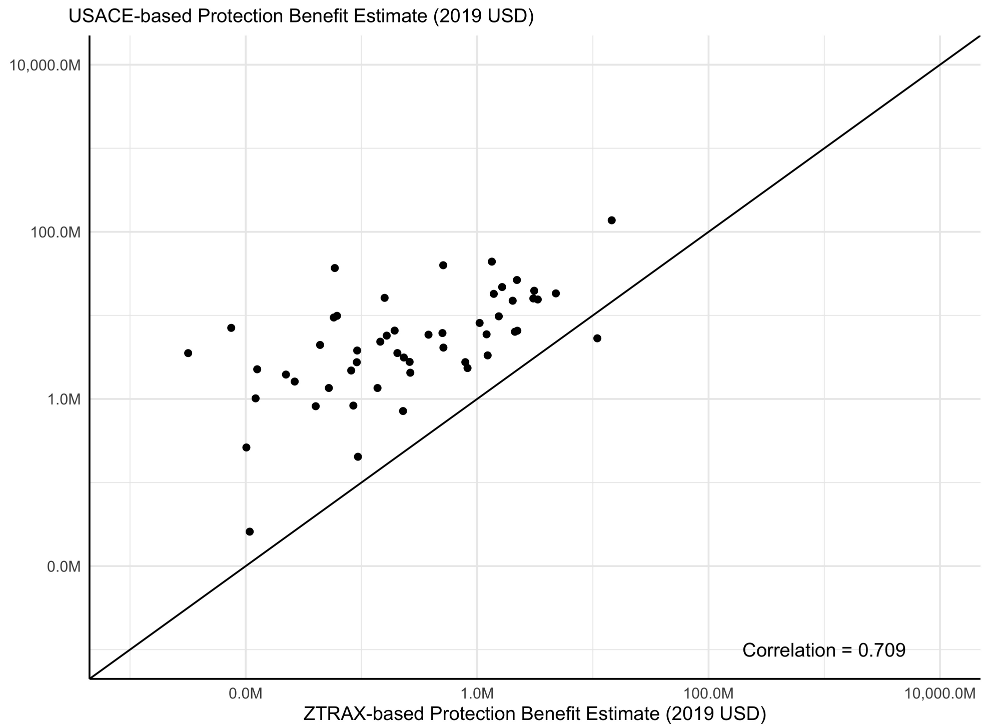
Note: This figure plots the distribution of National Flood Insurance Program (NFIP) premiums as a share of a home's sale price for all transactions of levee protected homes in our estimation sample between 2009 and 2020. For each levee protected home sale in this period, we assume that the household takes up the maximum allowable coverage of flood insurance under the NFIP and discount the stream of annual insurance premiums in perpetuity using a 4.09% annual discount rate, which corresponds to the average interest rate on a 30-year fixed rate mortgage for 2009-2020 according to Freddie Mac (retrieved from https://www.freddiemac.com/pmms/pmms_archives on 10/11/2024). We use policy-level observations of NFIP premiums for 2009-2020 to estimate the average premium per dollar of coverage for each census tract-year of this period and assume all protected households take-up insurance under the NFIP in perpetuity at a coverage level equal to the lower of the value of their home or the $250,000 building (plus $100,000 contents) NFIP coverage limit. This figure explores the potential for re-mapping out of Special Flood Hazard Areas (SFHAs) following levee construction to drive our main protection benefit estimates. Re-mapping out of SFHAs entails lower NFIP premiums and a removal of the mandatory flood insurance purchase requirement for homes with mortgages from federally-backed lenders. For this re-mapping to drive our results, the difference in the present discounted value of insurance premiums before and after levee construction would have to equal our estimate of the protection benefit. While on average the present discounted value of premiums as a share of home value is similar in magnitude to our main estimates, the assumptions of full take-up and complete coverage are strong and often not observed in practice.

Figure C5. Incomplete Capitalization of Flood Protection Benefits.



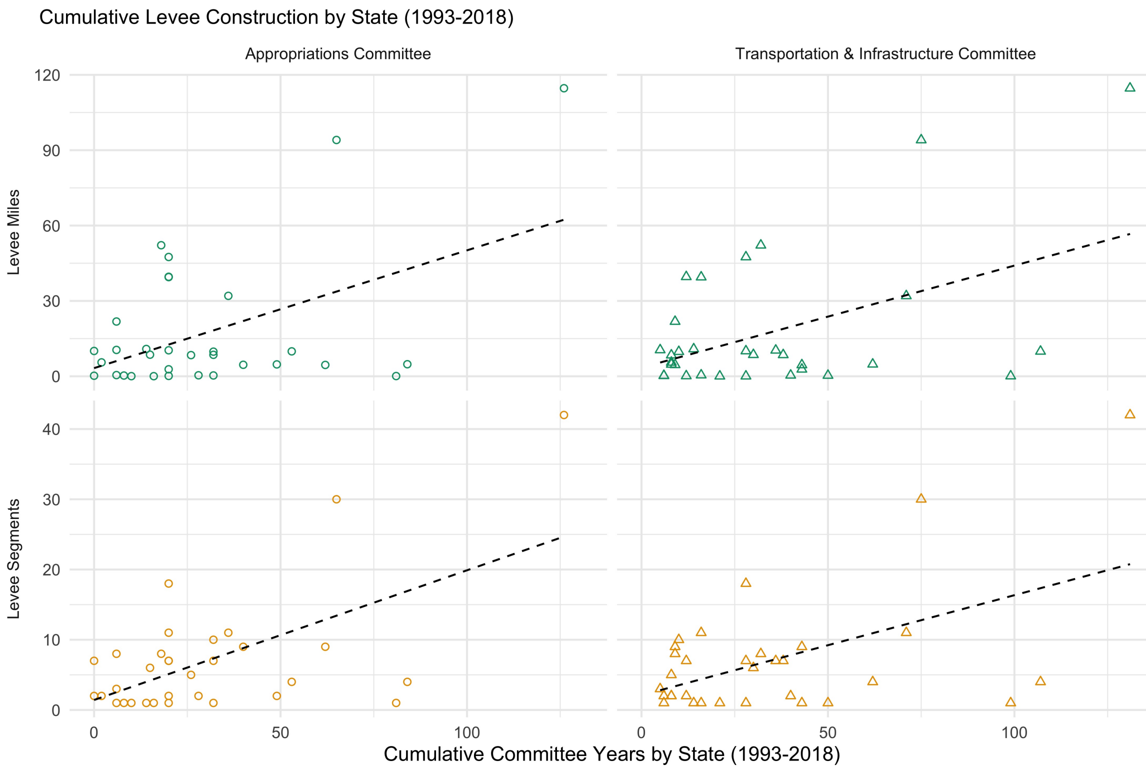
Note: This figure compares the estimated average capitalized effect of flood protection benefits with calculated present discounted value of expected damages from a 100-year flood over a 30-year period. We calculate expected damages using estimates of replacement costs per square foot from the Federal Emergency Management Agency's (FEMA) HAZUS Program, Version 6.0, which vary based on a structure's number of floors and the presence of a basement. Using the square footage for every transacted, protected parcel in our estimation sample and assuming a 1 percent annual probability of damages of either 50 or 100 percent of a home's structure for 30 years, we calculate two separate distributions of expected damages. In both cases, average expected damages as a share of home value exceed our estimate of the average protection benefit.

Figure C6. Comparison of ZTRAX and USACE Derived Protection Benefit Estimates.



Note: This figure shows the correlation between ZTRAX- and USACE-based aggregate protection benefit estimates for the 23 projects for which construction cost data are available. We apply the same protection capitalization estimate of 2% in generating each aggregate measure; however, differences between the two arise due to different approaches to constructing measures of the value of protected housing/building stock. The ZTRAX-derived measure uses assessed values from ZTRAX assessment data to construct the value of protected housing stock and the USACE-derived measure takes USACE's own estimates of the value of protected property, which are derived from the National Structures Inventory, Version 2 (2019) and include non-residential properties.

Figure C7. Congressional Committee Membership and USACE Levee Construction, 1993-2018.



Note: This figure shows the correlation between state-level measures of cumulative Congressional committee membership and USACE levee construction for the 103rd to 115th Congresses (1993-2018) for the relevant committees responsible for authorizing (Transportation and Infrastructure Committee) and funding (Appropriations Committee) USACE civil works projects. We generate two measures describing USACE levee construction at the state-level for this period—total levee miles constructed (top row) and total segments constructed (bottom row)—using data on the universe of USACE-constructed levee segments obtained from the National Levee Database. We generate measures of a state's cumulative years served on each committee by summing years served on the relevant committee across all US Representatives within a state from the 103rd to 115th Congresses. The dotted line shows a linear fit for each relationship.

Table C1. Effects of Levee Construction on Census Tract NFIP Outcomes

	$k \leq 0.1$ mi.			$k \leq 0.2$ mi.			$k \leq 0.3$ mi.		
	Take-up (1)	\$/Claim (2)	Avg. Premium (3)	Take-up (4)	\$/Claim (5)	Avg. Premium (6)	Take-up (7)	\$/Claim (8)	Avg. Premium (9)
Post × Intersects	−0.03	−518.3	75.0	−0.03	−269.9	77.8	−0.03	−283.2	78.4
	(0.009)	(4,120.9)	(65.2)	(0.009)	(3,680.2)	(65.7)	(0.009)	(3,675.6)	(65.8)
Post x k mi. of Water	0.006	6,581.3	18.4	0.001	5,478.6	24.3	0.005	5,414.9	26.2
	(0.007)	(3,315.2)	(17.4)	(0.008)	(3,181.0)	(17.7)	(0.009)	(3,216.0)	(17.6)
Sale Year FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Tract FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Levee Project FE-Sale Year FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Observations	19,284	1,374	17,210	19,284	1,374	17,210	19,284	1,374	17,210
R^2	0.9	0.9	0.8	0.9	0.9	0.8	0.9	0.9	0.8

This table reports estimates of the effects of levee construction on a set of census tract-level National Flood Insurance Program (NFIP) outcomes, including the census tract-wide take-up rate, the average claim value conditional on experiencing at least one claim, and the average NFIP premium amount. These results are estimated by aggregating the relevant NFIP policy and claims data to the census tract level for all census tracts that either intersect leveed areas or are within 5 miles of a leveed area boundary for a USACE-constructed levee in our sample. We then assign treatment status to each census tract based on whether they contain any parcels with the relevant treatment, either falling within a leveed area (protection effect treatment) or being not protected by a levee and adjacent to a waterway (spillover effect treatment). Note that this allows a given tract to be assigned to both, one, or neither treatment. We then estimate the following on a balanced panel at the census tract-by-year level:

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

where Y_{ct} is one of the three NFIP outcomes; T_{ct}, L_c, and W_c are as defined in Equation 5, now at the census tract, c, level; and ξ_c, $\mu_{l(c)t}$, and δ_t are tract, levee-by-year, and year fixed effects. Additional information on the NFIP data is available in Appendix A. Standard errors, clustered at the census tract level, are reported in parentheses.

Table C2. New Construction Probability on Spatial Treatment Indicators

	Pr(New Construction)		
	(1)	(2)	(3)
Post x Intersects	-0.004	-0.004	-0.005
	(0.003)	(0.003)	(0.003)
Post x k mi. of Water	-0.009	-0.007	-0.006
	(0.002)	(0.001)	(0.001)
Parcel FE	Yes	Yes	Yes
Year-Levee System FE	Yes	Yes	Yes
$k \leq$	0.1 mi.	0.2 mi.	0.3 mi.
Dependent variable mean	0.008	0.008	0.008
Observations	44,387,585	44,387,585	44,387,585
R^2	0.083	0.083	0.083

The dependent variable is an indicator variable of whether a parcel experiences new construction of a primary structure in a given year. Data include a panel of all parcels in the ZTRAX tax assessment database that either fall within leveed areas or are located within 5 miles of a leveed area boundary and for which we observe data on renovations. To ease the computational burden, we subset the parcel-year panel data to observations 5 years pre- and 5 years post-levee construction. Cluster robust standard errors are reported in parentheses.

Table C3. Renovation Probability on Spatial Treatment Indicators

	Pr(Remodel)		
	(1)	(2)	(3)
Post x Intersects	−0.002	−0.002	−0.002
	(0.002)	(0.002)	(0.002)
Post x k mi. of Water	−0.0008	−0.001	−0.001
	(0.0003)	(0.0005)	(0.0006)
Parcel FE	Yes	Yes	Yes
Year-Levee System FE	Yes	Yes	Yes
$k \leq$	0.1 mi.	0.2 mi.	0.3 mi.
Dependent variable mean	0.005	0.005	0.005
Observations	44,387,585	44,387,585	44,387,585
R^2	0.093	0.093	0.093

The dependent variable is an indicator variable of whether a parcel experiences a renovation or remodel in a given year. Data include a panel of all parcels in the ZTRAX tax assessment database that either fall within leveed areas or are located within 5 miles of a leveed area boundary and for which we observe data on renovations. To ease the computational burden, we subset the parcel-year panel data to observations 5 years pre- and 5 years post-levee construction. Cluster robust standard errors are reported in parentheses.

Table C4. Log Sale Price on Spatial Treatment Indicators Using a Matching Estimator

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

The dependent variable is the log of real sale price. Each transaction of protected and spillover-exposed parcels is matched to two relevant control transactions using nearest neighbor matching, with exact matching on the year of sale. Within sale year, nearest neighbor matching is based on house attributes, including the log of square footage, the number of bedrooms, the number of bathrooms, lot acreage, and quadratic polynomials in latitude and longitude. Once transactions of protected and spillover-exposed parcels are matched to controls, we separately regress the log of sale price on interactions between a post-levee construction indicator and the relevant treatment indicator as well as a fixed effect for each treatment-control match group. To ensure results using this alternative matching estimator are comparable to our main results reported in Table 1, we restrict data to parcels for which we observe more than one transaction during our sample period and to transactions of parcels that either fall within leveed areas or are located within 5 miles of a leveed area boundary, excluding transactions of parcels that are within 0.1 mi on either side of leveed area boundaries (see Section 3 for a discussion). Estimates of protection and spillover effects are reported for three different waterbody bandwidths, k, that define spillover exposed parcels (and hence the pool of eligible controls for protected parcels). Cluster robust standard errors are reported in parentheses.

Table C5. Robustness of Spillover Exposure Definition

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

The dependent variable is the log of real sale price. The table compares our main estimates of the spillover effects of levee construction with those using an alternative definition of spillover exposure based on whether a house fall outside of a levee protected area, but inside a FEMA-defined floodplain. The "Floodplain" variable is an indicator of whether a parcel falls within a FEMA-mapped 100-year floodplain and is outside of a levee protected area. Data are restricted to parcels for which we observe more than one transaction during our sample period. We further restrict our data to transactions of parcels that either fall within leveed areas or are located within 5 miles of a leveed area boundary, excluding transactions of parcels that are within 0.1 mi on either side of leveed area boundaries (see Section 3 for a discussion). We report estimates of Equation 5 using different waterbody bandwidths, k, that define spillover exposed parcels, namely 0.1, 0.2, and 0.3 mi from the nearest waterbody. Standard errors, clustered at the census tract level, are reported in parentheses.

Table C6. Robustness of Log Sale Price on Spatial Treatment Indicators to Income-Weighting and Alternative Fixed Effects

Panel A: Income-weighted Results

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

Panel B: System-by-Year Fixed Effect

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

Two sets of robustness checks of the primary capitalization results reported in Table 1. Panel A compares the set of preferred estimates with analogous estimates using weighted least squares, with transaction weights determined by purchaser income. Panel B compares the set of preferred estimates with analogous estimates replacing the preferred levee segment-by-year fixed effect with a levee system-by-year fixed effect. Note that levee systems often include multiple levee segments, each of which can be constructed in different years. Each panel reports the main estimates from Table 1 in the odd numbered columns. Standard errors, clustered at the census tract level, are reported in parentheses.

Table C7. Robustness of Log Sale Price on Spatial Treatment Indicators to Different Sample Restrictions

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

Robustness check of the primary capitalization results reported in Table 1 to alternative sample restrictions. Column 1 reports the preferred specification from the text. Columns 2 through 5 separately vary the size of the two spatial bandwidths used to restrict the main estimation sample. In particular, columns 2 and 3 test alternative definitions of the "donut design" sample restriction, which drops transactions of parcels within a specified distance on either side of levee protected area boundaries. Columns 4 and 5 test alternative restrictions of the pool of potential control and spillover-exposed parcels based as falling within a certain distance outside of leveed area boundaries. Standard errors, clustered at the census tract level, are reported in parentheses.

Table C8. Differential Capitalization of Protection Benefits for FEMA-accredited Levees

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

The dependent variable is the log of real sale price. Data are restricted to parcels for which we observe more than one transaction during our sample period. We further restrict our data to transactions of parcels that either fall within leveed areas or are located within 5 miles of a leveed area boundary, excluding transactions of parcels that are within 0.1 mi on either side of leveed area boundaries (see Section 3 for a discussion). We report estimates of Equation 5 using different waterbody bandwidths, k, that define spillover exposed parcels, namely 0.1, 0.2, and 0.3 mi from the nearest waterbody. The FEMA-accredited term is a binary indicator of whether a levee segment meets certain safety and protection benefit requirements established by FEMA. Parcels protected by FEMA-accredited levees are eligible for re-mapping out of FEMA's Special Flood Hazard Areas (SFHAs), which entails lower National Flood Insurance Program (NFIP) premiums and a removal of the mandatory flood insurance purchase requirement for homes with mortgages from federally-backed lenders. Standard errors, clustered at the census tract level, are reported in parentheses.

Table C9. Post-levee Construction Difference-in-Differences Estimates of Protection and Spillover Effects for Low- and High-Flood Exposure Transactions

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

The dependent variable is the log of real sale price. Data are restricted to transactions that occur after levee construction and to parcels for which we observe more than one transaction during the post-construction sample period. We are interested in whether there are differences in capitalized protection and spillover effects for high and low-flood exposure transactions. The above interaction terms compare the effects of falling within the relevant treatment area for high flood exposed areas to that for low flood exposed areas, which are the quantities of interest. "High Flood Exp." is a binary variable that equals 1 if the transaction is defined as high flood exposure and 0 otherwise. We define a high flood exposure transaction as a transaction of a parcel falling within a county with a greater than 75th percentile value of lagged 24-month count of flood-related storm events based on data from the NOAA Storm Events Database. Additional information on these data is available in Appendix A. Standard errors, clustered at the census tract level, are reported in parentheses.

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