

Adapting to Natural Disasters through Better Information: Evidence from the Home Seller Disclosure Requirement

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Abstract

While flood damage is determined by both flood intensity and population exposure, the US has predominantly focused on managing the former, with limited success. This paper studies whether a Home Seller Disclosure Requirement can reduce flood exposure and thus flood damage. Leveraging two quasi-experimental variations of the policy, I first show that mandating flood risk disclosure lowers the population living in high-risk areas. Further, using a hydrological measure of flood intensity, I find that it reduces the probability of flood damage by 33 percent. These findings illustrate that easing information frictions can promote voluntary adaptation to natural disasters.

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1 Introduction

Since 1980, floods in the United States have wrought over \$1 trillion in damage, making them the costliest type of natural disaster over the last 40 years (NOAA 2020). Climate scientists predict flooding is likely to happen with higher frequency and intensity in the future (Milly et al. 2002, Ghanbari et al. 2019). Thus, effective adaptation, which is an activity to moderate or avoid harm, is increasingly important (IPCC 2014, Aldy and Zeckhauser 2020).

While flood damage is determined by both flood intensity (i.e., physical characteristics) and exposure (i.e., population size in high-risk areas), flood policy in the US has focused primarily on managing the former by adding engineering structures (Changnon et al. 2000, Field et al. 2012, Tarlock 2012, Liao 2014). However, structural responses can attract more people and developments in flood-plains (the so-called “levee effect”) by converting wetlands into habitable land (Pinter 2005, Kousky et al. 2006, Collenteur et al. 2015). The fundamental problem is that none of these structures are perfectly safe. When the engineering structures fail, either due to extreme weather conditions or improper maintenance, the risk of flood damage is heightened with the increased population exposure (Pinter et al. 2016).¹ Consequently, governments end up spending billions of dollars for disaster relief and recovery on top of the resources devoted to flood prevention (CBO 2016). Although some local governments impose development restrictions and related policies to limit exposure, in most of the US, the population in flood-prone areas is expected to grow rapidly (Wing et al. 2018).²

This paper exploits quasi-experimental variations from a Home Seller Disclosure Requirement (hereafter “the disclosure requirement”) to study whether easing information frictions about flood risk can reduce (1) the number of households in high-risk areas and (2) resulting flood damage. Although official flood maps have long been publicly available, earlier research and anecdotal evidence suggest a lack of flood risk awareness among homebuyers. For instance, Chivers and Flores (2002) find only 14 percent of homebuyers in high-risk areas learned about flood risk before closing. Such low awareness makes it unlikely that homebuyers fully internalize the costs of flood risk during real estate transactions. Given that a potential reason for the friction is information acquisition and processing costs (Kunreuther and Pauly 2004), the disclosure requirement could alleviate the problem by

¹Over 1,000 levees failed during the 1993 Midwest Flood (LARSON 1996). A key factor behind frequent failure is the lack of maintenance. Pinter et al. (2016) find that only 1.9 percent of the levees in the US are rated “Acceptable”.

²For local governments, development restrictions are against their interests because they could hurt the tax base.

efficiently delivering risk information.

The policy mandates that home sellers must disclose known property issues on a wide range of dimensions including land, structure, and ambient environments using a standardized form (Lefcoe 2004). Regarding flood risk, a typical question is if a property is located in a Special Flood Hazard Area (SFHA)—an area with elevated risk defined by the official flood map. Home sellers are generally obliged to fulfill the disclosure requirement before closing (Stern 2005).

The disclosure requirement was rolled out across 26 states in the contiguous US from 1992–2003. The variation in implementation timing is from plausibly exogenous state court rulings on the extent of realtor liability for incomplete disclosure (Roberts 2006), which facilitates a difference-in-differences research design. In addition, the disclosure requirement treats properties located in and out of the SFHA differently, which introduces a third difference to further aid in identification. In exploiting the staggered adoption of the disclosure requirement, I use the stacked approach to overcome potential bias from conventional two-way fixed effect models (Cengiz et al. 2019, Brot-Goldberg et al. 2020, Goodman-Bacon 2021).

I also leverage additional variation stemming from the spatial discontinuity in flood risk information at the flood zone border. That is, homebuyers for two proximate properties located on opposite sides of an SFHA border—over which flood risk is changing continuously—receive starkly different flood risk information, which yields an opportunity to identify the information effect holding true flood risk constant. A potential concern is that being located in the SFHA could invite other treatments such as the mandatory purchase of flood insurance. Thus, I use the difference-in-discontinuity approach to control for time-invariant confounders (Grembi et al. 2016).

I collect multiple datasets to leverage all of this variation in empirical models designed to recover the causal effect of increased information about flood risk during real estate transactions. I use census-block-level demographic data from the decennial census, and community-level flood insurance policy counts from the National Flood Insurance Program (hereafter “flood insurance” or “NFIP”). To measure flood damage, I use damage records from flood insurance adjuster reports. I also construct a historical dataset of community-level flood events based on a hydrological measure of flood intensity (Saharia et al. 2017, England Jr et al. 2019). These data overcome the potential endogeneity of self-reported flood events, such as those from the National Weather Service Storm Events data (Gall et al. 2009). Because the main outcome variables used in the analysis have a mass point at

zero with a long right tail, I estimate the extensive and intensive margin effects separately following suggestions of Chen and Roth (2022).

I analyze the data in two parts that correspond to the two research questions posed earlier. First, I investigate homebuyer responses to the disclosure policy. Specifically, building on the insights from Ehrlich and Becker (1972)—households mitigate hazard risk by choosing between self protection and market insurance—I empirically estimate the impact of the disclosure requirement on the geographic distribution of the population and flood insurance take up rates. Second, I use a flood damage function to test if the disclosure policy reduces flood damage.

From the first part, I find that census blocks in an SFHA area (conditional on having a non-zero population) experiences a 7 percent decline in population after the disclosure policy. At the extensive margin, disclosure lowers the probability of a block in the SFHA having any population by 0.01 percentage points, or 1.5 percent from the baseline value of 0.67. Further, while most location adjustments occur within a community, homebuyers seem to choose alternative properties that have meaningfully lower flood risk. In contrast, I find a very small effect of the disclosure policy on insurance purchases: the probability of having a positive number of insurance policies in a community decreases by just 0.001 percentage points (or 0.1 percent) on the extensive margin, while insurance counts per housing unit decreases by 0.9 percent on the intensive margin. Investigating these two response channels is important because they have different implications for flood damage. That is, while choosing a safer location to live would reduce the probability of flooding, buying flood insurance would simply redistribute income from the “dry state” to the “flooding state” without necessarily affecting the probability distribution (Ehrlich and Becker 1972).

From the second part, I find that the disclosure policy reduces the expected probability of having any flood damage at the community level by 2.5 percentage points (or 33 percent of the baseline mean). To show this, I first estimate a non-parametric flood damage function—a mapping between flood size and damage—using community-level flood incidents and damage data. Then, I estimate the causal effect of the disclosure policy on the damage function and find that the slope of the function is substantially flatter after the policy. This analysis further reveals that the disclosure effect is disproportionately larger in communities with higher treatment intensities.

This paper contributes to four different bodies of literature. First, it is related to prior studies on factors that mitigate damage from climate change. While earlier studies primarily focus on technol-

ogy as a driver of adaptation (Miao and Popp 2014, Barreca et al. 2016, Burke and Emerick 2016), I focus on the role information can play in aligning private incentives with socially desirable outcomes.

Second, I contribute to the literature on the role of government in shaping household adaptation behaviors (Kousky et al. 2006, 2018, Gregory 2017, Peralta and Scott 2020, Baylis and Boomhower 2022). Perhaps the closest paper conceptually is Baylis and Boomhower (2021), which shows how building-code policies can mitigate wildfire damage. A key difference is that the policies studied by Baylis and Boomhower (2021) directly mandate adaptation, whereas disclosure policies studied in this paper encourage voluntary adaptation.

Third, and more broadly, I build on earlier work on the impacts of flood risk on the housing market (Hallstrom and Smith 2005, Pope 2008, Bin and Landry 2013, Muller and Hopkins 2019, Gibson and Mullins 2020, Hino and Burke 2021, Bakkensen and Barrage 2021). While most prior studies focus on understanding how changes to flood risk information and beliefs affect housing prices, I study the impacts on flood damage. Tracing the effect of flood information up to the damage amount is important because while housing price changes, in general, reflect transfers between homebuyers and sellers, a reduction in flood damage enhances social welfare.

Finally, I contribute methodologically by constructing a novel measure of flood exposure, which is a critical step in identifying climate change effects (Hsiang 2016). My approach leverages hydrological measures of flood intensity, allowing me to document flood events objectively for a wide range of causes including rainfall, snow melt, or storm surge. My measure complements existing ones that specialize in capturing the impacts of rainfall or hurricanes (Strobl 2011, Davenport et al. 2021).

The paper proceeds as follows. Section 2 provides background on the Home Seller Disclosure Requirement and the Special Flood Hazard Area. Section 3 details the data sources and provides some summary statistics. Section 4 presents estimation results on household responses while Section 5 shows the disclosure policy effect on flood damage. Section 6 concludes.

2 Background

2.1 Home Seller Disclosure Requirement

Publicly available Flood Insurance Rate Maps contain the information homebuyers need to determine whether a property is located in an SFHA. Furthermore, the Flood Insurance Reform Act of

1994 requires the purchase of flood insurance as a condition for federally-backed mortgage approval for properties in SFHAs, which should inform homebuyers of the associated flood risk. However, compliance with the flood insurance mandate is far from perfect (Tobin and Calfee 2005, Michel-Kerjan 2010, GAO 2021, Wagner 2022) and prior work shows homebuyers do not have a good understanding of the flood risk they face (Chivers and Flores 2002, Pope 2008, Bin and Landry 2013). A disclosure on flood risk could be a useful apparatus to address this information gap.

Disclosure content. A statutory disclosure requirement mandates that home sellers provide buyers with a detailed account of known material defects in the listed property by filling out a standardized form. Importantly, the disclosure requirement is not exclusively about flood risk. As Illinois Residential Real Property Disclosure Report in Appendix Figure C.1 illustrates, a typical form covers a wide range of property conditions including structural issues (e.g., problems with walls, roofs, or plumbing) and surroundings (e.g., natural hazards such as flood risk).³

The exact language of disclosure on flood risk varies slightly from state to state, but some combination of the following three questions usually appears: whether a property is in the SFHA; whether a property had flood damage history; and whether a property has flood insurance.⁴ Because properties on the SFHA are more susceptible to flooding, these questions are highly correlated. Indeed, flood insurance policy and claims data that I acquired through FOIA show that 71 percent (75 percent) of the claims (flood insurance policies) are from properties in the SFHA. Therefore, whatever the language, disclosure is likely to raise homebuyers' flood risk awareness for properties in SFHAs relative to those outside.

Disclosure background. Traditionally, homebuyers were legally expected to exercise proper caution with regard to potential defects of a property (the so-called “*caveat emptor*” or “let the buyer beware” doctrine). However, with the rise of consumer protectionism (Lefcoe 2004), and with higher public attention to environmental contamination and health issues during the 1980s (Weinberger

³Since the disclosure delivers a bundle of information, discerning treatment mechanism can be challenging especially when there is positive correlation between flood risk and other property defects. While I cannot directly observe property conditions, Appendix Table C.1 reveals that properties in tracts with SFHAs are significantly newer compared to those in tracts without SFHAs. Given that property defects tend to develop over time, this suggests that properties in SFHAs are less likely to have issues. As a result, any adverse impact of the disclosure policy on the housing value and population size is attributable to flood risk information and the estimated effects may well be attenuated.

⁴As of 2021, 5 states ask just the first question about the SFHA status, 15 states ask about SFHA status and past flood experience, and 4 states ask all three questions. MI and TN ask about the latter two only.

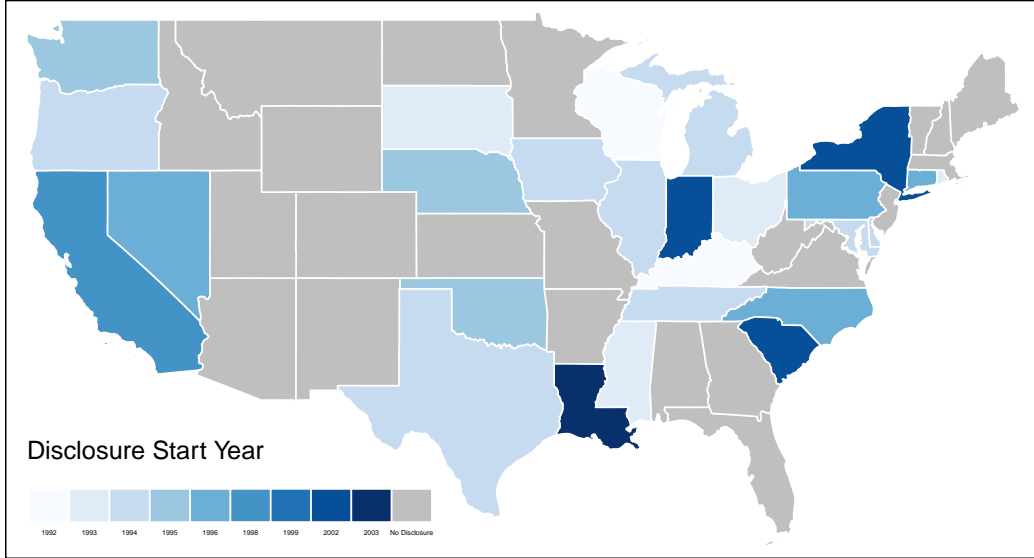


Figure 2.1: The Disclosure Requirement Implementation over Time

1996), state courts increasingly held listing agents responsible for incomplete disclosures. In response, the National Association of Realtors issued a resolution in 1991 encouraging state associations to develop and support legislation regarding the statutory disclosure requirement (Tyszka 1995).

Consequently, between 1992 and 2003, 26 states in the contiguous US implemented a disclosure requirement with an explicit question on flood risk (see Figure 2.1). As its historic origin suggests, the disclosure policy was primarily an effort of realtors to deflect potential liability to sellers (Washburn 1995) and the timing of the policy implementation is related to the timing of the change in the state court’s view on the *Caveat Emptor* doctrine (Roberts 2006).

Given the background and content of disclosure requirements, the implementation timing is unlikely to be correlated with each state’s underlying flood-risk profile. In Figure 2.2, I plot the relationship between disclosure year and (a) the average flood damage per housing unit and (b) the average proportion of land area inside of the SFHA. If the policy timing is correlated with underlying flood risk, we would expect to see a higher risk level for early adopters. However, both flood damage and the SFHA ratio are uncorrelated with the implementation year.⁵ In contrast to panels (a)–(b) where the x-axis is in calendar years, panel (c) shows the average flood size in event time, namely time relative to passage of the state’s disclosure legislation. If the decision to adopt a disclosure policy were a direct response to devastating flood events, the average flood size would be larger for

⁵Spikes in Figure 2.2 (a) and (b) are due to Louisiana, which has substantially higher flood damage per housing unit and a higher fraction of land area in SFHAs compared to other states.

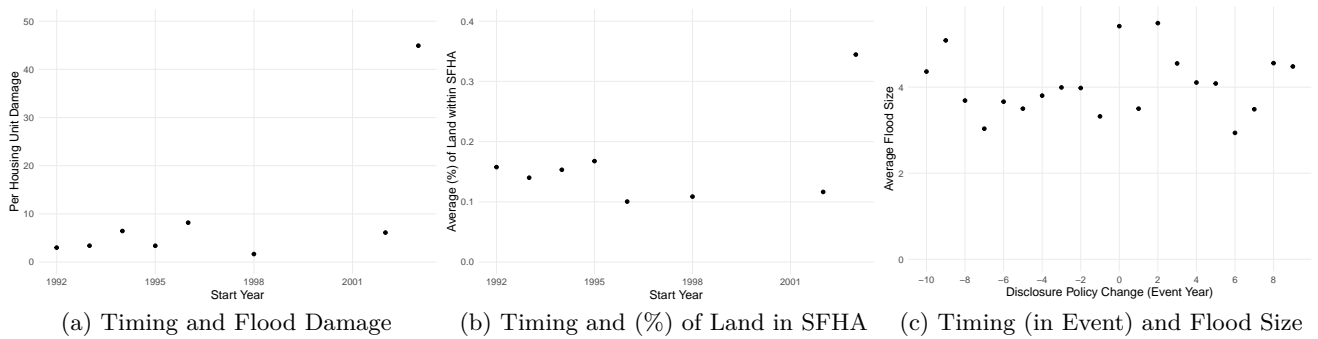


Figure 2.2: Correlation Between Disclosure Timing and Flood Profiles. These figures plot the disclosure policy timing against (a) past flood damage and (b) ex-ante flood risk profile. Panel (c) plots the average flood size in event time. Values on the y-axis is pooled across all states with the same treatment or event year.

event years right before 0. The plot also shows that flood size is essentially uncorrelated with policy adoption—if anything, flood size seems to be smaller in event years -1 and -2, which again suggests that the policy implementation is not driven by prior flooding.

Does the disclosure requirement matter? Although many states levy fines or even allow buyers to rescind their purchase agreement without penalty to ensure compliance, the disclosure policy might still fail to raise homebuyers’ flood risk awareness. For example, home sellers might not comply with the regulation. If they furnish the form with inaccurate information or ignore the requirement despite the potential penalty, the disclosure policy’s effectiveness could be seriously undermined. Homebuyers might also fail to process the new information. While the disclosure forms consist of straightforward check box questions (see Appendix Figure C.1), the implication of living in an SFHA might not be fully understood. Thus, while there are good reasons to expect the disclosure policy to reduce information frictions around flood risk, whether it does is an empirical question.

Unfortunately, I cannot observe homebuyers’ perceptions of flood risk directly. However, in Appendix B I find disclosure reduces housing prices in SHFA’s by 4.5 percent, which coincides with existing estimates of the effect of flood risk information on housing prices (e.g., see Hino and Burke (2021)). This finding provides evidence that at least some information is being conveyed to buyers through the disclosure policy. The extent to which this information translates to risk-mitigating behaviors is uncertain and the focus on my empirical work below.

States without disclosure requirements on flood. Before proceeding further, it is worth discussing

the 22 states in the contiguous US (excluding Washington DC) that do not mandate home sellers to disclose on flood risk. Despite the lack of mandatory requirements, more than 60 percent of these states have seen the formation of voluntary disclosure forms by their respective state realtor associations. In some states, realtor associations even require member realtors to use these forms.⁶ Thus, a non-trivial number of homebuyers in these “non-disclosure” states might have received information on flood risk. The timing of these realtor-driven behavior is uncertain, as is compliance. For this reason, I exclude non-disclosure states and use later-treated states instead as the control group for earlier-treated states when I exploit the staggered adoption variation.⁷

Importantly, five of the 22 non-disclosure states adopted a variant of a home seller disclosure mandate, although it does not have a question on flood risk.⁸ These “placebo” states are useful for checking the robustness of the main results.

2.2 Flood Map and Special Flood Hazard Area (SFHA)

The SFHA, an area expected to be inundated with a 100-year flood, is a particularly important concept in flood risk because communications frequently refer to it.⁹ An official flood map, or the Flood Insurance Rate Map, allows stakeholders to identify the boundary of an SFHA, determine a specific property’s SFHA status, and determine the Base Flood Elevation (FEMA 2005).

The flood mapping process involves three key steps (FEMA 2005): (1) hydrologic analysis that determines the water amount in a stream channel for a given weather event; (2) hydraulic analysis that translates water amount to water surface elevation; and (3) floodplain mapping, which determines the boundary of inundation by comparing water surface elevation with the ground elevation. The procedure implies that flood risk, which is a function of land contour, is continuously changing even at the SFHA border (Noonan et al. 2022). This gives rise to the spatial discontinuity design at the

⁶See Colorado, for instance, from Flood Disclosure Scorecard from NRDC <https://www.nrdc.org/flood-disclosure-map> (accessed on Sep 8, 2022).

⁷Indeed, the inclusion of these states seriously attenuates the treatment effect and/or creates a pre-trend (see Appendix Figure B.1 panel (b) and Appendix Table C.6 and accompanying texts). Even in the late-adopting states, some realtor-driven disclosure behavior might have been in place prior to the state policy change, which can be viewed as attenuating my findings relative to a pure counterfactual of no disclosure.

⁸For details regarding the extent of disclosure in these states, see the following. Idaho: 1994 Ida. HB 825 (1994), Maine: Title 33 Section 173 (1999), Minnesota: CHAPTER 306—S.F.No. 2697 (2003), New Hampshire: NH. Rev. Stat. Ann. § 477:4-c (1994), and Virginia: VA. CODE ANN. §§ 55.1-704 (2005).

⁹Flood is defined as “a general and temporary condition of partial or complete inundation of two or more acres of normally dry land area or two or more properties from an overflow of inland or tidal waters, from unusual and rapid accumulation or runoff of surface waters from any source, or from mud flow” (FEMA 2005).

SFHA border because the disclosure form treats flood risk discontinuously for two areas on different sides of the border with possibly very similar true flood risk.

It is also worth noting that these maps are updated occasionally, which could potentially confound the disclosure policy. While the National Flood Insurance Reform Act of 1994 requires that FEMA assess the need to revise and update all flood maps every 5 years, the vast majority of the maps fail to meet the required update cycle (DHS Office of Inspector General 2017). This is favorable for my research design because flood zone status for the majority of areas remains constant over the study period. Indeed, in Appendix B, I show that excluding properties from communities with map updates does not change the estimated effect of disclosure on the housing price.

The jurisdiction of each flood map is a National Flood Insurance Program “community”. These communities are local political entities comparable to a US Census place. Appendix Figure C.2 shows a sample Flood Insurance Rate Map from a part of the Borough of Stonington, CT, and similar to this place, a typical entity has both SFHA and non-SFHA areas. Indeed, a histogram in Appendix Figure C.3 illustrates that there is substantial variation in the fraction of area covered by an SFHA for communities in the sample, which suggests that the intensity of disclosure treatment varies across communities.

3 Data

I compile multiple data sets on block and tract level demographics, community-level numbers of flood insurance policies, and flood damage. I also construct a community-level flood history dataset. In this section, I describe each data source and provide descriptive statistics.

Demography and flood insurance. Demographic characteristics come from two sources. I collect Census-block-level population and occupancy data from the 1990, 2000, 2010, and 2020 decennial Censuses. To account for changing block boundaries and resulting one-to-many matches across different decennial census years,¹⁰ I calculate the weighted sum of count variables using interpolation weights from the NHGIS block-to-block crosswalk (Manson et al. 2022).¹¹ This creates a geographi-

¹⁰For instance, block G06000104003003006 in 2000 is matched to five different blocks in 2010 ending in 3010, 3011, 3017, 3020, and 3028.

¹¹Interpolation weights represent the expected proportion of the source block’s counts (e.g., population or housing units) located in each target block (Manson et al. 2022)

cally standardized time series. For other demographic characteristics such as income, age, race, and education, which are not available at the block level—the smallest Census geographic unit—I use tract-level data from the Geolytics for the 1990, 2000, and 2010 decennial Censuses.¹² Data on the number of flood insurance policies at the NFIP community level come from FEMA for 1978–2008.¹³

Flood damage. I use damage records from the flood insurance adjuster’s report. The damage amount is defined by the actual cash value—a replacement value net of depreciation (FEMA 2014). I observe individual property level damage with loss date, community ID, and building type. I restrict the sample to damage records from single-family houses that has sustained the largest flood event for a given community-year. Then I collapse the data to the community by year level to match it with the annual maximum flood event data.

Flood history. The measurement of climate exposure is a critical methodological step in identifying climate effects on economic outcomes (Hsiang 2016). In the domain of floods, two different measures have been widely used. The first approach measures flood intensity using outcome variables such as economic cost, which suffers an endogeneity problem by construction (for a review, see Felbermayr and Gröschl (2014)). The second approach uses a meteorological measure, but only for a subset of events such as a hurricane or rainfall (Strobl 2011, Hsiang and Jina 2014, Deryugina 2017, Davenport et al. 2021). Given that rainfall alone explains just one-third of cumulative flood damage in the US (Davenport et al. 2021), such an approach cannot capture the entire scope of floods.

To overcome these limitations, I construct hydrology-based flood history dataset at the community level using daily water volume records from over 3,000 USGS and NOAA stations located within my 26-state sample (Milly et al. 2002, Mallakpour and Villarini 2015, Slater and Villarini 2016). Using this approach, flood size is described by the recurrence interval (Task Committee on Hydrology Handbook of Management Group D of ASCE 1996): the expected number of years for a flood of the same magnitude to come back for a given site. For instance, a 10-year flood is the size of a flood that would happen on average once every 10 years, which would be less severe than a 100-year flood that is large enough to happen only once in 100 years on average. An idea behind this approach is similar to model extreme temperatures as deviations from local mean temperatures.

¹²Geolytics data provide tract level data after accounting for changing boundaries across different survey years (for more details, see www.geolytics.com).

¹³I thank Justin Gallagher for graciously sharing these data.

Practically speaking, I construct the data in four steps. First, I estimate a gauge-specific flood frequency distribution by fitting the Log-Pearson III distribution using the annual peak flow records of each gauge. Second, I convert the daily maximum discharge volume at each gauge into quantiles of the fitted distribution from step 1. Third, I translate the quantiles into recurrence intervals and take the maximum recurrence interval for each year.¹⁴ Finally, I match each community to the three nearest gauges and calculate community-year-level flood size by taking the inverse-distance weighted average of three closest gauges’ recurrence intervals. More details on the flood data construction procedure and summary statistics are in the Appendix A.1.

Other data sources. As the disclosure policy differentially treats the properties in and out of the SFHA, I spatially merge the NFIP community, census block, and census tract with the digitized flood map to determine the SFHA status of each geographic unit. Specifically, I use the Q3 map—the first generation of a digitized flood map—that captures flood risk as of the mid-1990s for over 1,300 counties (FEMA 1996). Finally, the primary data source to track the disclosure requirement legislative history is the *Nexisuni* database. I cross-validate this database with prior studies on the disclosure requirement (Washburn 1995, Pancak et al. 1996, Lefcoe 2004) and reports from the National Association of Realtors (National Association of Realtors 2019).

Summary statistics. Table 3.1 shows summary statistics for key independent variable: flood size; and dependent variables: population, flood insurance policy counts per housing unit, and flood damage per housing unit. Population figures are for the Census blocks within the optimal bandwidth, which I provide more detail in Section 4. The last three values are for the NFIP communities in my sample.

A notable aspect of the data is the high prevalence of zeros among the dependent variables. For instance, 27 percent of observations for the block population and counts and 17 percent of the observations of flood insurance policy counts are zeros. For the community-level flood damage per housing unit variable, 95 percent of observations are zero. The high prevalence of zeroes for these variables is consistent with external sources (details are in Appendix A.2).

In addition, these variables also exhibit substantial skewness (long and thin right tails), as the

¹⁴The recurrence interval for quantile q is $\frac{1}{1-q}$. For instance, a discharge volume of the 90th percentile, which means it is the 90th highest among 100 yearly maximum observations, corresponds to a 10-year flood.

Table 3.1: Summary Statistics for Key Variables

Variables	Min.	Q25	Median	Mean	Q75	Max.	N
Census Block Population	0	0	10	34.4	40	7,597	1,465,392
NFIP Policies Per Housing Unit	0	0.001	0.006	0.03	0.019	6.53	439,822
Flood Damage Per Housing Unit	0	0	0	5.8	0	23,991	505,383
N of 10-Year Floods (For 20 Years)	0	1	2	2.18	3	15	8,194

difference between median and mean values suggests. To account for this, I follow Chen and Roth (2022) and estimate extensive and intensive margin effects separately for each dependent variable. This approach resonates with a hurdle or two-part model, which is used extensively in modeling health expenditures characterized by a similar distribution (Mullahy and Norton 2022).

Finally, the last row of Table 3.1 indicates that an average community experiences 2.18 10-year flood events over a 20-year period. This is close to the expected value of 2.0.

4 Responses to the Disclosure Requirement

In this section, I investigate how homebuyers respond to flood risk information by estimating the impact of the disclosure policy on geographic distribution of the population and flood insurance take up. As noted above, investigating both responses is important because they have starkly different implications for flood damage—responses along the first margin can reduce total flood risk whereas responses along the second margin simply redistribute income from the “dry state” to the “flooding state” without necessarily affecting exposure (Ehrlich and Becker 1972).¹⁵

4.1 Estimation Framework

Spatial Discontinuity. Yes-or-no check box questions on disclosure forms create a spatial discontinuity in flood risk information, which allows me to disentangle the flood risk information effect from the true risk effect. However, a potential concern is that other policies such as flood insurance requirements also change at the border, which could confound the disclosure effect. To account for this issue, I leverage a difference-in-discontinuity approach, which takes the difference between the two

¹⁵Ehrlich and Becker (1972) suggests that, when self-protection is financially rewarded, self-protection and market insurance are complements. However, as Kousky (2019) points out, the NFIP premium is heavily subsidized and the NFIP premium structure is too coarse to account for all self-protection measures. Wagner (2022) also finds that substitution between self-protection (property elevation) and flood insurance is prevalent in the flood insurance market.

spatial regression discontinuity estimates from pre and post-disclosure periods.

Following Grembi et al. (2016), I estimate the policy effect on population residing in the SFHA and the vacancy rate using block-level decennial census data, which is the smallest Census geographical unit.¹⁶ For states that have implemented disclosure policies between 1990-1999 (2000-2009), I use the 1990, 2000, and 2010 (2000, 2010, and 2020) decennial census.

$$Y_{bst} = \delta_0 + \delta_1 X_{bs} + \delta_2 D_{bs} + \delta_3 X_{bs} * D_{bs} + T_{st}[\delta_4 + \delta_5 X_{bs} + \delta_6 D_{bs} + \delta_7 X_{bs} * D_{bs}] + \epsilon_{bst} \quad (1)$$

In equation (1), Y_{bst} is an outcome variable such as the probability of having any population, log of population conditional on having non-zero population, or the vacancy rate in block b in state s in time t . X_{bs} is the distance between a block border and the closest SFHA border in meters (negative if in a non-SFHA area),¹⁷ $D_{bs} = 1$ if $X_{bs} > 0$ is a treatment group indicator variable, and $T_{st} = 1$ if $t > T_s^*$ is a post-period indicator variable, where T_s^* is the policy change date for s . δ_6 captures the impact of the disclosure policy for blocks located in close proximity to the SFHA border. To estimate δ_6 , I first estimate the optimal bandwidth for each outcome variable. Then, I estimate equation (1) using blocks within the optimal bandwidth (Calonico et al. 2014, Cattaneo et al. 2019).¹⁸

A potential concern of using a geographic area such as a census block (namely, a polygon) rather than a property (namely, a point) is that a block might contain an SFHA border within it. In this case, the distance from a block to an SFHA border is not well defined. While this might be a serious problem for larger geographical units such as tracts, it will be less of a problem for blocks. For context, the median size of blocks in my sample is just 0.009 square miles, and 83 percent of blocks are entirely within or outside an SFHA as illustrated in Appendix Figure C.4. I remove the 17 percent of blocks that contain SFHA borders from the analysis.

Staggered Adoption. Flood insurance policy counts and local-area characteristics are observed at the community or tract levels, respectively. As these geographic units are typically much larger than

¹⁶A property is considered vacant if no one is residing in the unit at the time of enumeration unless its occupants are only temporarily absent (US Census Bureau 2000).

¹⁷ X_{bs} is approximated by taking the difference of (1) the distance between block centroids and the closest SFHA border and (2) a block diameter.

¹⁸I estimate the mean squared error optimal bandwidth for 2000 and 2010 respectively and take the average following Grembi et al. (2016). I ignore 1990 and 2020 because these years have only a subset of the states in the sample.

the SFHA (Appendix Figure C.4 (b)), the distance to the nearest SFHA border is not well defined. Thus, I employ a triple difference design using equation (2). Here, Y_{mstd} denotes various outcome variables on NFIP and demographic characteristics for geographic unit m in state s in year t in stack d . H_{md} is an indicator variable equal to one if a geographic unit has an above-median fraction of the area covered by an SFHA, which proxies for the treatment intensity. I_{std} is a post disclosure indicator and D_{std} is a treatment group indicator. α_7 captures the disclosure effect.

$$\begin{aligned} \log(Y_{mstd}) = & \alpha_1 H_{md} + \alpha_2 D_{std} + \alpha_3 I_{std} + \alpha_4 H_{md} D_{std} + \alpha_5 I_{std} D_{std} + \alpha_6 H_{std} I_{std} + \\ & \alpha_7 H_{md} D_{std} I_{std} + \omega_{td} + \psi_{md} + \epsilon_{mstd} \end{aligned} \quad (2)$$

As the stack subscript d indicates, I use the stacked approach to estimate the policy impact using clean controls (Cengiz et al. 2019, Brot-Goldberg et al. 2020). This approach alleviates concerns about potential biases in the staggered adoption design (Goodman-Bacon 2021). As I exploit the timing of the disclosure requirement for identification, not-yet-treated states form the control group. To construct the stacked dataset, I first keep each state’s flood insurance policy counts for seven years before and seven years after the policy change. Inclusive of the change year, I use 15 years of data for each state.¹⁹ Each stack consists of geographic units in the treated states, which have implemented the disclosure policy in year t^* , and geographic units in the control states, which have implemented the policy in year $\tilde{t} > t^*$.²⁰ I drop observations from the control states for $t \geq \tilde{t}$ because it is no longer “not-yet-treated”. Equation (2) also include ω_{td} , the time \times stack fixed effect to account for year-specific common shocks and a community or tract \times stack fixed effect ψ_{md} , which captures unobserved community or tract characteristics. Including fixed effects interacted with stack d ensures that the comparisons are made within each stack.

It is worth discussing one additional detail about the tract-level analysis. Because the decennial census occurs once every 10 years, states that implemented the policy after 2000 are used only as a control group. This is because there is no control group for them—every ever-treated state is treated by the 2010 decennial census. Thus α_3 is estimated from a single data stack that consists of early

¹⁹The data from 1978–2008 are sufficient to cover a 15-year window for policy changes in all states except Louisiana, which implemented its policy in 2003, leaving just six post-policy years for analysis.

²⁰Stack refers to data that is created for a specific treatment year (or a cohort year). A state belongs to either the treatment or control group depending on the stack. For instance, PA and CT, which changed their policy in 1996 are in the “treatment group” in a stack for $t^* = 1996$. The two states belong to the “control group” when $t^* < 1996$.

treated states (treated before 2000) and late treated states (treated after 2000).²¹ Because only two time periods are used the estimating equation (2) reduces to a standard triple difference specification with discretized treatment. Throughout the analysis, spatial-HAC standard errors that allow spatial correlation of up to 500 miles are estimated for inference (Newey and West 1987, Conley 1999).²²

4.2 Findings

Self-protection. Table 4.1 reports the impact of the disclosure policy on the population over a period up to 20 years after the policy change. In column (1), I find that the disclosure reduces the probability of having any population in an SFHA block by 0.01 percentage points relative to a non-SFHA block (or 1.5 percent of the baseline value 0.68). In column (2), I limit the sample to blocks with non-zero population and find that the disclosure reduces population in a populated SFHA block by 7 percent relative to a non-SFHA block. Taking these extensive and intensive margin effects together, the policy discourages both in-migration into SFHAs with existing population and new developments in previously uninhabited SFHAs.

Using equation (2), I show in column (3) that the effect of the disclosure policy on the community level population is only -0.6 percent—an order of magnitude smaller than in column (2).²³ This is plausible because, as Appendix Figure C.3 shows, a typical community has a large fraction of land area outside of SFHAs and thus flood risk can be easily avoided by within-community adjustments. Such local location adjustments documented in columns (2) and (3) are consistent with evidence on the response to flood risk documented in prior research (Noonan and Sadiq 2019).

In column (4), I report that the disclosure increases the vacancy rate for the blocks in an SFHA from 0.095 to 0.109. This finding suggests that after the disclosure, selling properties in the SFHA becomes harder (or takes longer) and a larger share of them are vacant at any given time.²⁴ This finding is consistent with evidence that people migrate away from negative environmental conditions, although the extent of migration here is highly localized (Banzhaf and Walsh 2008, Boustan et al. 2012, Hornbeck 2012, Hornbeck and Naidu 2014).²⁵

²¹Note the analysis on flood insurance take up does not have this problem as the observations are community-year.

²²When the variance-covariance matrix is not positive-semidefinite, I use eigendecomposition of the estimated variance matrix and convert any negative eigenvalue(s) to zero following Cameron et al. (2011).

²³I use the decennial census to linearly interpolate annual community population.

²⁴Indeed, New Orleans, one of the highest flood-risk areas in the nation, has the highest vacancy rate among the 75 largest MSAs in the US (Fudge and Wellburn 2014).

²⁵When the housing supply is fixed, the disclosure will not affect the population distribution (market will clear via

Table 4.1: Effect of Disclosure Requirement on Net Population Flow

	Prob. of Any Population	Log Population		Vacancy Rate
	(1)	(2)	(3)	(4)
SFHA \times Post	-.011*** (.003)	-.072** (.034)		.014*** (.005)
High SFHA \times Disclosure \times Post			-.006** (.003)	
Avg D.V.	0.674			0.097
Year \times Stack FE			X	
Community \times Stack FE			X	
Bandwidth	136	250		190
Num. obs.	1465392	1651843	499075	1306372

Note: Estimates are based on equation (1) and (2). Columns (1)–(2) and (4) are estimated using the decennial census block-level data in 1990, 2000, 2010, and 2020. Column (3) is estimated using community-level population data. Spatial-HAC standard errors that allow spatial correlation of up to 500 miles are estimated for inference. * $p < 0.1$; ** $p < 0.05$; *** $p < 0.01$.

Figure 4.1 (a) graphically illustrates the effect in column (2) of Table 4.1. The horizontal axis is the running variable of the spatial RD design, which is the distance between a block and the nearest SFHA border. The blocks within an SFHA are presented on the right-hand side of the border (the vertical line at 0), and the blocks outside of an SFHA are presented on the left-hand side. The solid lines represent the regression fit from equation (1) and the change in the logged population between the pre and post disclosure periods for the non-SFHA blocks is normalized to 0. I also overlay a scatterplot, which shows the difference in log population between pre and post treatment periods for each bin.

The figure indicates there is a sharp drop in the log population for SFHA blocks relative to the log population of non-SFHA blocks at the SFHA boundary. Visually, the discontinuous jump is approximately 0.07 log points, matching the estimate in column (2) of Table 4.1. Note, the regression line fits the scatter plot tightly, which suggests that the choice of functional form for the running variable is unlikely to have a substantial impact on the RD estimates.

Table 4.1 implies that most location adjustments are local, which raises a concern about the disclosure policy’s deterrence effect. That is, if diverted buyers choose a property outside the SFHA but very close to the border, the exposure to flood risk would be essentially unchanged. To gain insights on this issue, I replicate my analysis using a doughnut RD where I remove blocks that are

price adjustment alone). However, with an upward-sloping housing supply curve, which is likely to be the case given the time frame in Table 4.1, the disclosure will impact both the price and population distribution.

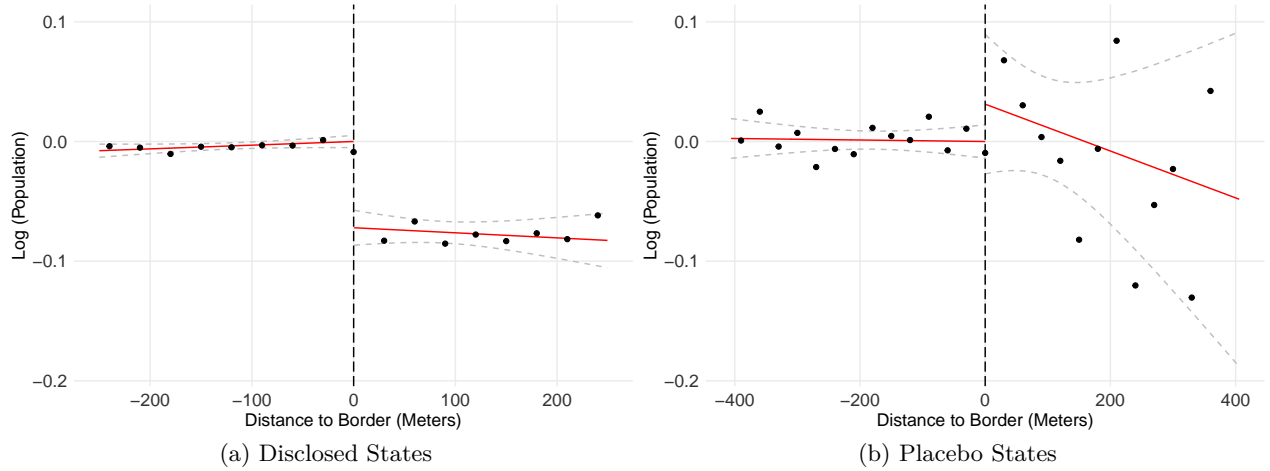


Figure 4.1: The Effect of Disclosure on Population. These figures illustrate difference-in-discontinuity estimates for the log of block population for the (a) treated and (b) placebo states. The discontinuity at the threshold (dashed vertical line) corresponds to the δ_6 term in equation (1). Dependent variables come from the decennial census block-level data in 1990, 2000, 2010, and 2020. The running variable is defined by the distance between a census block and the nearest SFHA border.

within 20 and 40 meters of the border. In Appendix Table C.3, I show that the estimates are similar. Moreover, Appendix Figure C.5 shows the policy effect does not diminish as I expand the bandwidth. These findings suggest when homebuyers are deterred from an SFHA, they choose locations that meaningfully lower flood risk.²⁶

In Appendix Table C.4, I explore the change in demographic composition caused by the disclosure policy. I find that higher-risk tracts become less affluent and less old in comparison to lower-risk tracts. This finding coincides with Bakkensen and Ma (2020) in that those with more resources choose to live in safer places.

While my difference-in-discontinuity design controls for time-invariant confounders, concurrent policy changes are still a threat to identification. A notable concern is that flood insurance premiums may have changed differentially over time in SFHA and non-SFHA areas. Another possibility is that there have been changes in the enforcement of the flood insurance purchase requirement over time. To explore the potential for these confounders to bias my findings, I use the five placebo states that have implemented disclosure policies without a question about flood risk. If my findings are driven by concurrent policy changes rather than the disclosure of flood risk, I would expect to find similar

²⁶These findings also rule out the Stable Unit Treatment Value Assumption (SUTVA) violation, which could overestimate the effect size in Table 4.1.

results in the placebo states.

In Appendix Table C.2, I find no evidence of a reduction in population or an increase in the vacancy rate in the placebo states. If anything, my estimates are either null (for the extensive margin population and the vacancy rate) or positive (for the intensive margin population). Figure 4.1 (b) provides corresponding visual evidence.²⁷

While choosing a safe location represents an extensive margin self-protection strategy, previous studies consider property elevation as a potentially important intensive margin responses (Mobley et al. 2020). Although data limitations do not allow me to analyze this possibility directly, property elevation is unlikely to be a widely adopted self-protection measure because of its high cost. For instance, the median cost of elevations through the FEMA mitigation program (between 2008 and 2013) is \$166,000 (National Research Council 2015), which is over 50 percent of the average property value in the SFHA area (\$327,171). In addition, elevation takes at least several months to complete, which means that the foregone use value is also substantial. This assessment is consistent with Montgomery and Kunreuther (2018), which finds that property elevation in general is rarely cost effective.

Market Insurance. My data on insurance responses are at the community level, making distance to an SFHA border ill-defined. Therefore, I leverage the staggered adoption of the disclosure policy across states to study its impact on insurance take up in a triple difference framework. The differences are over time, treatment group assignments, and between communities with high versus low exposure to SFHA areas (measured by the fraction of total area covered by an SFHA).

In Table 4.2 column (1), I show the disclosure policy reduces the probability of having at least one flood insurance policy in high-risk communities relative to low-risk communities by just 0.001 percentage points (or 0.1 percent from the baseline of 0.83).²⁸ Column (2) indicates the intensive margin effect of the disclosure policy on the number of insurance policies per housing unit is also small at -0.9 percent. Given the tight standard errors and small point estimates, homebuyers do not seem to respond to the disclosure policy in a meaningful way through the purchase of flood insurance.

²⁷In Appendix Figure C.7, I conduct a more formal test by taking the difference of the diff-in-disc terms for the treated and placebo states by estimating an augmented version of equation (1): $Y_{bmst} = \delta_0 + \delta_1 X_{bms} + \delta_2 D_{bms} + \delta_3 X_{bms} * D_{bms} + T_{st}[\delta_4 + \delta_5 X_{bms} + \delta_6 D_{bms} + \delta_7 X_{bms} * D_{bms}] + H_s[\delta_8 + \delta_9 X_{bms} + \delta_{10} D_{bms} + \delta_{11} X_{bms} * D_{bms}] + T_{st}[\delta_{12} + \delta_{13} X_{bms} + \delta_{14} D_{bms} + \delta_{15} X_{bms} * D_{bms}] + \epsilon_{bmst}$. Here δ_{14} is the coefficient of interest. The estimates suggest that the effect size (in magnitude) is even larger when we consider the trends in the placebo states.

²⁸While columns (1) and (2) report coefficients of the High Risk \times Disclosure \times Post term only, I include a full set of interaction terms for estimation.

Table 4.2: Effect of Discosure Requirement on Flood Insurance Take-Up

	Prob. of Any Insurance	Log Insurance Per Housing Unit
	(1)	(2)
High SFHA \times Disclosure \times Post	−.001 (.006)	−.009 (.008)
Avg D.V.	0.826	
Year \times Stack FE	X	X
Community \times Stack FE	X	X
Num. obs.	439822	363476

Note: This table is produced from equation (2) using community-level National Flood Insurance Program data. Spatial-HAC standard errors that allow spatial correlation of up to 500 miles are estimated for inference. * $p < 0.1$; ** $p < 0.05$; *** $p < 0.01$.

Why do homebuyers engage in self-protection despite the option to buy flood insurance? One possibility is that the benefit of flood insurance could be small. For instance, the NFIP offers incomplete insurance with coverage capped at \$250,000. Further, a flood could negatively affect an individual’s health or employment status and disrupt daily life, all of which are not covered by flood insurance (Kahn 2005, Deryugina 2017, Lee et al. 2023). Moreover, the cost of location adjustment is substantially lower for many homebuyers—especially in comparison to non-moving households. Indeed, Zumpano et al. (2003) documents that homebuyers actively search across alternatives, and an average buyer physically visits 17 properties before closing.

Findings in this section collectively indicate that households primarily respond to the risk information by selecting a safer location. If instead, the primary response is purchasing more flood insurance (and thus muting self-protection measures), the disclosure policy would have a limited impact on damage reduction.

5 The Effect of the Disclosure Requirement on Flood Damage

5.1 Estimation Framework

For a flood of a given size, how does flood damage change after the disclosure requirement? To answer this question, I estimate a damage function, which is a mapping between flood size and damage, and show how the functional relationship changes due to the policy. Damage functions have been widely used in the economics literature to understand the relationship between heat and economic

outcomes.²⁹ Surprisingly, there has been limited attention directed towards damage functions specific to floods, despite the substantial disruptions they cause. This is partly because objective measurement of flood size is difficult. I overcome this challenge by constructing a hydrology-based flood history dataset described in detail in Appendix A.1.

$$\text{Per Housing Unit Damage} = \sum_k [\alpha_1^k F^k + \alpha_2^k F^k D] \quad (3)$$

Before delving into the specifics of the estimation procedure, it is beneficial to conceptualize the damage function. Consider equation (3), where the dependent variable is flood damage per housing unit, D is an indicator variable for the treated group assignment and F^k is an indicator variable equal to 1 when the annual maximum flood size is in flood size bin k where $k \in \{2-10, 10-20, 20-30, 30-40, 40-50\}$. k is in units of the level of the flood event in years (e.g., $k = 40 - 50$ means the flood size is of the magnitude that would be expected every 40–50 years).

I take a non-parametric approach following Barreca et al. (2016) to let the data, rather than the functional form assumption, determine the shape of the function. In my models, flood sizes between 1–2 serve as the baseline omitted category. Thus, α_1^k indicates the additional flood damage per housing unit when a community in the control group experiences a flood of size k as opposed to a flood size between 1–2. α_2^k allows a different slope for the treated group for flood size k .

There are three points to discuss regarding F^k . First, I use the annual maximum flood size as a proxy for flood exposure for a given community-year. While this means smaller floods in the same community and year are ignored, this is unlikely to be a practical concern because the majority of the community-years in the dataset had just one flood (see Appendix Figure A.3 (c)). Moreover, after restricting attention to floods of size over 10 or larger, which cause disproportionately large damage, over 90 percent of community-years have only one incident (Appendix Figure A.3 (d)).

Second, I focus on flood sizes between 1 and 50 because larger floods are frequently accompanied by interrelated perils, which cause substantial measurement errors (Kron et al. 2012). Further, as shown in Appendix Figure A.3 (b), the frequency of flood events reduces exponentially as flood size increases, making it difficult to non-parametrically identify statistical relationships for very large floods. Flood sizes 2–50 cover a wide enough band to capture floods of different severity. Indeed,

²⁹For a review, see Dell et al. (2014), Carleton and Hsiang (2016), and Auffhammer (2018).

Appendix Table A.2 shows that the threshold for flood sizes 10 and 50 are closely matched to the threshold for moderate and major floods defined by the National Weather Service.

Lastly, the assumption behind binning is that the damage per housing unit is identical within each k . While flood sizes of 41 and 49, for example, might have a different effect in reality, I choose a bin size of 10 to strike a balance between flexibility and precision (Barreca et al. 2016).

Equation (4), which mirrors a canonical difference-in-differences model, shows how equation (3) changes when the post disclosure indicator I is introduced. The coefficient for the interaction term (β_4^k) captures the treatment effect.

$$\text{Per Housing Unit Damage} = \sum_k [\beta_1^k F^k + \beta_2^k F^k I + \beta_3^k F^k D + \beta_4^k F^k ID] \quad (4)$$

For estimation, I use equation (5). Y_{mtd} is either an indicator variable for positive flood damage in community m (extensive margin), or $\log(\text{Per Housing Unit Damage})$ conditional on having positive damage for community m (intensive margin), in year t for data stack d . I also includes year \times stack (ω_{td}) and community \times stack (θ_{md}) fixed effects, to control for overall time trend and unobserved community characteristics. Similar to Section 4.2, I exploit the timing of the disclosure requirement for identification and thus not-yet-treated states form the control group. Also, equation (5) is a stacked difference-in-differences model (i.e., ignoring differences in treatment intensity), a choice made for tractability.³⁰ I use 20 years of observation for each state around the disclosure policy change year. Throughout the analysis, I use spatial-HAC standard errors that allow spatial correlation of up to 500 miles (Newey and West 1987, Conley 1999).³¹

$$Y_{mtd} = \sum_k [\beta_1^k F_{mtd}^k + \beta_2^k F_{mtd}^k I_{mtd} + \beta_3^k F_{mtd}^k D_{mtd} + \beta_4^k F_{mtd}^k I_{mtd} D_{mtd}] + \theta_{md} + \omega_{td} + \epsilon_{mtd} \quad (5)$$

Before proceeding further, it is worth discussing the difference between the damage function of this paper and “depth-damage functions” from earlier engineering studies. As its name suggests, the measure of flood size in these engineering studies is the water depth for an individual property (Meyer et al. 2013). While useful for predicting property-level flood damage, this approach has two

³⁰I exploit the differences in treatment intensity by estimating heterogeneous treatment effects.

³¹Weights in this matrix are uniform up to that cutoff distance. Further, similar to Section 4, when the variance-covariance matrix is not positive-semidefinite, I use eigendecomposition and convert any negative eigenvalue(s) to zero following Cameron et al. (2011).

limitations for estimating aggregate flood damage. First, by focusing on an individual property, it does not directly take into account that a larger flood increases the number of affected properties. A detailed hydraulic study can overcome this issue, but most communities either lack access to them or are reliant on outdated versions because of cost issues (FEMA 2005, Bakkensen and Ma 2020, Weill 2021). Second, and more importantly, it typically lacks the capability to account for adaptations at the property level, which is likely to cause bias in the estimated damage function.³²

I take a “reduced-form” approach to overcome these issues. By directly relating flood size, which is measured at the community level using water gauge records, to community-level flood damage, my approach can be applied even in areas without up-to-date hydraulic studies. Moreover, the community level damage metric factors in the number of properties damaged and embeds the impact of any pre-existing adaptation measures.

5.2 Findings

In Figure 5.1, I plot the damage functions for the (a) control and (b) treatment groups using the estimated coefficients from equation (5).³³ For instance, $\hat{\beta}_1^k$ and $\hat{\beta}_1^k + \hat{\beta}_3^k$ for each k are used to plot the pre-treatment period damage functions (red solid line). Because the dependent variable in the Figure 5.1 is the probability of any damage, the estimated coefficients indicate the additional probability of damage when the baseline flood ($k=1-2$) is replaced by a flood of size k .

Figure 5.1 allows visual inspection of the validity of the estimated damage function. To begin, I first focus on the slope of this function, which reveals a monotonically increasing relationship between flood size and the probability of any flood damage. In subsequent panels (c)–(f), I test heterogeneity in the damage function for further assessment. That is, even when faced with floods of the same size (as defined by community-specific recurrence intervals, which, heuristically, can be considered as deviations from local averages), communities with higher risk should exhibit higher levels of damage.³⁴ Indeed, I find that high risk communities in panels (c)–(d) (an above-median fraction of the area covered by an SFHA) have much higher vertical levels and steeper slopes in comparison to

³²In theory, this issue can be addressed by (1) modeling how various defensive measures such as property elevation or the use of waterproof building materials impact damage, and (2) collecting property level data on these defensive measures. However, this approach is impractical due to limitations in modeling techniques and data availability.

³³Appendix Figure C.8 reproduces Figure 5.1 with a 95 percent confidence interval.

³⁴To illustrate this, consider two communities, A and B with starkly different risk profiles: A is entirely situated within the SFHA while B lies outside the SFHA. In the event of a 100-year flood, the entire property in A would be expected to be underwater (by the definition of SFHA), whereas B would remain unaffected.

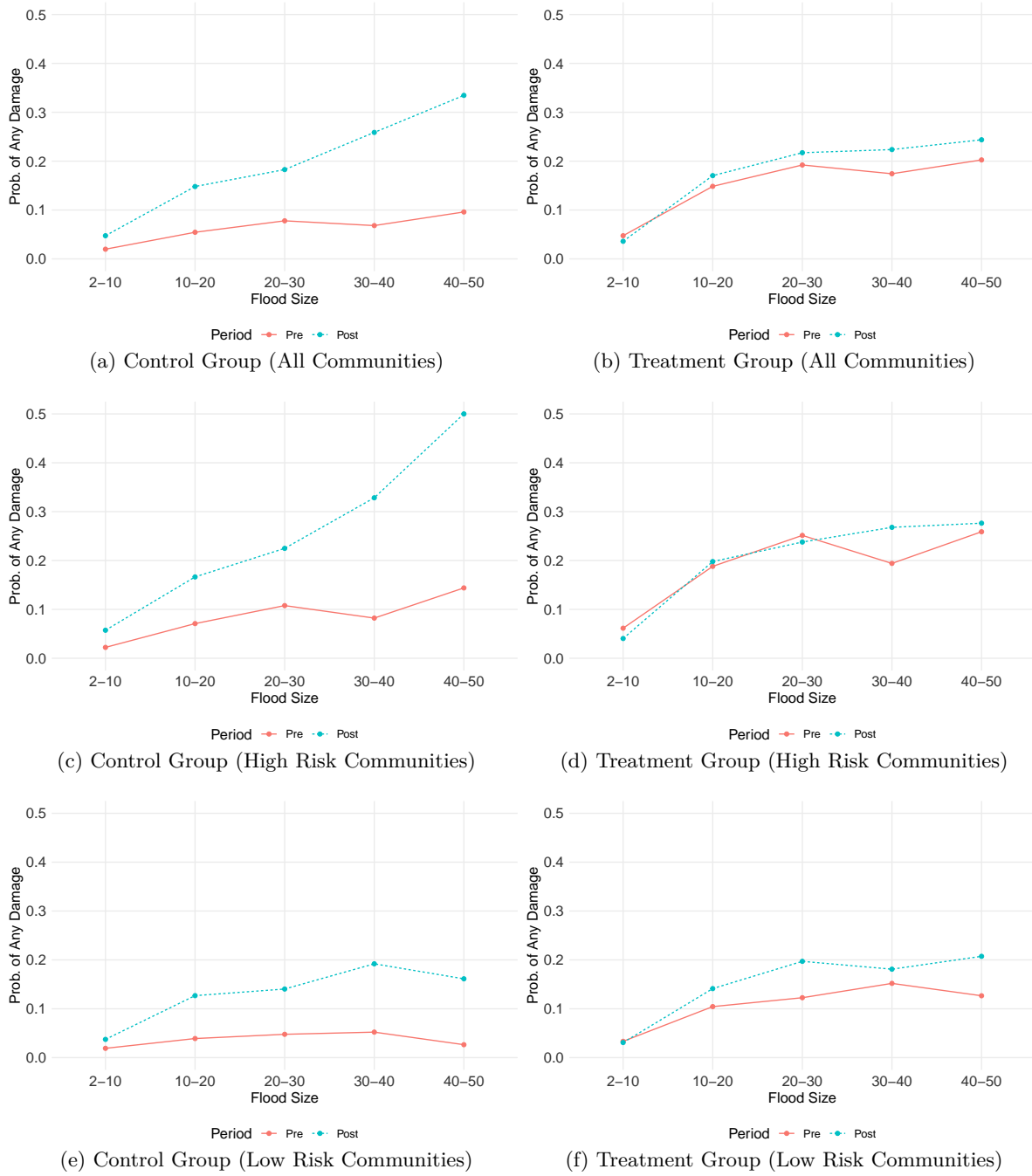


Figure 5.1: The Effect of Disclosure on the Damage Function. These plots illustrate estimated damage functions (dep.var: probability of any damage) from equation (5). Panels (a)–(b) are damage functions for all communities. Panels (c)–(d) and (e)–(f) illustrate the damage functions for high (above–median SFHA ratio) and low (below–median SFHA ratio) flood risk communities, respectively. Appendix Figure C.8 reproduces Figure 5.1 with 95% confidence intervals.

the low risk communities ((e)–(f)).

Table 5.1 highlights the impact of the disclosure requirement on flood damage. For brevity, I only report $\hat{\beta}_4^k$ from equation (5), but the full sets of coefficients are in Appendix Table C.5. In column (1), I report the policy effect using all communities in my sample. The results show that the disclosure requirement reduces the probability of having any flood damage per housing unit by 4–20 percentage points for each k for the communities in the disclosed states relative to the ones in the not-yet-disclosed states.³⁵ The damage reduction effect can be verified visually as well: Figure 5.1 shows that in the control group (panel a), flood probability has substantially increased over time, whereas in the treated group (panel b), post-period damage probability is not much different from the pre disclosure period.

Using equation (6), I summarize the coefficients in Table 5.1 into probability-weighted average treatment effects. Note, because $Pr(K = k)$ is the likelihood of flood occurrence for bin size k each year and β_4^k is reduced probability of having damage, equation (6) can be interpreted as the reduction in annualized loss probability due to the disclosure policy.³⁶

$$\sum_k Pr(K = k) \times \beta_4^k \quad (6)$$

In Table 5.1, I report that the reduction in the annualized loss probability is 2.5 percentage points. When I compare this with the baseline probability of 7.4—average probability of having any damage conditional on exposure to a flood of size 2 or larger—the effect size is a 33 percent reduction.

In columns (2) and (3), I split the sample into communities with above- and below-median fractions of the area covered by an SFHA to investigate the heterogeneous treatment effects. Because the disclosure policy targets properties in an SFHA, the policy effect should be driven by the high-SFHA communities. Indeed, the reduction in the annual loss probability, which summarizes treatment effect for each k , is three times larger for high-SFHA communities than low-SFHA communities (–3.6 vs. –1.3 percentage points).³⁷ Figure 5.2 (a) further splits columns (2) and (3) and presents the change in the annualized probability of having any damage for four groups of communities with differential SFHA ratios, which clearly shows monotonically increasing magnitude in the SFHA ratio.

³⁵For per housing unit damage, I divide community-year level damage using the housing stock in 1990.

³⁶Since the flood size is defined by recurrence interval, the inverse of the size corresponds to $Pr(K = k)$. For instance, the probability of having a flood of size 40–50 in a given year is $\frac{1}{45}$ (45 is the median value of the bin).

³⁷These are 37.5 percent and 23 percent reduction from the respective benchmark probabilities.

Table 5.1: Effect of Disclosure Requirement on Flood Damage

	Prob. of Any Damage Per Housing Unit			Log Damage Per Housing Unit
	(1)	(2)	(3)	(4)
Post \times Disclosure (Size 2-10)	-.039* (.023)	-.056* (.030)	-.021 (.015)	-.063 (.325)
Post \times Disclosure (Size 10-20)	-.072* (.039)	-.086* (.050)	-.051* (.029)	.189 (.189)
Post \times Disclosure (Size 20-30)	-.080*** (.029)	-.131*** (.038)	-.018 (.031)	.170 (.562)
Post \times Disclosure (Size 30-40)	-.141* (.073)	-.172** (.072)	-.111 (.082)	-.360 (.442)
Post \times Disclosure (Size 40-50)	-.197*** (.055)	-.339*** (.061)	-.054 (.068)	-.425 (.540)
Annual Effect	-0.025** (0.01)	-0.036*** (0.012)	-0.013 (0.009)	-0.014 (0.074)
Sample	All	High SFHA	Low SFHA	Damage > 0
Year \times Stack FE	X	X	X	X
Community \times Stack FE	X	X	X	X
Num. obs.	505383	242458	262925	22100

Note: The dependent variable in columns (1) to (3) is the probability of having any flood damage per housing unit. Column (1) is from the entire set of communities while in columns (2) and (3), I repeat (1) using the subsample of communities with different levels of risk exposure. Dependent variables in columns (4) is log transformed per housing unit damage. Spatial-HAC standard errors that allow spatial correlation of up to 500 miles are estimated for inference. * $p < 0.1$; ** $p < 0.05$; *** $p < 0.01$.

Column (4) reports the intensive margin effect, where the dependent variable is the log of damage per housing unit.³⁸ Because the sample for this exercise is restricted to community-years with positive damage, the model is under powered. Still, I find suggestive evidence that the disclosure policy reduces damage for communities with repetitive flood events.

Taken together, Table 5.1 indicates that disclosure curbs flood damage for the treated communities relative to the control communities, a finding consistent with the reduction in flood risk exposure in Section 4.2. To investigate the mechanism further, in Figure 5.3 (a), I plot the average population for census blocks inside and outside of an SFHA—the same blocks used to generate Table 4.1 column (2)— in event time, which is defined as -1 for pre-treatment periods, 0 for post-treatment periods up to 9 years, and 1 for post-treatment period of 10–19 years. The figure illustrates that the relative population of SFHA blocks is decreasing because of an increasing population of non-SFHA blocks (blue dotted lines) rather than a shrinking population of SFHA blocks (red solid lines). Similarly,

³⁸While I report both the extensive and intensive margin effects, an emphasis is given to the former due to greater generalizability—only a small fraction of communities experience repeated damage—and higher statistical power.

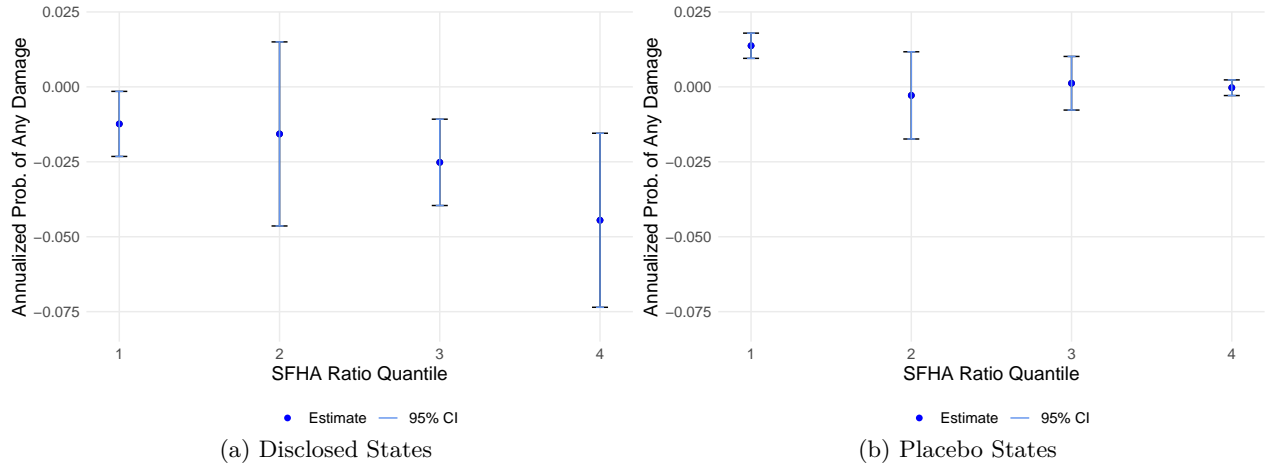


Figure 5.2: Annual Expected Damage Reduction Effect by the Ratio of SFHA. These figures plot the annual expected damage reduction effect from disclosure against SFHA ratios. I estimated equation (5) for communities in different quantile of SFHA ratio, and aggregated coefficients using equation (6).

in panel (b), I find a rapid expansion of housing units in non-SFHA blocks (blue dotted lines) and a stagnation for SFHA blocks (red solid lines). These empirical patterns suggest that the damage reduction effect is driven by diverted in-migration (and resulting suppressed development) rather than active out-migration from SFHA areas.

While the estimated impact of a simple disclosure policy is non-trivial, this number is likely to underestimate the true benefit because the analysis excludes flood sizes over 50, which incur disproportionately large damage. Besides, I abstract away from a potential gain due to a better matching in flood risk preferences between properties and homebuyers (Bakkensen and Ma 2020).

Robustness check. I test the robustness of my findings by conducting a placebo test using the five states (ID, ME, MN, NH, and VA) that had implemented disclosure policies without a question on the flood risk. In Appendix Table C.7, I estimate a version of equation (5) with coarser flood bins based on these five states.³⁹ In columns (1) to (3), the coefficients suggest that disclosure without flood risk information does not reduce the probability of flood damage at all. The estimates are statistically insignificant and economically small, which is consistent with Figure 5.2 (b): the effect is zero for all four groups of communities with varying SFHA exposure.

Before concluding, in Appendix Table C.6 I report how the results in Appendix Table C.5 change

³⁹For statistical power, I group flood events into baseline ($k = 1 - 2$), small ($k = 2 - 30$) and large ($k = 30 - 50$).

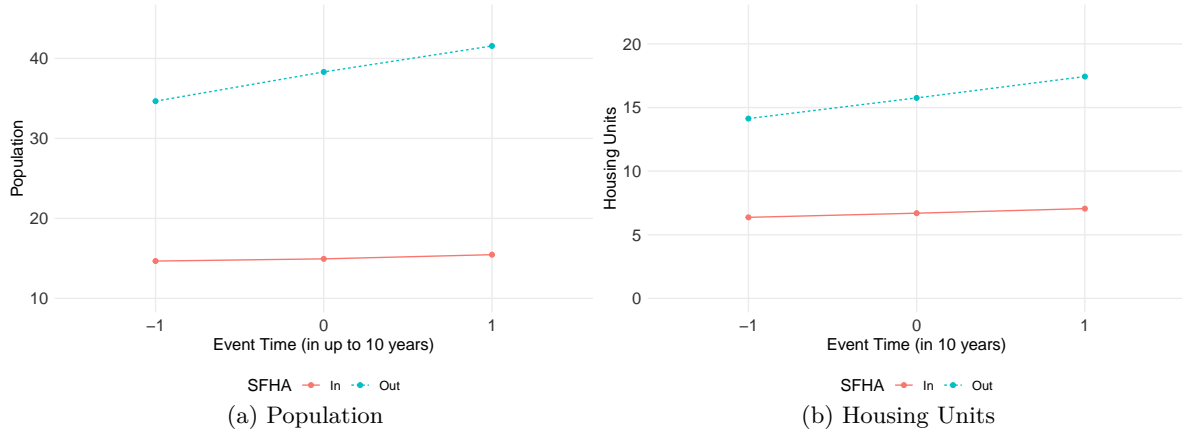


Figure 5.3: Population and Housing Unit Trends in Event Time. These figures plot the (a) average population and (b) number of housing units for SFHA and non-SFHA blocks within the optimal bandwidth in event time. Event time is defined as -1 for pre-treatment periods, 0 for post-treatment periods up to 9 years after the policy change, and 1 for post-treatment period of 10–19 years.

when I add never-treated states to the control group.⁴⁰ A comparison of the two tables produces two observations. First, the shape of the damage functions is identical. For instance, the coefficients for the control group in the pre-treatment period (Flood Size terms) monotonically increase in flood size in both tables. Similarly, the Post \times Flood Size terms are positive and increasing in flood size for both tables. Second, the magnitudes of the interaction terms, which capture the treatment effect, are 20–40 percent as large when the control group includes never-treated states. The attenuated estimates are consistent with a non-trivial number of homebuyers in these non-disclosure states having received some form of information even in the absence of the required disclosure policy, as discussed in Section 2.1. As such, I use not-yet-treated states as a primary control group.

6 Conclusion

Floods are the costliest natural disaster in the US and are expected to become more frequent and severe in the future. Thus, curbing economic loss from these events is of first-order importance. The primary policy prescription in the US to flood risk is engineering-based—i.e., using physical structures and other building-based responses to reduce damage. However, this approach can attract more people to areas with flood risk by distorting location choices.

In this paper, I study whether alleviating information frictions regarding flood risk in the housing

⁴⁰Out of 22 never-treated states, 5 are placebos. For this exercise, I consider placebo states as never-treated states.

market can be an effective way to foster adaptation. I exploit plausibly exogenous variations created by flood-risk disclosure requirements. I explore if and how home buyers respond to required flood-risk disclosure and investigate its implications for flood damage. I find the disclosure requirement reduces the population and increases the vacancy rate in high-risk areas. With fewer people exposed to flood risk, the probability of having any flood damage in an area decreases by 2.5 percentage points (or 33 percent from the baseline probability).

The findings of this paper have important policy implications as disclosure is getting more attention as a flood risk management tool. For instance, FEMA has recently proposed an NFIP reform that conditions a community's flood insurance eligibility on the implementation of a mandatory flood risk disclosure (U.S. Department of Homeland Security 2022). My analysis shows that such a policy can facilitate voluntary adaptation by helping homebuyers make more informed choices.

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A Appendix A: Data Appendix

A.1 Flood History Data

Background

A key input to flood damage function is flood size data. An ideal measure of flood size should satisfy the following four conditions. First, it should be a continuous measure that allows a non-linear relationship between flood size and damage (Burke et al. 2015, Hsiang 2016).

Second, it should be objective. For instance, the widely used EM-DAT measures flood size using economic cost or death tolls, which are directly correlated with outcome variables of interest (Felbermayr and Gröschl 2014). Another example of potentially endogenous measure is the occurrence of the Presidential Disaster Declaration (PDD) floods (Gallagher 2014), which depends on the discretion of the president and thus could reflect political interests (Reeves 2011).

Third, it should be comprehensive. A few existing studies have leveraged meteorological measures to objectively measure disasters, but most of them focus on a subset of events. For instance, Deryugina (2017), Hsiang and Jina (2014), and Strobl (2011) have used physical measures of hurricane intensity while Davenport et al. (2021) leveraged precipitation data. Despite objectivity, such an approach has limits in coverage—for instance, precipitation changes alone can explain only one-third of cumulative flood damages (Davenport et al. 2021).

Lastly, since I measure flood damage at the community by year level, flood size should be measured at the same level. This is not trivial because most climate data are collected to answer physical science questions, and thus are not readily mapped into an administrative unit such as community (Carleton and Hsiang 2016).

To the best of my knowledge, no existing dataset satisfies all of these properties. In this paper, I construct an objective measure of past flood events by applying a hydrologic method to the USGS/NOAA water gauge records. This approach does not distinguish the cause of floods—hurricane, rainfall, snow melt, etc, as long as it is reflected in the water gauge level. Flood size is defined and recorded by a recurrence interval, which represents the expected number of years for a flood of given size to come back, and thus is continuous by construction. Also, by matching gauge stations to a community, I can measure flood size at the community level.

Procedure

Following the USGS guideline (England Jr et al. 2019), I implemented the following steps using USGS/NOAA water levels data from 3,505 gauge stations distributed in the 26 ever-disclosed states in the contiguous US (Appendix Figure A.1).⁴¹

First, I construct a site-specific flood size distribution. For this, I retrieved annual peak flow records using the R package “dataRetrieval” and fit the Log-Pearson III distribution to estimate gauge-specific parameters (Cicco et al. 2018). Importantly, as I use annual peak discharge data to fit the distribution, the quantile of the distribution has an intuitive interpretation. For instance, if a certain water level is the 95th percentile of the distribution, it means that such an event would happen with a 5 percent probability in a given year. Equivalently, such an event is called a 20-year ($\frac{1}{0.05} = 20$) flood. I keep stations with at least 10 or more annual peak observations following the USGS guideline. Also, I use annual peak data until 1990 to fix flood thresholds and make flood size comparable across different years.

Second, I convert daily water level into the recurrence interval using the fitted flood size distri-

⁴¹I randomly sampled 1000 sites in Appendix Figure A.1 for visibility.

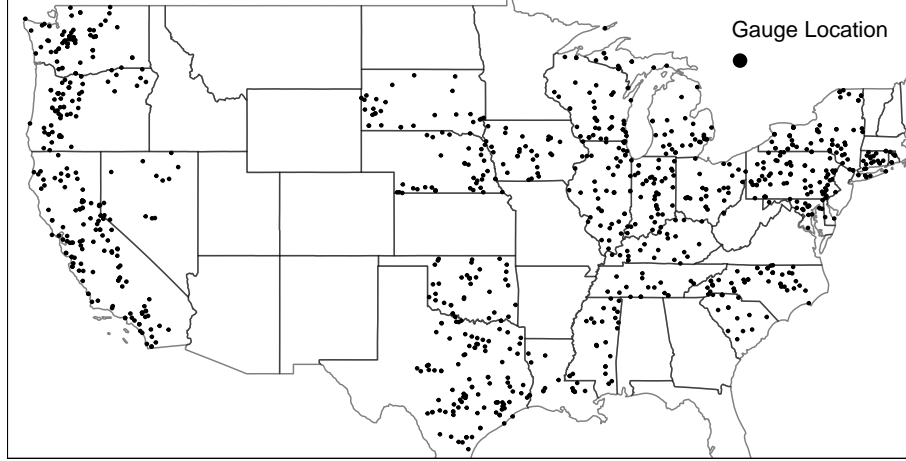


Figure A.1: The Distribution of a Sample of USGS/NOAA Gauges

Table A.1: Number of MDF Stations vs. IPF Stations in Iowa

Name	1989	1990	1991	1992	1993	1994	1995	1996	1997	1998
N Gauges (Mean Daily Flow)	112	112	105	107	109	109	105	109	112	111
N Gauges (Maximum Daily Flow)	3	8	40	72	34	31	29	34	59	95

bution from step 1. For this, I need an instantaneous flow, because flood exposure is determined by the maximum, rather than mean, water level. The problem is that for most of the stations, the maximum daily flow (or more precisely the instantaneous peak flow which enables calculating maximum daily flow) data have too many missing values. This is problematic because, with many missing observations, flood events will be significantly under-recorded. To solve this problem, I estimate a projected instantaneous peak flow from the *mean* daily flow. In Appendix Table A.1, I report the number of water gauge stations in Iowa that have daily water level records for at least 80 percent of the days (i.e., 292 days or more) for a given year. It can be easily seen that there can be an order of magnitude difference in the number of stations that have mean versus maximum daily water records.

To estimate the daily maximum water level from daily mean water level, I use the Fuller method (Fuller 1913). Specifically, for a given geographical unit, I estimate Fuller coefficients by regressing instantaneous peak flow (Q_{it}^{IPF}) for site i in time t on mean daily flow (Q_{it}^{MDF}) and the size of the drainage area (A) as equation (7) (Fuller 1913).⁴² I use three different levels of geographic units, namely state, HUC4, and HUC2 and separately estimate Fuller coefficients.⁴³ Using the estimated coefficients, I calculate projected instantaneous peak flow, and compare that with the actual instantaneous peak flow to pick the geographic unit that minimizes the prediction error.⁴⁴

⁴²I also did conversion following Sangal (1983), but the error between actual and the estimated IPF was much smaller with Fuller (1913).

⁴³A watershed is uniquely identified by a hydrologic unit code (HUC). There are six levels in the hierarchy, and HUC2 (regions) and HUC4 (sub-regions) are two highest levels. There are total of 18 and 202 HUC2s and HUC4s in the contiguous US (Maimone and Adams 2023).

⁴⁴Practically, I apply the following hierarchy between state, HUC4, and HUC2 models: (1) When a site has the best match (meaning that a site has both daily mean flow and instantaneous flow records), I use it. (2) If a site does not have site-specific match (meaning that this site did not have instantaneous flow records), I use prioritized HUC4, HUC2, and State, because HUC4 had the least overall prediction error. I also remove the cases where a site does not have drain area (and thus Fuller coefficients cannot be estimated).

$$Q_{it}^{IPF} = Q_{it}^{MDF}(1 + \alpha A^\beta) \quad (7)$$

Now, by converting the estimated instantaneous peak flow to the quantile of the estimated Log-Pearson III CDF from step 1, I identify each day’s flood size.

Finally, to translate gauge-level flood events to the community-level floods, I match each community to the three nearest gauges based on the distance between a centroid of community and gauge station. Then, I calculate the average flood size for a community using the inverse distance as a weight. Appendix Figure A.2 (b) presents the distribution of the average distance between gauges and community centroid. Over 90 percent of them are within 20 miles with a median distance of 13.5 miles.

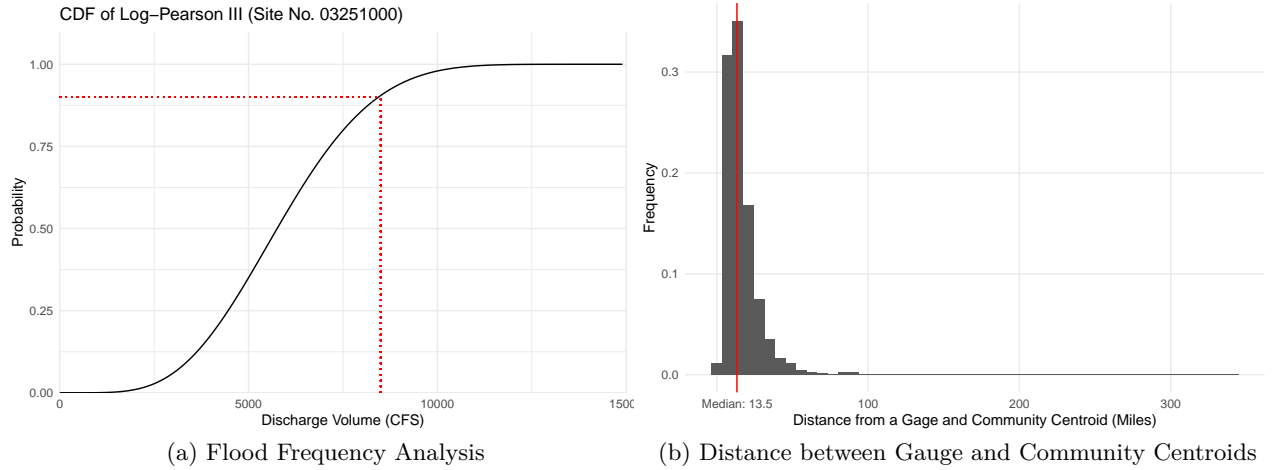


Figure A.2: Flood Frequency Analysis and Gauge Matching. Plot (a) is an example of flood frequency analysis. The black solid line represents the CDF of the fitted Log-Pearson III distribution from the USGS site 03251000. If a daily discharge volume is 8,500 CFS, it corresponds to the 90th quantile or a 10-year flood. Plot (b) presents the distribution of the average distance between a gauge and community centroid. Over 90% of them are within 20 miles with the median distance 13.5 miles.

Appendix Figure A.2 (a) illustrates steps 1 and 2 described above. The black solid line is the fitted Log-Pearson III CDF from the USGS site 03251000. To fit the distribution, I use the annual peak flow data from 1947 to 1990 to calculate the mean, standard deviation, and skewness parameters. Now suppose that on a given date, the daily discharge volume is 8,500 CFS. As it corresponds to the 90th percentile of the CDF, it can be concluded that there was a 10-year flood on that day.

Note, because the USGS gauge stations rarely cover coastal areas, I add 45 additional NOAA sites to the gauge station data. Zervas (2013) documents the flood threshold for the all NOAA sites by fitting GEV distribution, so I adopt them directly. NOAA water level data are retrieved using the R package “Rnoaa” (Edmund et al. 2014).

Unified Flash Flood Database

The Unified Flash Flood Database (Gourley et al. 2013) is USGS-gauge record based dataset constructed following a similar procedure outlined. It is a comprehensive and objective measure of flood events that can present the overall trend of flood events for the contiguous US, which overcomes many limitations of the existing data. However, I decided not to use this database because the data are constructed based on the instantaneous peak flow. As Appendix Table A.1 shows, relying solely

on the instantaneous peak flow can substantially under report flood events due to missing water level records.

Validation and Summary Statistics

To validate the flood history data, I check the number of the average 10-year flood events over a 20-year period for the 8,194 communities. These communities are from the 26 ever-disclosed states that are on the Q3 map. By definition, a 10-year flood happens twice in a 20-year period on average. Figure A.3 (a) shows that most communities had 1 or 2 10-year floods over the 20 years whereas the average number of 10-year floods is 2.18. While this is slightly higher than 2, it is plausible given that I use the annual peak flow data until 1990. Fixing flood threshold is necessary to compare floods across different times (namely, a 10-year flood should have the same magnitude whether it is in 1990 or 2000). Although this approach can be problematic as the period in consideration gets longer, it should not be a major problem for this paper as the longest sample period is 20 years.

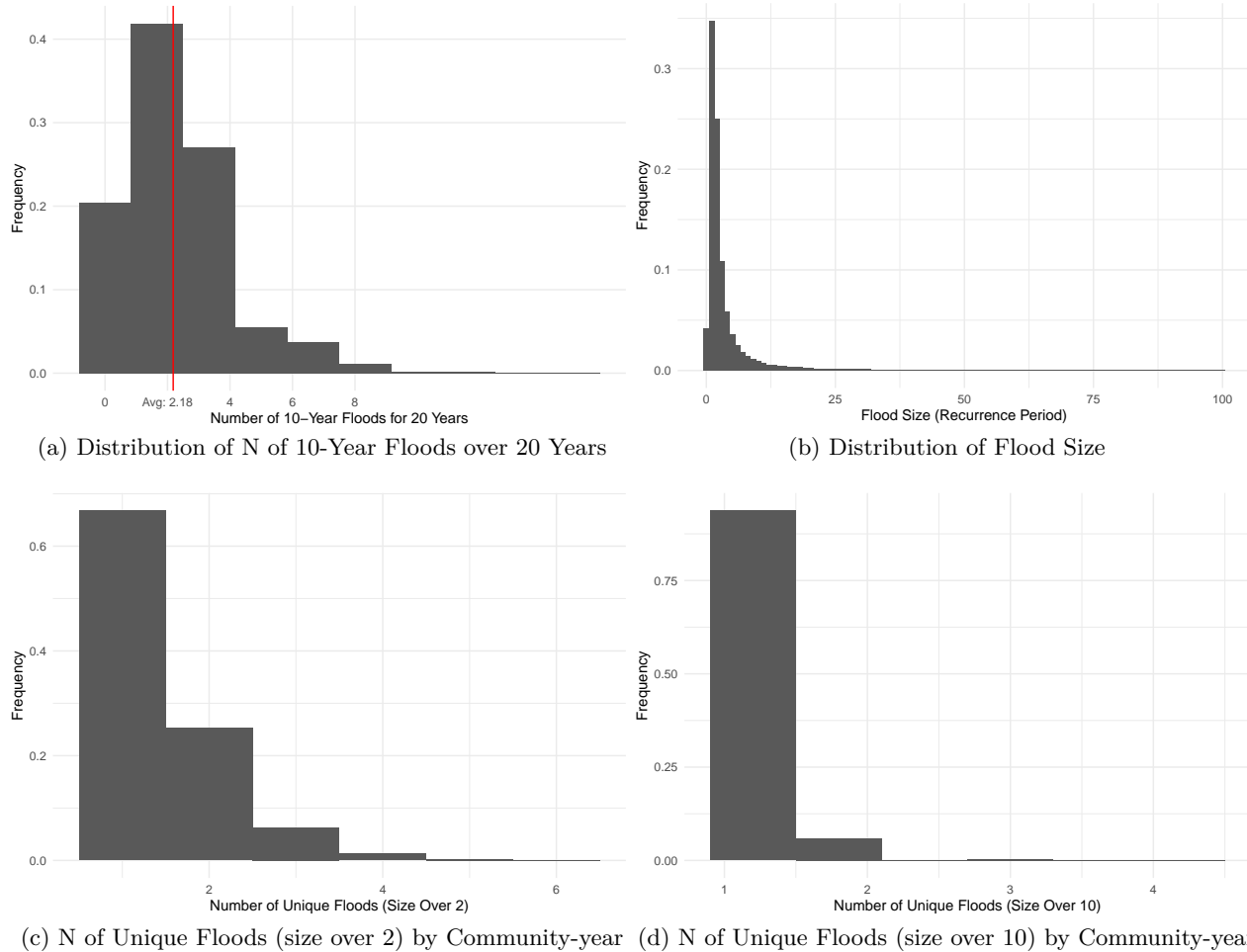


Figure A.3: Flood Data Summary Information. Panel (a) shows that on most communities had 1 or 2 10-year floods over the 20 years and the average number of 10-year flood is 2.18. Panel (b) shows the distribution of flood event size (i.e., recurrence interval), where flood size is truncated at 100 for readability. Panel (c) illustrates the number of unique floods (size over 2) for community-year. Panel (d) repeats panel (c) for floods with size over 10.

Figure A.3 (b) shows the distribution of flood size (i.e., recurrence interval), where flood size is truncated at 100 for readability. As is well documented in the literature, the histogram follows a log-normal distribution, and the frequency decreases as an inverse power function of the flood size (Jackson 2013).

In panel (c), I plot the number of unique flood events for each community-year, conditional on having an event with flood size between 2 and 50. The histogram shows that about 70 percent of the community-years have exactly one event. This alleviates a concern over measuring flood exposure as the maximum flood size for a given year. More importantly, when I limit attention to floods with size over 10, which incurs disproportionately large damage, over 90 percent of the community-year pairs have only one such event.

Table A.2: Comparing the Estimated Flood Size Thresholds with the NWS Threshold

	2 Year Flood	10 Year Flood	50 Year Flood	100 Year Flood
Minor	0.778*** (0.052)	1.285*** (0.071)	1.74*** (0.102)	1.944*** (0.124)
Moderate	0.594*** (0.042)	0.994*** (0.06)	1.36*** (0.085)	1.526*** (0.103)
Major	0.45*** (0.034)	0.771*** (0.043)	1.081*** (0.051)	1.226*** (0.06)

Note:

Note: The entries report the results from 12 separate regressions where each column represents four different dependent variables and each row represents three different regressors. Standard errors are clustered at the gauge level. * $p < 0.1$; ** $p < 0.05$; *** $p < 0.01$.

To better contextualize the recurrence interval based flood size, in Appendix Table A.2, I compare flood size with the gauge-specific NWS thresholds for minor, moderate, and major floods.⁴⁵ Specifically, I estimate equation (8) where Q_{ik} is the estimated flood threshold for site i for flood size k where $k \in \{2, 10, 50, 100\}$. NWS_{ij} is flood thresholds from the NWS for site i for flood severity j where $j \in \{\text{minor, moderate, major}\}$.

$$Q_{ik} = \beta NWS_{ij} + \epsilon_{ijk} \quad (8)$$

β is the coefficient of interest which illustrates how comparable two thresholds are. Namely, the closer β is to 1, the more comparable two thresholds are. For this analysis, I use 2,093 sites that have both recurrence interval based flood size and the NWS flood thresholds. Appendix Table A.2 reports the estimated β for 12 separate regressions and provides useful insights. First, a minor flood from the NWS is comparable to a flood of size between 2 and 10. To see this, observe that when minor threshold increases by 1 unit, a 2-year flood threshold is increasing by only 0.78 units. Conversely, when minor threshold increases by 1 unit, a 10-year flood threshold is increasing by 1.29 units. Second, a 10-year flood threshold is tightly comparable to a moderate flood threshold ($\beta = 0.99$). Similarly, a 50-year flood closely matches with a flood with major impact ($\beta = 1.08$). Note, a 100-year flood threshold is 23 percent higher than a major flood threshold, which is plausible given that a 50-year flood threshold is comparable to the major category.

⁴⁵NWS defines each flood category as the following (National Weather Service 2019). Minor: minimal or no property damage, but possibly some public threat (e.g., inundation of roads). Moderate: some inundation of structures and roads near stream, evacuations of people and/or transfer of property to higher elevations. Major: extensive inundation of structures and roads, significant evacuations of people and/or transfer of property to higher elevations.

A.2 Validation of Key Dependent Variables

Table 3.1 shows that key dependent variables in this paper have prevalence of zeros. These statistics are consistent with findings from external sources.

Block population. Bureau of the Census (1994) reports that a substantial number of blocks have zero population, with state-level proportions ranging from 14 percent (RI) to 65 percent (WY), and a median value of 31 percent (WA). In my sample, the numbers are slightly different at 17 percent for RI and 26 percent for WA (WY is a non-disclosure state). A minor discrepancy is not surprising given that blocks not included in the digitized flood map are excluded from the analysis.

Flood insurance counts. There is no prior work that has documented the fraction of communities with zero insurance policies. However, when I compare the total number of insurance policies by state in my sample with other studies, I find them highly congruent. For instance, in my sample, Louisiana had 504,641 policies as of 2007, a figure closely matching the documented 502,085 flood insurance policies as of December 2007 in Michel-Kerjan and Kousky (2010). Other disclosing states listed in Michel-Kerjan and Kousky (2010) Table 1 are also well matched: CA (258,808 vs. 266,171), NC (123,949 vs. 133,955), NY (141,525 vs. 144,253), SC (190,997 vs 197,334), and TX (508,348 vs. 666,920) where the first number is from my sample and the second number is from Michel-Kerjan and Kousky (2010). Note, for TX, there is a noticeable gap primarily because Harris County is not in my sample (the county is not included in the digitized flood map described in Section 3).

Flood damage. Similar to the flood insurance policy counts, no prior studies have cataloged the fraction of community-years with zero flood damage. However, a back-of-the-envelope calculation suggests that this statistic is in line with existing studies. For that, I take the average probability (1.45 percent) of filing a claim per policy over 1980–2012 from Kousky and Michel-Kerjan (2015) and multiply it with the number of flood insurance policies by the community in my sample. The result reveals that 17 percent of communities are predicted to have more than one claim in a given year (i.e., 83 percent of community-year observations are predicted to have zero claims). Note, while 83 percent is substantially lower than 95 percent as discussed in Section 3, this is a direct consequence of sample restriction: as I discuss in detail in Section 5.1, I remove floods with size 50 or above from my analysis for various economic and statistical reasons. When I undertake the same calculation without imposing these sample restrictions, I find that 86 percent of community-year observations have zero claims, a figure consistent with the 83 percent calculated based on Kousky and Michel-Kerjan (2015).

B Appendix B: Disclosure Requirement and Housing Price

Housing price change to the disclosure policy is of interest in its own right, but it is also a first pass at testing the efficacy of the disclosure policy. That is, by comparing the estimated effect of flood risk information (through the disclosure requirement) to estimates from prior studies, I can indirectly test whether the disclosure requirement was effectively raising homebuyers' flood risk awareness.

For housing prices, I use the Zillow Transaction and Assessment Database (ZTRAX).⁴⁶ It documents transaction dates, sales prices, and housing characteristics such as type (e.g., single house, condominium, etc.), exact longitude and latitude, year built, and the number of bedrooms.⁴⁷

A combination of the different policy implementation timing and the differential treatment of properties located in and out of an SFHA allows me to employ a triple difference design using the stacked DDD approach. I use not-yet-treated states as clean controls and exploit the policy implementation timing among the ever-treated states. Equation (9) estimates the impact of the disclosure policy on the housing price.

$$\log(\text{Price}_{ijmstd}) = \beta T_{ijmstd} + \theta_{mjhl}d + \mu_{jtd} + \lambda_{mtd} + \epsilon_{ijmstd} \quad (9)$$

Price_{ijmstd} is the housing price for a property i with SFHA status j in community m in state s at time t in stack d and T_{ijmstd} is the treatment status dummy, which takes on a value of 1 when $\text{SFHA} = \text{Post} = \text{Disclosure} = 1$ where SFHA is a dummy for the SFHA status, Post is a dummy for the post-disclosure period, and Disclosure is a dummy for the treatment group assignment.⁴⁸ Importantly, Post and Disclosure dummies are defined for each stack.

I also include a complete set of two-way fixed effects μ_{jtd} : $\text{SFHA} \times \text{Time} \times \text{Stack}$, λ_{mtd} : $\text{Community} \times \text{Time} \times \text{Stack}$, and $\theta_{mjhl}d$: $\text{Community} \times \text{SFHA} \times \text{Building Age} \times \text{Number of Beds} \times \text{Stack}$ to estimate β . These fixed effects allow me to estimate the policy effect using the sales price variation before and after the disclosure policy, inside and outside of the SFHA while controlling for the community by SFHA specific property characteristics. Further, these fixed effects are interacted with the stack d , to ensure that comparisons are made within each stack. For building age h , I group construction years into 10-year bins (e.g., 2000-2009, 1990-1999, etc.) and for the number of bedrooms l , I group them into 1-3, 4-6, 7-10, and 10-or-more bedrooms bins. The identification comes from plausibly exogenous disclosure policy change timings after conditioning on the set of fixed effects.

In Table B.1 column (1), I report the estimated coefficients of equation (9) to find that the disclosure requirement reduces the price of the properties in the SFHA by 4.5 percent in comparison to those outside of the SFHA. To put this number in context, I multiply the estimate from column (1) to the average price of properties located in the SFHA in the pre-disclosure period (\$327,171) to produce the estimated reduction in the housing price of \$14,598. Importantly, community by year level potential confounders such as flood exposure or flood insurance premiums are controlled by the community by year fixed effects in this specification. In column (2), I show that the estimate in column (1) is robust to occasional flood map updates, which can coincide with the disclosure policy change. Specifically, I repeat column (1) after removing 6 percent of communities that have experienced a flood map update over the sample period. The estimate in column (2) is essentially identical, suggesting that map updates are uncorrelated with the disclosure policy implementation.

⁴⁶I thank Eyal Frank for his generous help with data access.

⁴⁷I apply the following sample restrictions. First, I drop observations without longitude and latitude information. Second, I keep only single-family houses in the sample, reflecting the fact that the disclosure requirement in many states is applied only to one to four dwelling units. Third, I restricted the transaction price to be between \$10,000 and \$100,000,000 in nominal dollars.

⁴⁸For details on creating data stacks, see Section 4.1.

Table B.1: Effect of Disclosure Requirement on the Housing Prices

	(1)	(2)
SFHA \times Disclosure \times Post	-.045*** (.015)	-.046** (.018)
Sample	Entire Communities	No-Revision Communities
Stack \times Community \times Year FE	X	X
Stack \times Community \times Year FE	X	X
Stack \times Community \times SFHA \times Year Built \times N Beds FE	X	X
Num. obs.	6249070	5931016

Note: Column (1) shows $\hat{\beta}$ from equation (9) from the 26 ever-disclosed states. In column (2), I remove observations from communities that have experienced Flood Insurance Rate Map, or an official flood map, update during the sample period. The dependent variable is log(sales price). All standard errors are clustered at the state level. * $p < 0.1$; ** $p < 0.05$; *** $p < 0.01$.

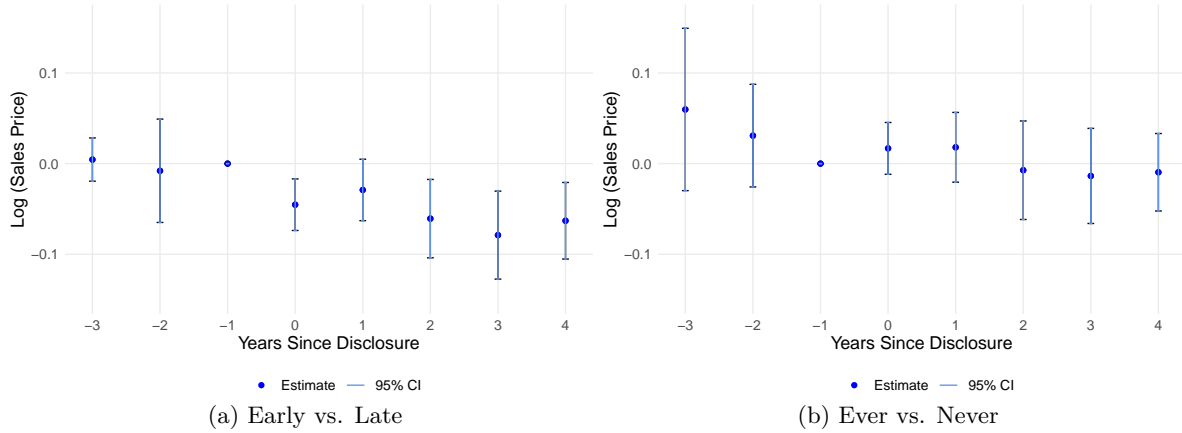


Figure B.1: The Effect of the Disclosure Requirement on Housing Price. These figures plot the coefficients of interaction terms between the SFHA status and disclosure policy dummies in event time. The dependent variable is the log of housing price. Panel (a) uses not-yet-treated states as a control group whereas panel (b) uses never-treated states as a control group. Standard errors are clustered on state.

Figure B.1 (a) presents an event study style graph, measuring the policy effect over event time. $\hat{\beta}_k$ in the pre-disclosure periods are almost zero, satisfying the parallel trend assumption. Since the first year of the policy change, the price of affected properties has fallen by about 4 percent. The effect is persistent up until five years after the policy implementation.

Importantly, this is a notable contrast to the figure in Panel (b), which has included never-treated (namely, states that have not implemented a home seller disclosure requirement on flood risk) states as a control group. In contrast to Panel (a), the plot exhibits a clear pre-trend. Further, the impact of the disclosure policy on the treated properties is substantially attenuated, which is consistent with an earlier discussion that homebuyers in the non-disclosure states are also exposed to information treatment from realtor association-driven disclosure efforts.

Finally, it is worth pointing out that the violation of the SUTVA assumption would not be a major concern in this setting because such an effect is likely to be small. The number of properties inside of the SFHA is equal to or less than 10 percent (average: 4.8 percent) for every state except Louisiana. Thus even if homebuyers sort into the non-SFHA area after the disclosure policy, the effect would not be large enough to change the counterfactual price of the non-SFHA properties. Further, even

if the SUTVA assumption is violated, the estimated housing price change can still show that the disclosure policy is effective and would be a policy relevant parameter because it reflects an actual housing market response to the flood risk information.

C Appendix C: Additional Tables and Figures

Table C.1: Balance Table (Tracts by the SFHA Status)

Variables	No SFHA		With SFHA		Difference	
	Mean	SE	Mean	SE	Mean	t-stat
N Housing Unit	1377	6.31	1408	4.2	32	1.2
N Home Age Below 6	92	1.58	160	1.14	68	4.64
N Home Age Above 42	558	5.09	343	2.44	-216	-3.7
(%) Home Age Below 6	0.078	0.0012	0.1296	9e-04	0.052	4.1
(%) Home Age Above 42	0.3961	0.0028	0.2337	0.0014	-0.162	-3.8

Note:

This table compares the proportion of older and newer housing stocks in census tracts with and without SFHAs. The last two columns show mean differences with t-statistics. Standard errors are clustered at the state level.

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Table C.2: Effect of Discosure Requirement on Household Responses (Placebo States)

	Prob. of Any Population	Log Population	Vacancy Rate
	(1)	(2)	(3)
SFHA \times Post	.004 (.004)	.031 (.062)	.004 (.010)
Avg D.V. (Within BW)	0.602		0.095
Bandwidth	494	406	477
Num. obs.	357459	188304	209918

Note: This table is produced from equation (1). Columns (1)–(3) are estimated using the decennial census block-level data in 1990, 2000, 2010, and 2020. Spatial-HAC standard errors that allow spatial correlation of up to 500 miles are estimated for inference. * $p < 0.1$; ** $p < 0.05$; *** $p < 0.01$.

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Table C.3: Effect of Discosure Requirement on Population and Vacancy Rate (Donut Specification)

	Prob. of Any Population	Log Population	Vacancy Rate	Prob. of Any Population	Log Population	Vacancy Rate
	(1)	(2)	(3)	(4)	(5)	(6)
SFHA \times Post	-.011*** (.003)	-.077** (.035)	.013*** (.005)	-.007* (.003)	-.079** (.038)	.015** (.006)
Avg D.V. (Within BW)	0.691		0.095	0.703		0.094
Doughnut Size	20	20	20	40	40	40
Num. obs.	1209186	1499805	1155519	966183	1343715	1000621

Note: This table is produced from equation (1) after excluding observations closest to the SFHA border. In columns (1)–(3), doughnut sizes are 20 meters and in columns (4)–(6) doughnut sizes are 40 meters. Spatial-HAC standard errors that allow spatial correlation of up to 500 miles are estimated for inference. * $p < 0.1$; ** $p < 0.05$; *** $p < 0.01$.

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Table C.4: Effect of Disclosure Requirement on Demographic Compositions

	Log Median Income	(%) 65+	(%) BA	(%) Black
	(1)	(2)	(3)	(4)
High SFHA \times Disclosure \times Post	-.034*** (.012)	-.770*** (.268)	.512 (.376)	-.004 (.657)
Avg D.V.		12.3	24	14.8
Year FE	X	X	X	X
Tract FE	X	X	X	X
Num. obs.	73702	73702	73702	73702

Note: This table is produced from equation (2) using the decennial census data in 1990 and 2000. Outcome variables and their average values can be found in the table text. Spatial-HAC standard errors that allow spatial correlation of up to 500 miles are estimated for inference. * $p < 0.1$; ** $p < 0.05$; *** $p < 0.01$.

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Table C.5: Effect of Disclosure Requirement on Flood Damage

	Prob. of Any Damage Per Housing Unit			Log Damage Per Housing Unit
	(1)	(2)	(3)	(4)
Flood Size 2-10	.020*** (.007)	.022*** (.008)	.019** (.008)	.223*** (.054)
Flood Size 10-20	.054*** (.012)	.071*** (.016)	.039*** (.010)	1.140*** (.104)
Flood Size 20-30	.078*** (.023)	.108*** (.032)	.048*** (.013)	2.095*** (.419)
Flood Size 30-40	.068*** (.024)	.082*** (.031)	.052* (.027)	1.584*** (.338)
Flood Size 40-50	.096** (.042)	.144*** (.046)	.026 (.040)	1.850*** (.254)
Disclosure \times Size 2-10	.028*** (.009)	.039*** (.015)	.014*** (.005)	.087 (.164)
Disclosure \times Size 10-20	.094*** (.017)	.117*** (.026)	.065*** (.009)	-.003 (.086)
Disclosure \times Size 20-30	.114*** (.018)	.144*** (.028)	.075*** (.017)	-.164 (.138)
Disclosure \times Size 30-40	.106*** (.030)	.112*** (.033)	.100*** (.030)	.077 (.156)
Disclosure \times Size 40-50	.107** (.044)	.115** (.054)	.100*** (.031)	-.048 (.406)
Post \times Size 2-10	.028** (.012)	.035*** (.012)	.018* (.010)	.452** (.184)
Post \times Size 10-20	.094*** (.030)	.096*** (.034)	.088*** (.030)	.086 (.076)
Post \times Size 20-30	.105*** (.028)	.117*** (.032)	.093*** (.032)	-.349 (.326)
Post \times Size 30-40	.191*** (.054)	.246*** (.044)	.140* (.078)	.668* (.361)
Post \times Size 40-50	.239*** (.040)	.356*** (.042)	.135*** (.046)	.629** (.312)
Post \times Disclosure \times Size 2-10	-.039* (.023)	-.056* (.030)	-.021 (.015)	-.063 (.325)
Post \times Disclosure \times Size 10-20	-.072* (.039)	-.086* (.050)	-.051* (.029)	.189 (.189)
Post \times Disclosure \times Size 20-30	-.080*** (.029)	-.131*** (.038)	-.018 (.031)	.170 (.562)
Post \times Disclosure \times Size 30-40	-.141* (.073)	-.172** (.072)	-.111 (.082)	-.360 (.442)
Post \times Disclosure \times Size 40-50	-.197*** (.055)	-.339*** (.061)	-.054 (.068)	-.425 (.540)
Sample	All	High SFHA	Low SFHA	Damage > 0
Year \times Stack FE	X	X	X	X
Community \times Stack FE	X	X	X	X
Num. obs.	505383	242458	262925	22100

Note: This table shows the full sets of coefficients for Table 5.1. * $p < 0.1$; ** $p < 0.05$; *** $p < 0.01$.

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Table C.6: Effect of Disclosure Requirement on Flood Damage (Including Never Disclosed States)

	Prob. of Any Damage Per Housing Unit			Log Damage Per Housing Unit
	(1)	(2)	(3)	(4)
Flood Size 2-10	.026*** (.005)	.035*** (.006)	.019*** (.004)	.146 (.130)
Flood Size 10-20	.091*** (.009)	.116*** (.015)	.064*** (.008)	.531*** (.192)
Flood Size 20-30	.132*** (.012)	.169*** (.015)	.094*** (.017)	.841*** (.296)
Flood Size 30-40	.154*** (.022)	.179*** (.029)	.123*** (.017)	1.394*** (.133)
Flood Size 40-50	.191*** (.022)	.251*** (.027)	.119*** (.019)	1.776*** (.199)
Disclosure \times Size 2-10	.019** (.009)	.022** (.011)	.016*** (.006)	.046 (.200)
Disclosure \times Size 10-20	.058*** (.017)	.066*** (.023)	.049*** (.012)	.534*** (.114)
Disclosure \times Size 20-30	.060*** (.020)	.084*** (.031)	.034** (.015)	.995*** (.241)
Disclosure \times Size 30-40	.028 (.021)	.022 (.023)	.037 (.030)	.271*** (.104)
Disclosure \times Size 40-50	.025 (.022)	.031 (.033)	.015 (.023)	.052 (.328)
Post \times Size 2-10	.020** (.008)	.025*** (.009)	.013* (.007)	.440*** (.131)
Post \times Size 10-20	.062** (.026)	.062** (.027)	.059** (.026)	.563*** (.105)
Post \times Size 20-30	.080** (.037)	.078* (.046)	.082*** (.030)	.593** (.234)
Post \times Size 30-40	.103*** (.038)	.100*** (.034)	.107** (.048)	.373*** (.104)
Post \times Size 40-50	.119** (.047)	.119** (.058)	.117*** (.033)	.374** (.165)
Post \times Disclosure \times Size 2-10	-.016 (.011)	-.022 (.015)	-.009 (.010)	.113 (.158)
Post \times Disclosure \times Size 10-20	-.017 (.020)	-.022 (.032)	-.005 (.020)	-.174* (.101)
Post \times Disclosure \times Size 20-30	-.028 (.030)	-.057 (.038)	.010 (.036)	-.599** (.234)
Post \times Disclosure \times Size 30-40	-.028 (.046)	.008 (.042)	-.055 (.052)	.095 (.240)
Post \times Disclosure \times Size 40-50	-.055 (.040)	-.068 (.050)	-.020 (.050)	-.183 (.260)
Sample	All	High SFHA	Low SFHA	Damage > 0
Year \times Stack FE	X	X	X	X
Community \times Stack FE	X	X	X	X
Num. obs.	1084023	542442	541581	57343

Note: This table repeats Appendix Table C.5 after including 22 non-disclosure states as control group. * $p < 0.1$; ** $p < 0.05$; *** $p < 0.01$.

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Table C.7: Effect of Disclosure Requirement on Flood Damage (Placebo States)

	Prob. of Any Damage		
	(1)	(2)	(3)
Post \times Disclosure (Size 2-30)	.007 (.006)	.003 (.006)	.010 (.008)
Post \times Disclosure (Size 30-50)	.045 (.138)	-.046 (.152)	.175 (.132)
Sample	All	High SFHA	Low SFHA
Year \times Stack FE	X	X	X
Community \times Stack FE	X	X	X
Num. obs.	29626	14864	14762

Note: This table repeats Table 5.1 using the placebo states. The dependent variables in columns (1) to (3) are the probability of having any flood damage per housing unit. Column (1) is based on the entire set of communities while in columns (2) and (3), I repeat (1) using the subsample of communities with an above median SFHA ratio and below median SFHA ratio. Spatial-HAC standard errors that allow spatial correlation of up to 500 miles are estimated for inference for columns (1)–(3). * $p < 0.1$; ** $p < 0.05$; *** $p < 0.01$.

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Illinois REALTORS®
RESIDENTIAL REAL PROPERTY DISCLOSURE REPORT
(765 ILCS 77/35)

NOTICE: THE PURPOSE OF THIS REPORT IS TO PROVIDE PROSPECTIVE BUYERS WITH INFORMATION ABOUT MATERIAL DEFECTS IN THE RESIDENTIAL REAL PROPERTY. THIS REPORT DOES NOT LIMIT THE PARTIES' RIGHT TO CONTRACT FOR THE SALE OF RESIDENTIAL REAL PROPERTY IN "AS IS" CONDITION. UNDER COMMON LAW, SELLERS WHO DISCLOSE MATERIAL DEFECTS MAY BE UNDER A CONTINUING OBLIGATION TO ADVISE THE PROSPECTIVE BUYERS ABOUT THE CONDITION OF THE RESIDENTIAL REAL PROPERTY EVEN AFTER THE REPORT IS DELIVERED TO THE PROSPECTIVE BUYER. COMPLETION OF THIS REPORT BY THE SELLER CREATES LEGAL OBLIGATIONS ON THE SELLER; THEREFORE SELLER MAY WISH TO CONSULT AN ATTORNEY PRIOR TO COMPLETION OF THIS REPORT.

Property Address: _____

City, State & Zip Code: _____

Seller's Name: _____

This Report is a disclosure of certain conditions of the residential real property listed above in compliance with the Residential Real Property Disclosure Act. This information is provided as of _____, 20____, and does not reflect any changes made or occurring after that date or information that becomes known to the seller after that date. The disclosures herein shall not be deemed warranties of any kind by the seller or any person representing any party in this transaction.

In this form, "am aware" means to have actual notice or actual knowledge without any specific investigation or inquiry. In this form, a "material defect" means a condition that would have a substantial adverse effect on the value of the residential real property or that would significantly impair the health or safety of future occupants of the residential real property unless the seller reasonably believes that the condition has been corrected.

The seller discloses the following information with the knowledge that even though the statements herein are not deemed to be warranties, prospective buyers may choose to rely on this information in deciding whether or not and on what terms to purchase the residential real property.

The seller represents that to the best of his or her actual knowledge, the following statements have been accurately noted as "yes" (correct), "no" (incorrect), or "not applicable" to the property being sold. If the seller indicates that the response to any statement, except number 1, is yes or not applicable, the seller shall provide an explanation, in the additional information area of this form.

	YES	NO	N/A	
1.	___	___	___	Seller has occupied the property within the last 12 months. (No explanation is needed.)
2.	___	___	___	I am aware of flooding or recurring leakage problems in the crawl space or basement.
3.	___	___	___	I am aware that the property is located in a flood plain or that I currently have flood hazard insurance on the property.
4.	___	___	___	I am aware of material defects in the basement or foundation (including cracks and bulges).
5.	___	___	___	I am aware of leaks or material defects in the roof, ceilings, or chimney.
6.	___	___	___	I am aware of material defects in the walls, windows, doors, or floors.
7.	___	___	___	I am aware of material defects in the electrical system.
8.	___	___	___	I am aware of material defects in the plumbing system (includes such things as water heater, sump pump, water treatment system, sprinkler system, and swimming pool).
9.	___	___	___	I am aware of material defects in the well or well equipment.
10.	___	___	___	I am aware of unsafe conditions in the drinking water.
11.	___	___	___	I am aware of material defects in the heating, air conditioning, or ventilating systems.
12.	___	___	___	I am aware of material defects in the fireplace or wood burning stove.
13.	___	___	___	I am aware of material defects in the septic, sanitary sewer, or other disposal system.
14.	___	___	___	I am aware of unsafe concentrations of radon on the premises.
15.	___	___	___	I am aware of unsafe concentrations of or unsafe conditions relating to asbestos on the premises.
16.	___	___	___	I am aware of unsafe concentrations of or unsafe conditions relating to lead paint, lead water pipes, lead plumbing pipes or lead in the soil on the premises.
17.	___	___	___	I am aware of mine subsidence, underground pits, settlement, sliding, upheaval, or other earth stability defects on the premises.
18.	___	___	___	I am aware of current infestations of termites or other wood boring insects.
19.	___	___	___	I am aware of a structural defect caused by previous infestations of termites or other wood boring insects.
20.	___	___	___	I am aware of underground fuel storage tanks on the property.
21.	___	___	___	I am aware of boundary or lot line disputes.
22.	___	___	___	I have received notice of violation of local, state or federal laws or regulations relating to this property, which violation has not been corrected.
23.	___	___	___	I am aware that this property has been used for the manufacture of methamphetamine as defined in Section 10 of the Methamphetamine Control and Community Protection Act.

Note: These disclosures are not intended to cover the common elements of a condominium, but only the actual residential real property including limited common elements allocated to the exclusive use thereof that form an integral part of the condominium unit.

Note: These disclosures are intended to reflect the current condition of the premises and do not include previous problems, if any, that the seller reasonably believes have been corrected.

Figure C.1: Example of the Home Seller Disclosure Form (IL)

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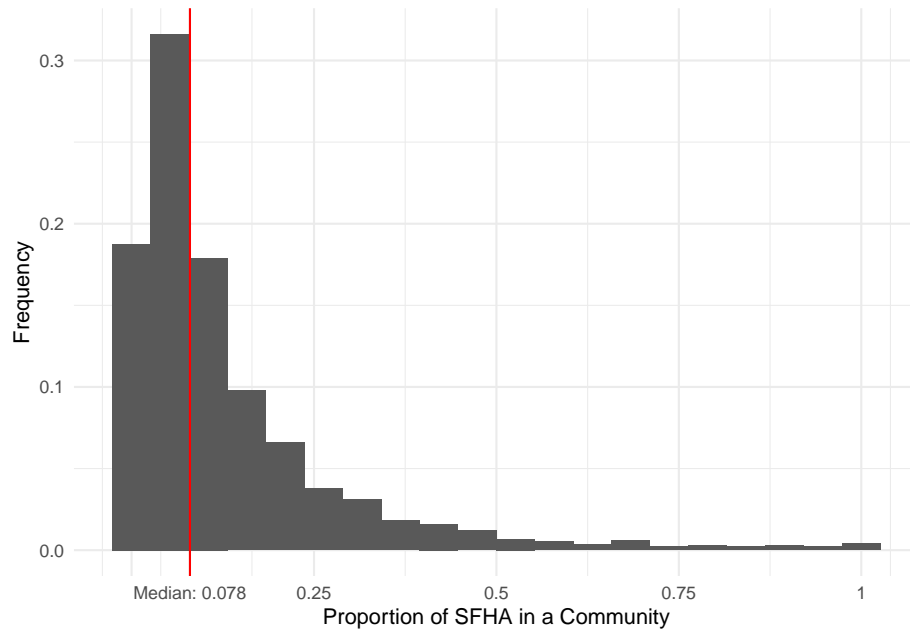
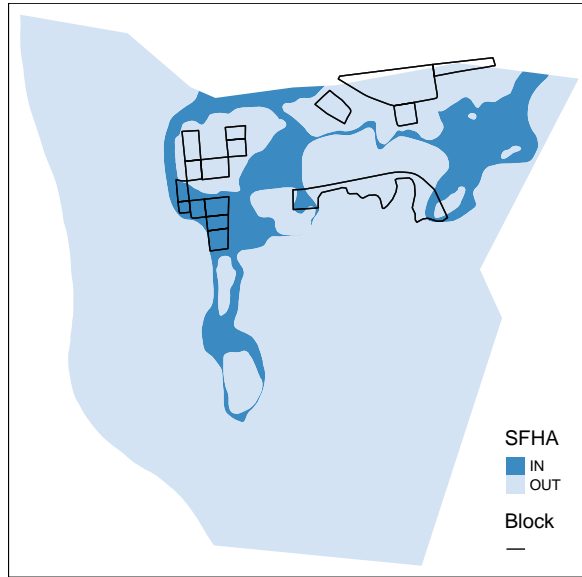
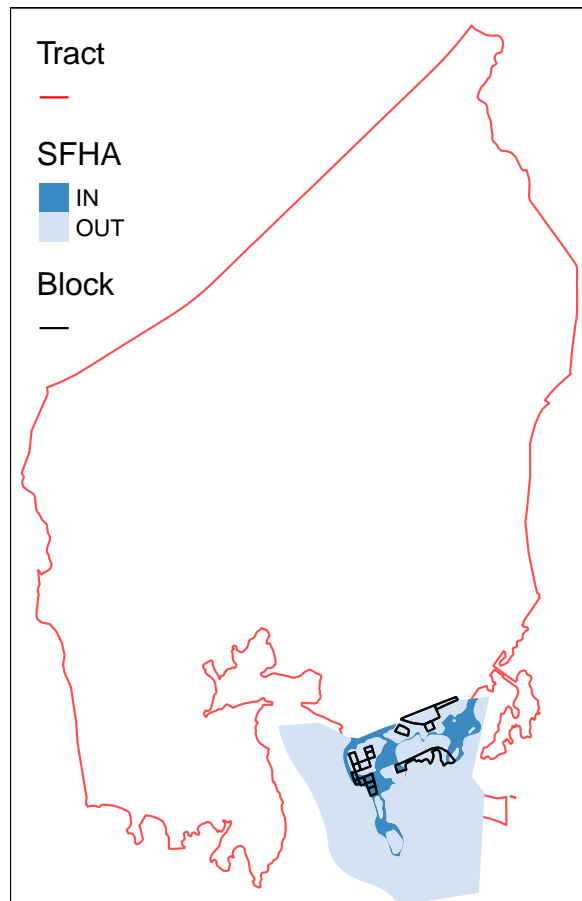


Figure C.3: Histogram of the Proportion of the SFHA at the Community Level. The plot shows the distribution of the SFHA ratio for the 8,194 communities that are on the Q3 map (first generation of digitized flood map) and in the 26 ever-disclosed states.

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(a) Census Block vs. SFHA Status



(b) Census Tract vs. SFHA Status

Figure C.4: Census Geographies and the SFHA Status (Borough of Stonington, CT)

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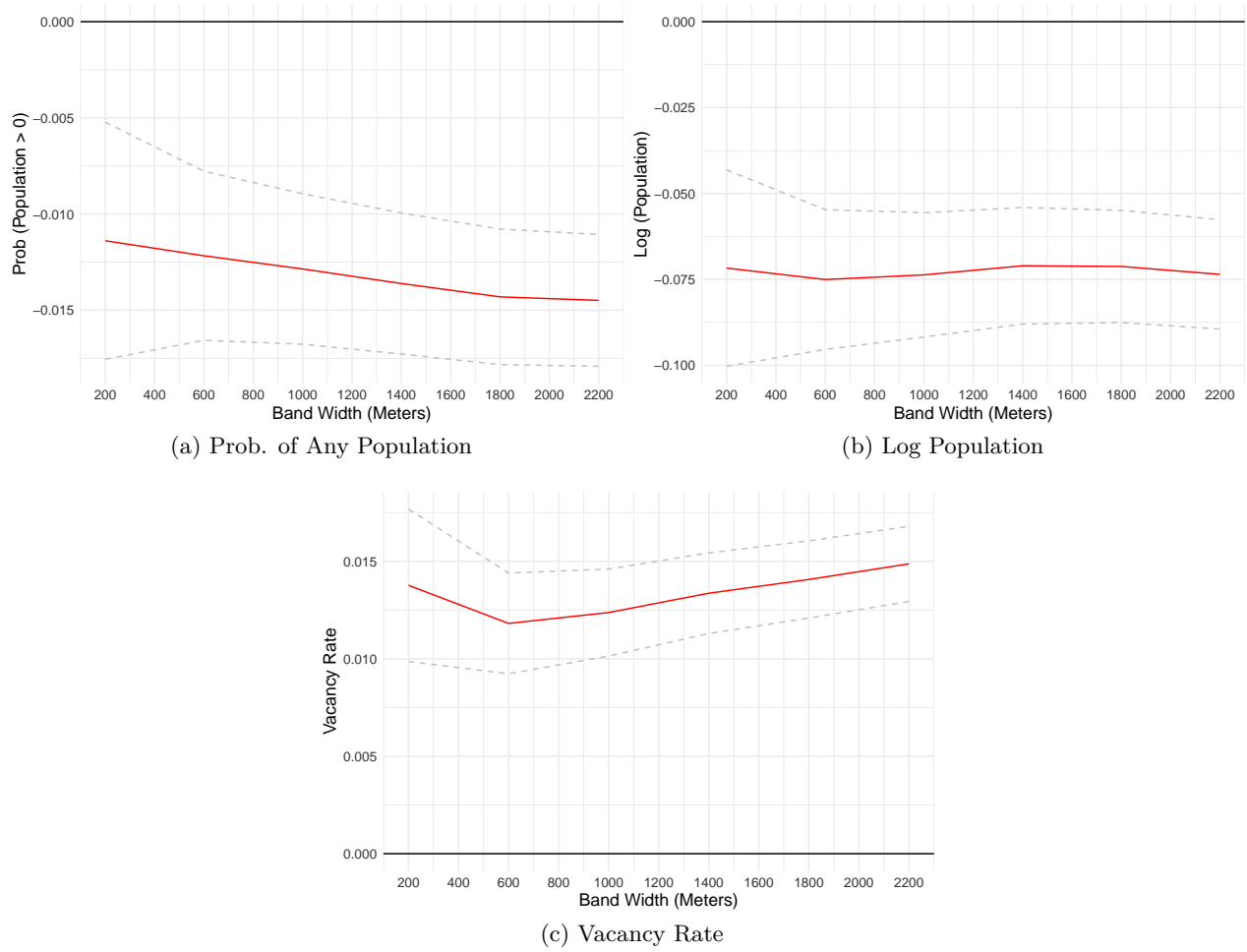


Figure C.5: The Effect of the Disclosure Requirement on Population and Vacancy Rate for Different Bandwidths. These figures plot $\hat{\delta}_6$ from equation (1) for a range of bandwidths. The level of observation is census block, which is the smallest census geographical unit. Spatial-HAC standard errors that allow spatial correlation of up to 500 miles are estimated for inference

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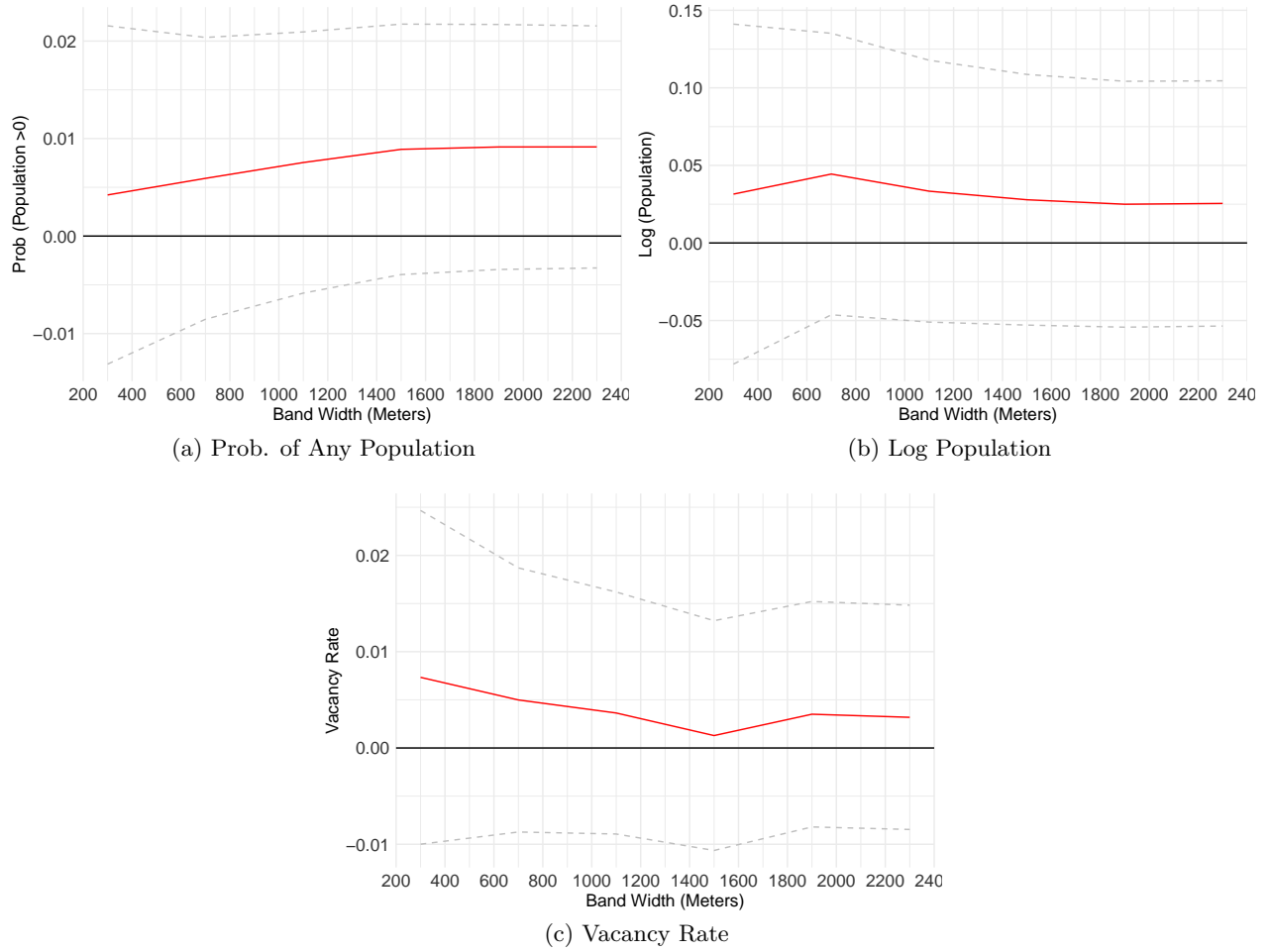


Figure C.6: The Effect of the Disclosure Requirement on Population and Vacancy Rate for Different Bandwidths (Placebo States). These figures plot $\hat{\delta}_6$ from equation (1) for a range of bandwidths for the placebo states. The level of observation is census block, which is the smallest census geographical unit. Spatial-HAC standard errors that allow spatial correlation of up to 500 miles are estimated for inference.

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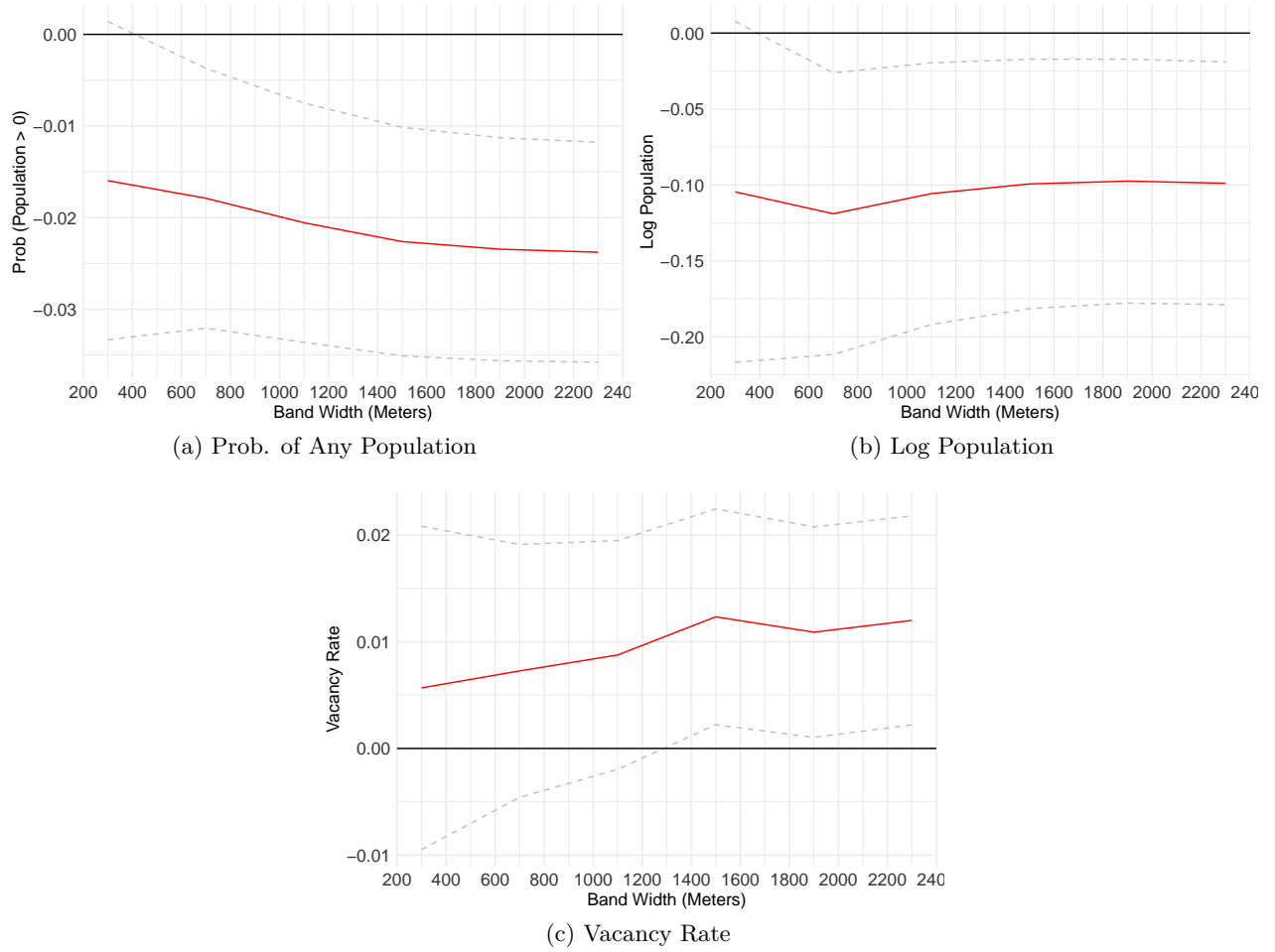


Figure C.7: The Difference in Diff-in-Disc Estimates Between Treated and Placebo States. These figures plot the difference in diff-in-disc estimates between the treated and placebo states for a range of bandwidths. The level of observation is census block, which is the smallest census geographical unit. Spatial-HAC standard errors that allow spatial correlation of up to 500 miles are estimated for inference. See the text for additional details.

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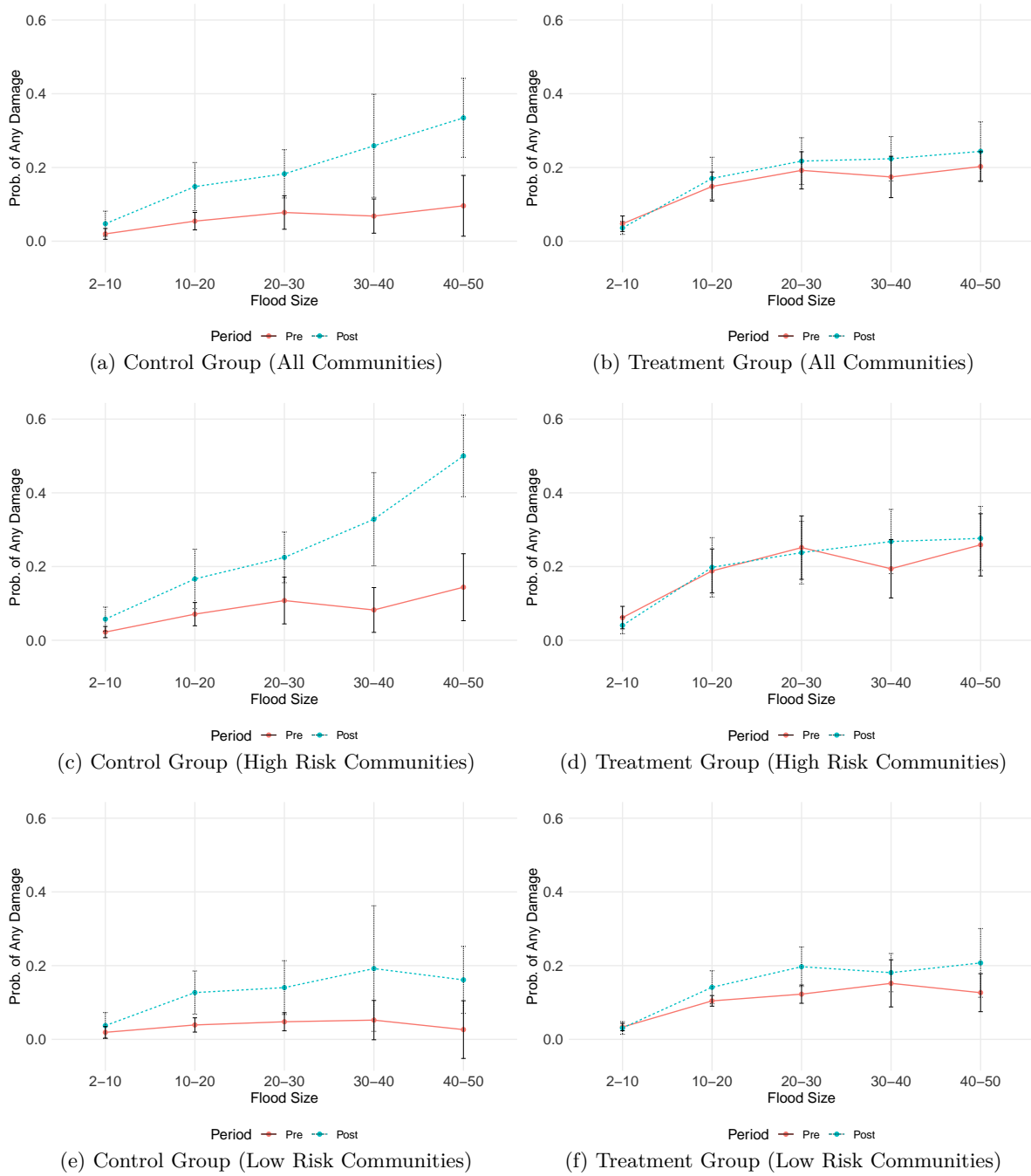


Figure C.8: The Effect of Disclosure on the Damage Function with 95% Confidence Intervals. These plots reproduce Figure 5.1 with corresponding confidence intervals.

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