Climate change, flood risk, and property values: Evidence from New York City

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Abstract

Applying a hedonic difference-in-differences framework to a census of residential property transactions in New York City 2003-2016.5, we estimate the effects of 3 flood risk signals: 1) the Biggert-Waters Flood Insurance Reform Act of 2012, which increased premiums; 2) Hurricane Sandy; and 3) new FEMA floodplain maps. On average each signal decreases sale prices by approximately 5 percent. Properties for which a signal provides more new information exhibit larger effects: for properties not flooded by Sandy but included in the new floodplain, sale prices fall approximately 12 to nearly 23 percent. Informed by a theoretical model, we decompose our reduced-form treatment effects into the costs of insurance premium changes and updating, finding that new maps (an information signal) induce belief changes broadly comparable to those from insurance reform (a price signal). Using Google data, we document increases in flood-related search intensity coincident with flood risk signals.

1 Introduction

Sea-level rise and increased storm intensity due to climate change are increasing flood risk in the United States [Cleetus, 2013]. Integrated assessment models forecast that under warming of 2.5 degrees Celsius, more than half of climate change damages will arise from sea-level rise and catastrophes, including flooding [Nordhaus and Boyer, 2000]. The extent to which such forecasts are realized depends on human behavior. Homeowner decisions about coastal retreat, adaptation (e.g. raising homes), and insurance takeup will all influence realized flood damages. Such decisions depend in turn on homeowner beliefs about flood risk. Understanding such beliefs and how they change is therefore important for policy design. In this paper we study residential property market responses to three flood risk signals: 1) the Biggert-Waters Flood Insurance Reform Act of 2012, which increased flood insurance premiums (prices); 2) Hurricane Sandy (experience);

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and 3) new FEMA floodplain maps (information). Informed by a theoretical model, we use these market responses to study changes in buyer beliefs over flood risk.

These three treatments provide an opportunity to compare the effects of risk signals in an economically important city facing increased flood risk from climate change. Using a census of property transactions from the New York City Department of Finance 2003-2016, we estimate treatment effects in a hedonic difference-in-differences framework. Our identifying assumption is that absent the three treatments, the average sale prices of treated properties would have evolved in parallel with the average sale prices of the properties unaffected by each signal (i.e.- the untreated properties). Graphs of pre-treatment trends in sale prices suggest the common trends assumption is reasonable in each of these settings. The richness of our property transactions data allows us to employ specifications with tax lot fixed effects, which use only repeated sales for identification.

We find the Biggert-Waters Act, which rolled back premium subsidies on many National Flood Insurance Program (NFIP) policies, decreased sale prices of impacted properties between 3 and 6 percent. These estimates reflect higher expected future premiums and belief updating over the uninsured value of the property. Flooding during Sandy decreased home values by nearly 3 to 5 percent, but the estimates are not statistically significant in the more saturated specifications. These estimates reflect unrepaired storm damage and belief updating. We find suggestive evidence of larger effects for properties outside the flood zone, consistent with flooding conveying more new information in such cases. Finally, we find new flood maps decrease the sale prices of properties placed in the floodplain by 7 to 8 percent on average. These estimates reflect expected future premiums and belief updating. The average effect of the map signal masks interesting heterogeneity: sale prices of Sandy-flooded properties do not change, but sale prices of properties not flooded by Sandy fall by 10 to 22 percent coincident with their new floodplain designation. This is consistent with updated maps providing no new information for Sandy-flooded properties.

Our theoretical model extends the framework of Kousky [2010] to include insurance premiums and forecasts. Assuming a risk-neutral marginal buyer and Bernoulli (all or nothing) losses, we can use data on insurance premiums to recover changes in beliefs from our reduced-form treatment effects. We estimate that the Biggert-Waters act increased subjective annual probabilities of catastrophic flooding by 0.48 percentage points among affected policyholders. Corresponding estimates for Sandy and updated FEMA floodplain maps are .14 and .56 percentage points respectively, though among properties that were flooded by Sandy and were not previously in identified floodplains, the estimated increase in subjective annual flood risk is .36. While these changes are small in absolute terms, they are proportionally large relative to the roughly 1 percent annual flood risk estimated by FEMA for these properties.

Flood risk signals can influence sale prices only if the marginal buyer is aware of them. Using Google
Trends data for New York City, we identify local maxima in searches for “floodplain” simultaneous to the risk signals. While this is only a correlation, it is consistent with updated information on flood risk diffusing through the New York property market. The corresponding time series for the United States does not exhibit these local maxima.

Our study contributes to the hedonic literature on climate change, which to date has largely focused on agricultural land [Deschenes and Greenstone, 2007, Schlenker and Roberts, 2009, Ashenfelter and Storchmann, 2010]. It also contributes to the literature on capitalization of flood risk [Bin and Polasky, 2004, Kousky, 2010, Atreya et al., 2013, Bin and Landry, 2013] and the NFIP [Kunreuther and Slovic, 1978, Chivers and Flores, 2002, Michel-Kerjan et al., 2012]. More generally, it speaks to literatures on tail risk perceptions [Botzen et al., 2015] and the relative effectiveness of price and information signals [Ferraro and Price, 2013, Jessoe and Rapson, 2014, Delaney and Jacobson, 2015]. To the best of our knowledge, this is the first study to estimate the effect of flood risk on sale prices in New York City’s large and valuable property market. Today property in the New York City floodplain is valued at $129 billion [Stringer, 2014], and that figure will likely increase as rising seas and stronger storms expand the floodplain. Our paper joins a growing, but still small, group of hedonic studies that exploit repeated sales of the same property for identification [Buck et al., 2014, West and Pilgram, 2016]. Lastly this is, to the best of our knowledge, the first hedonic flood-risk study to recover estimated changes in beliefs.

Our results are consistent with homeowner beliefs lagging actual risk. They suggest information signals may generate updating roughly comparable in magnitude to that from price signals, counter to the priors of some economists. This finding is important for policy design, particularly in an environment where programs involving price signals may face political constraints. With climate change increasing flood risk, the social returns to effective flood-risk policies may be large.

The rest of the paper proceeds as follows. Section 2 provides policy background and detail on the three treatments we study. Section 3 explains our theoretical model. Section 4 describes our data and Section 5 discusses our empirical strategy. Section 6 first presents reduced-form results, then decomposes these estimates into premium changes and updating. Section 7 concludes.

2 Policy background

The following brief description of the National Flood Insurance Program (NFIP) draws on Michel-Kerjan [2010]. Congress created the NFIP in 1968 to provide flood insurance to property owners. The NFIP maps flood risks, sets premiums, and ultimately underwrites policies. The 1973 Flood Disaster Protection Act

1Other important related papers include: Donnelly [1989], Shilling et al. [1989], Macdonald et al. [1990], Kunreuther [1996], Harrison et al. [2001], Hallstrom and Smith [2005], Smith et al. [2006], Morgan [2007], Bin et al. [2008], Pope [2008], Michel-Kerjan and Kousky [2010].
made coverage mandatory for properties that: 1) are located in a “Special Flood Hazard Area,” an area with annual flood risk above 1 percent; and 2) have a mortgage from a federally regulated financial institution. Despite this de jure insurance mandate, noncompliance remains a problem [Tobin and Calfee, 2005]. In 1983 Congress initiated the “Write Your Own” (WYO) program, which allowed private insurers to administer NFIP policies, though the federal government continued to underwrite them. Today nearly all NFIP policies are issued under WYO. Coverage of residential structures is capped at $250,000 per insured property and the cap is the same everywhere.

At inception in 1968, the NFIP offered subsidized rates (rates below actuarially fair levels) on existing homes while charging actuarially fair rates on new structures. This was designed to maintain property values and encourage participation. Purchasers of properties built before creation of the first risk map in their area continued to be eligible for subsidized rates. On average, premiums for subsidized properties are approximately 40 percent of the actuarially fair level [Hayes et al., 2007]. Though premiums often lag behind true risk even for properties that are supposed to face actuarially fair premiums. This is because: 1) NFIP maps are updated infrequently; and 2) “grandfathering,” which allows properties to keep their original risk ratings even when floodplain maps change.

Historically the NFIP maintained fiscal balance. During the 2005 hurricane season, however, damage from Hurricanes Katrina, Rita, and Wilma put NFIP nearly $18 billion in debt. Payouts from Hurricane Sandy pushed NFIP debt to nearly $30 billion [Cleatus, 2013]. Even as its fiscal balance has deteriorated, NFIP has grown rapidly. In the early 1980s there were roughly 2 million NFIP policies. As of July 2016, the NFIP has more than $1.2 trillion under coverage and more than 5 million policies in-force. For more on the history and administrative details of the NFIP, see: Michel-Kerjan [2010], Michel-Kerjan and Kunreuther [2011], Knowles and Kunreuther [2014].

In response to increasingly negative fiscal balance of the NFIP, in 2012 Congress passed the Biggert-Waters Flood Insurance Reform Act. President Obama signed the bill on July 6 and the first provisions of the act took effect on July 10. Beginning January 1, 2013, Biggert-Waters called for subsidized premiums to increase 25 percent per year until reaching actuarially fair levels FEMA [2013]. It also eliminated grandfathering of risk ratings. FEMA received numerous complaints in response to premium increases. In response, Congress passed the Homeowner Flood Insurance Affordability Act (HFIAA) of 2014. The HFIAA lowered the maximum rate of premium increase to 18 percent per year and restored grandfathering for properties continuously covered by the NFIP. Because HFIAA does not change the long-run level of premiums for most properties under Biggert-Waters, we do not expect it to alter sale prices and do not analyze it in this study.

\[\text{2} \text{An additional $100,000 in coverage is permitted for the contents of structures.}\]

Hurricane Sandy is important to both the fiscal balance of the NFIP and capitalization of risk in New York City. The storm hit New York on October 29-30, 2012. While Sandy weakened to a post-tropical cyclone before landfall, it was a very large storm and resulted in a “catastrophic” storm surge. In total the storm caused roughly $50 billion in damage, surpassed among twentieth century US hurricanes only by Katrina in 2005, and led directly to 147 deaths Blake et al. [2013].

At the time Sandy hit New York City, the existing floodplain maps had not changed substantially since 1983. FEMA had, however, begun to create new maps in 2008. The agency issued the first public version of the new maps, the Advisory Base Flood Elevation (ABFE) Maps, on January 28, 2013 [Buckley, 2013]. They came from the agency’s new flood risk models, which reflected roughly 3.5 inches of sea level rise and increased storm activity since 1983. Subsequently released versions of provisional floodplain maps went by different names, but were largely unchanged. FEMA issued Preliminary Work Maps June 10, 2013 and Preliminary Flood Insurance Rate Maps (FIRMs) January 30, 2015. The Preliminary FIRMs represent the agency’s proposed maps for determining risk levels under the NFIP.

New York City appealed the Preliminary FIRMs in June of 2015, arguing the new floodplains were too large [Zarrilli, 2015]. Pending the outcome of the appeal, the NFIP insurance mandate did not apply to properties newly placed in the proposed floodplain. In October of 2016, FEMA publicly agreed with the technical complaints of the appeal and announced that it would work closely with the City of New York to revise the Preliminary FIRMs before they would go in to force. It was also announced that construction permitting decisions in New York City will be based on the Preliminary FIRMs during the revision period, and that maps of predicted future floodplain extents will be produced in addition to the official (current) FIRMs FEMA [2016]. For a timeline of these events, see Table 1.

Since the events of Hurricane Sandy, a number of infrastructure plans have been proposed to provide protection against future flooding. A small number of these proposals have led to feasibility studies and funded projects. However, construction has not begun on any major infrastructure that provides additional flood protection to that present at the time of Hurricane Sandy. While such infrastructure may be expected to impact perceived flood risk, the early stages of such projects in New York City do not yet permit the investigation of such effects. For further discussion of proposed infrastructure to address flood risk in New York City, see Appendix A.

[FEMA’s FIRMs have not been significantly updated since 1983, and the New York City maps are currently being updated by FEMA.” http://www1.nyc.gov/site/floodmaps/index.page. Last visited October 2, 2016.]
3 Model

The following theoretical model clarifies the conditions under which we can infer changes in beliefs from changes in home prices. It is an extension of the model in Kousky [2010], which draws on the foundational work of Rosen [1974] and more directly from Smith [1985] and MacDonald et al. [1987]. We model the property prices as a function of a vector of structural, locational, and environmental characteristics \( Z \), and a property owner’s subjective probability of a flood event, \( p \). The hedonic property price function is defined as: \( H(Z, p) \). Allowing \( Y \) to be homeowner income and \( X \) to be consumption of a numeraire good (with price equal to 1) yields a budget constraint of: \( Y = X + H(Z, p) \) when insurance and flood damage are not taken into account. Defining \( I \) to be flood insurance costs, \( L \) to be anticipated losses from a flood, and \( V \) to be the insurance payout in the case of a flood, yields state-dependent budget constraints defined as:

\[
X_1 = Y - H(Z, p) - I - L + V \\
X_0 = Y - H(Z, p) - I
\] (1)

where \( X_1 \) and \( X_0 \) are consumption levels under the flood and non-flood states of the world respectively.

The expected utility can thus be written simply as:

\[
EU = p * U(X_1, Z) + (1 - p) * U(X_0, Z)
\] (2)

The subjective probability of flood, \( p \), is a function of a property’s official floodplain designation \( F \), flood insurance premiums faced by the property owner \( I \), and experience with past flooding events \( E \). Similarly the anticipated magnitude of losses (conditional on flooding) depends on \( F \), \( I \), and \( E \). Insurance premiums are based only on objective risk levels and thus depend only on the official flood zone, \( F \), and the characteristics of the property, \( Z \). Expected utility can now be rewritten as:

\[
EU = p(F, I, E) * U(Y - H(Z, p(F, I, E)) - I(F) - L(F, I, E) + V(Z), Z) \\
+(1 - p(F, I, E)) * U(Y - H(Z, p(F, I, E)) - I(F), Z)
\] (3)

3.1 Biggert-Waters

The passage of the Biggert-Waters Act served as a shock to insurance premiums, \( I \), because it removed (over time) subsidies that had previously kept premiums artificially low. Maximizing \( EU \) with respect to \( I \) and
subject to the budget constraints allows us to solve for the marginal effect on housing prices of a change in insurance premiums.

\[
\frac{\partial H}{\partial p} \frac{\partial p}{\partial I} = \frac{\frac{\partial p}{\partial I} \cdot [U(X_1) - U(X_0)] - p \cdot \frac{\partial U}{\partial X_1} \cdot \frac{\partial L}{\partial I} - p \cdot \frac{\partial U}{\partial X_1} - (1 - p) \cdot \frac{\partial U}{\partial X_0}}{p \cdot \frac{\partial U}{\partial X_0} + (1 - p) \cdot \frac{\partial U}{\partial X_0}}
\]

(4)

We treat the utility function as effectively linear in the region surrounding the change in consumption captured by a move from \(X_0\) to \(X_1\). Further, a marginal utility of consumption equal to 1 in the relevant consumption region is also assumed. While this implies a risk-neutral marginal buyer, we will consider the implications and importance of risk averse actors later in this investigation. For now, equation 4 simplifies to:

\[
\frac{\partial H}{\partial I} = \frac{\partial p}{\partial I} \cdot (V - L) + p \cdot \frac{\partial L}{\partial I} - 1
\]

(5)

Thus the relationship between home prices and insurance costs works through perceptions of risk, expected magnitude of losses and directly through the cost of future insurance premia.\(^5\)

3.2 Hurricane Sandy

Flooding by Hurricane Sandy changed neither the insurance premiums nor official flood zone designations. Once the costs of flood damages are addressed, any remaining reduction in property values can be attributed to a change in the perceived risk of future floods based on the experience with flooding during Hurricane Sandy. This is characterized functionally as:

\[
\frac{\partial H}{\partial p} \frac{\partial p}{\partial E} = \frac{\frac{\partial p}{\partial E} \cdot [U(X_1) - U(X_0)] - p \cdot \frac{\partial U}{\partial X_1} \cdot \frac{\partial L}{\partial E} - p \cdot \frac{\partial U}{\partial X_1} \cdot (1 - p) \cdot \frac{\partial U}{\partial X_0}}{p \cdot \frac{\partial U}{\partial X_0} + (1 - p) \cdot \frac{\partial U}{\partial X_0}}
\]

(6)

Applying the chain rule and utility function simplifications noted earlier to Equation 6 yields:

\[
\frac{\partial H}{\partial E} = \frac{\partial p}{\partial E} \cdot (V - L) - p \cdot \frac{\partial L}{\partial E}
\]

(7)

Our model does not include a channel by which \(E\) affects property values directly via flood damage; thus, \(Z\) is not treated as a function of \(E\).\(^6\) When it comes to the application of Equation 7, we will take steps to ensure that flood damages are appropriately addressed.

\(^5\)The term on the left hand side, \(\frac{\partial H}{\partial p} \frac{\partial p}{\partial I}\), simplifies to \(\frac{\partial H}{\partial I}\) via the chain rule, as \(p\) is the only channel through which \(I\) impacts the hedonic function.

\(^6\)The relevant analog to Equation 6 which accounts for flood damages is:

\[
\frac{\partial H}{\partial p} \frac{\partial p}{\partial E} + \frac{\partial H}{\partial Z} \frac{\partial Z}{\partial E} = \frac{\frac{\partial p}{\partial E} \cdot [U(X_1) - U(X_0)] - p \cdot \frac{\partial U}{\partial X_1} \cdot \frac{\partial L}{\partial E} + \frac{\partial Z}{\partial E} \cdot (1 - p) \cdot \frac{\partial U}{\partial Z} + (1 - p) \cdot \frac{\partial U}{\partial X_0} + \frac{\partial U}{\partial X_1} \cdot \frac{\partial V}{\partial Z} \cdot \frac{\partial Z}{\partial E} - (1 - p) \cdot \frac{\partial U}{\partial X_0} \cdot \frac{\partial Z}{\partial E}}{p \cdot \frac{\partial U}{\partial X_0} + (1 - p) \cdot \frac{\partial U}{\partial X_0}}
\]
3.3 Updated Flood Maps

Upon the release of updated floodplain maps, a number of properties had an effective shift in their future flood zone (and thus the officially identified level of flood risk), \( F \). Differentiating Equation 3 with respect to \( F \), setting equal to zero, and solving for \( \frac{\partial H}{\partial F} \) - which is equivalent to \( \frac{\partial H}{\partial p} \frac{\partial p}{\partial F} \) in this model as subjective risk perceptions are the only channel through which the flood zone enters the hedonic price function - yields the following:

\[
\frac{\partial H}{\partial p} \frac{\partial p}{\partial F} = \frac{\frac{\partial p}{\partial F} \left[ U(X_1) - U(X_0) \right] - p \frac{\partial U}{\partial X_1} \frac{\partial L}{\partial F} - p \frac{\partial U}{\partial X_1} \frac{\partial I}{\partial F} - (1 - p) \frac{\partial U}{\partial X_0} \frac{\partial I}{\partial F}}{p \frac{\partial U}{\partial X_1} + (1 - p) \frac{\partial U}{\partial X_0}}
\]

(8)

Reapplying the simplifying assumptions on utility and the left hand side terms, leaves us with:

\[
\frac{\partial H}{\partial F} = \frac{\partial p}{\partial F} (V - L) + p \frac{\partial L}{\partial F} - \frac{\partial I}{\partial F}
\]

(9)

which implies that official flood zone status impacts property values through perceived risk levels, the anticipate magnitude of flood losses, and insurance premiums.

4 Data

Publicly available data on real estate sales in New York City from 2003 to June 2016 are from the New York City Department of Finance.\(^7\) The addresses from this data are geocoded using the Geocoding Services of the New York State GIS Program Office.\(^8\)

Information on official estimates of flood risk comes from the flood risk maps produced by FEMA. We use four different maps. For New York City, the original Flood Insurance Risk Map (FIRM) was produced in 1983 and remained essentially unchanged for 30 years. FEMA began the process of revising these maps in 2008. On 1/28/2013, FEMA released preliminary maps for areas affected by Hurricane Sandy (including New York City) known as Advisory Base Flood Elevation (ABFE) maps. Updates to the ABFEs came in June 2013 (“Preliminary Work Maps”) and on January 30, 2015 (“Preliminary FIRMs”). While the official names differ, each of these 4 maps assigns a flood risk level to each property in New York City, and thus we are able to assign flood risk to each property in our data for each map. These risk measures reported in the updated maps reflect sea-level rise and changes in storm activity since 1983, but they do not reflect climate change forecasts [Buckley, 2013]. Flood inundation during Hurricane Sandy (also provided by FEMA) is also mapped onto each property. For each map, counts of properties in the data which are assigned to each of the four flood risk levels are presented in Table 2.


\(^8\) Information and service available: http://gis.ny.gov/gisdata/inventories/details.cfm?DSID=1278.
In this paper, we say a property is “in the floodplain” if it falls into what FEMA calls a “high-risk zone” (VE or A). Officially estimated annual flood risk for such properties is one percent or greater. We call properties in zones X and X500 “outside the floodplain.” These designations are based on forecasts, not flood histories; of the 47,649 properties in our data that were flooded by Hurricane Sandy, 12,948 were in Zone X and 14,278 were in Zone X500, meaning they were not thought to be in the 100 year floodplain. Of these 27,226 properties that were not considered to be in the floodplain prior to Sandy, but were in fact flooded by Sandy, 5,283 (or about 1/5th) were still not classified as in the floodplain by the ABFE maps released three months later.

Ultimately, “1.2 million real estate transactions are mapped to flood risk zones and are therefore available for use in our analysis. Figure 1 presents transactions in the data by year and borough. Our results to date are based on the subset of properties in New York’s Tax Class 1: “Most residential property of up to three units (family homes and small stores or offices with one or two apartments attached), and most condominiums that are not more than three stories.” We exclude transactions less than $100,000 because they may not be arm's-length (e.g. they may be deals among family members). We exclude transactions greater than $6.75 million, the 99th percentile in our data, to limit the influence of outliers.

Data on web searches for flooding- and flood-insurance-related “search terms” come from Google Trends, which provides monthly data from 2004 to the present. The finest available geographic resolution is a metropolitan area. For a given search term, Google Trends provides a normalized measure of “interest” so that the maximum value achieved in the period equals 100 and all other values are fractions of this maximum level.

Descriptive statistics for our primary estimation samples are in Table 4. The average sale price in the broader sample, in 2010 dollars, is approximately $582,000. Three percent of transactions occur in the old (1983) floodplain and eight percent of transactions occur in the new (post-2013) floodplain. Treated groups are proportionately small but large in absolute terms, allowing reasonably precise estimation. One percent of observations (~3400 transactions) are treated by Biggert-Waters, two percent (~6800 transactions) by Sandy, and two percent by new floodplain maps. Summary statistics for the sample of sales of properties for which more than one sale is observed in the data (referred to as the repeated sales sample) are also presented in Table 4.

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10[https://www.google.com/trends/. “Numbers represent search interest relative to the highest point on the chart for the given region and time. A value of 100 is the peak popularity for the term. A value of 50 means that the term is half as popular. Likewise a score of 0 means the term was less than 1% as popular as the peak.” Last accessed September 15th, 2016.](https://www.google.com/trends/. “Numbers represent search interest relative to the highest point on the chart for the given region and time. A value of 100 is the peak popularity for the term. A value of 50 means that the term is half as popular. Likewise a score of 0 means the term was less than 1% as popular as the peak.” Last accessed September 15th, 2016.)

5 Empirical strategy

We estimate difference-in-differences hedonic models whose theoretical underpinnings derive from Rosen [1974]. Our identifying assumption is common trends: had the treated properties not been treated, their average potential outcome (sale price) would have differed from the average outcome among control properties only by a constant. One can evaluate this assumption indirectly by examining pre-treatment trends. We will do so for each treatment in turn using Figures 3, 4, and 5, which plot time series of residual sale prices, net of block dummies.

- Biggert-Waters: Figure 3 shows that sale prices in the 1983 floodplain moved in parallel with sale prices outside the floodplain until after Biggert-Waters became law on July 6, 2012. Many properties in the 1983 floodplain also flooded during Sandy in late October 2012, so the peak-to-trough drop apparent in the figure reflects both events. This raises an important point of interpretation for our Biggert-Waters estimate. If the effect of Biggert-Waters had not fully realized by the time Sandy struck, then our Biggert-Waters estimate is a lower bound on the true effect and our Sandy estimate is an upper bound on the true effect.

- Sandy: Figure 4 plots three series: 1) properties not flooded by Sandy; 2) properties flooded by Sandy and located in the 1983 floodplain; and 3) properties flooded by Sandy and located outside the 1983 floodplain. Sale prices for flooded properties moved closely in parallel with sale prices for non-flooded properties 2003-2008. There is some divergence 2009-2011, particularly for flooded properties located in the 1983 floodplain, but prices for this group converge to those for non-flooded properties by mid-2012. If group 3 properties would have decreased relative to group 1 prices, even without Sandy, our Sandy estimates for 1983 floodplain properties will be biased downward (upward in magnitude).

- New floodplain maps: Figure 5 also plots three series: 1) properties outside the new floodplain\(^{12}\); 2) properties in the new floodplain and flooded by Sandy; and 3) properties in the new floodplain and not flooded by Sandy. Groups 1 and 2 exhibit common trends throughout the figure. Group 3 shares a trend with Group 1 2003-2010, but diverges upward 2011-2012 before converging to group 1 just before the release of the ABFE maps in January 2013. If group 1 prices would have increased relative to group 3 prices without the new maps, then our new map estimates for properties not flooded by Sandy will be biased upward (downward in magnitude). Note that the sample period concludes prior to the October 2016 FEMA announcement that the Preliminary FIRMs would be revised, so we do not consider that event to have any impact on our analysis. The announcement of the appeal took place

\(^{12}\)The new floodplain is a superset of the old.
in June 2015. To the extent that property market participants anticipated the success of the appeal, its filing may correspond with a reduction of the salience of the updated flood maps. We address this possibility further below, but find that such considerations do not meaningfully impact our results.

While we have pointed out a few areas of concern, the common trends assumption looks broadly reasonable. Conditional on that assumption, our difference-in-differences models will recover causal effects.

In a typical hedonic analysis, property and building attributes are included in the model to control for attributes that impact value and may be correlated with the non-market good of interest, but are not the focus of investigation. Because our data contain few measures of such attributes, we rely instead on large sets of fixed effects. If properties within the cells defined by these fixed effects are sufficiently similar, this approach effectively addresses potential endogeneity from property attributes we do not observe.

\[
\ln(Y_{nblwt}) = \alpha_1 \text{Old}_{-} \text{floodplain}_l + \alpha_2 \text{Old}_{-} \text{floodplain}_l \times \text{Post}_{-} \text{BW}_t \\
+ \beta_1 \text{Sandy}_{-} \text{flooded}_l + \beta_2 \text{Sandy}_{-} \text{flooded}_l \times \text{Post}_{-} \text{Sandy}_t \\
+ \gamma_1 \text{New}_{-} \text{floodplain}_l + \gamma_3 \text{New}_{-} \text{floodplain}_l \times \text{Post}_{-} \text{new}_{-} \text{maps}_t \\
+ \delta_w + \eta_n + \epsilon_{nblwt}
\]  

In equation 10, \(n\) indexes neighborhood, \(b\) block, \(l\) lot, \(w\) year-week, and \(t\) date. For each of the treatments we include two of the standard three difference-in-differences variables: a dummy for time-invariant cross-sectional differences between treatment and control properties and its interaction with a “post” dummy. Because we include a vector of year-week dummies \(\delta_w\) to control flexibly for secular time trends, the post dummies do not enter separately. The parameters of interest are \(\alpha_2\), \(\beta_2\), and \(\gamma_2\). We pool across the map releases discussed in Section 2, as fewer than 100 properties in our estimation sample change status between update releases. To control for unobserved time-invariant differences across properties, we employ neighborhood dummies \(\eta_n\) in our least saturated specifications, then move to block dummies \(\eta_b\) and lot dummies \(\eta_l\). The last approach leaves only within-lot (within-property) variation to identify treatment effects and so omits the perfectly collinear cross-sectional dummies (\(\text{Old}_{-} \text{floodplain}_l\), \(\text{Sandy}_{-} \text{flooded}_l\), and \(\text{New}_{-} \text{floodplain}_l\)).
To investigate heterogeneity in the Sandy and new-map effects, we estimate the following specification.

\[
\ln(Y_{\text{nbwt}}) = \alpha_1 \text{Old}_{\text{floodplain}} + \alpha_2 \text{Old}_{\text{floodplain}} \times \text{Post}_{\text{BW}}
+ \beta_1 \text{Sandy}_{\text{flooded}}
+ \beta_2 \text{Sandy}_{\text{flooded}} \times \text{Post}_{\text{Sandy}} \times \text{Old}_{\text{floodplain}}
+ \beta_3 \text{Sandy}_{\text{flooded}} \times \text{Post}_{\text{Sandy}} \times \text{Not}_{\text{old floodplain}}
+ \beta_4 \text{Sandy}_{\text{flooded}} \times \text{Post}_{\text{Sandy}} \times \text{Old}_{\text{floodplain}} \times \text{Depth}_i
+ \beta_5 \text{Sandy}_{\text{flooded}} \times \text{Post}_{\text{Sandy}} \times \text{Not}_{\text{old floodplain}} \times \text{Depth}_i
+ \gamma_1 \text{New}_{\text{floodplain}}
+ \gamma_2 \text{New}_{\text{floodplain}} \times \text{Post}_{\text{new maps}} \times \text{Sandy}_{\text{flooded}}
+ \gamma_3 \text{New}_{\text{floodplain}} \times \text{Post}_{\text{new maps}} \times \text{Not}_{\text{Sandy}_{\text{flooded}}}
+ \delta_w + \eta_n + \varepsilon_{\text{nbwt}}
\]

Indices and controls are the same as in equation 10. We interact the Sandy treatment with indicators for being in or out of the 1983 (old) floodplain, and with depth of inundation. A given level of inundation plausibly produced the same physical damage, irrespective of whether a property was in the 1983 floodplain. For properties outside the 1983 floodplain, however, a given level of inundation plausibly conveyed more information on future risk and we test that hypothesis. The parameters of interest are \(\beta_2, \beta_3, \beta_4, \) and \(\beta_5\). We interact the new maps treatment with indicators for being flooded or not flooded by Sandy. This allows us to test the hypothesis that inclusion in the 2013 (new) floodplain conveyed more information for properties that were not flooded by Sandy. The parameters of interest are \(\gamma_2\) and \(\gamma_3\).

Equations 10 and 11 are designed to estimate unbiased reduced-form impacts. In Section 6 we discuss the mechanisms behind these estimates and decompose them into effects from insurance premiums and effects from updating of beliefs.

6 Results & discussion

6.1 Reduced-form results

Table 5 presents estimates corresponding to equation 10: the average effects of the three risk signals we study on property sale prices. All specifications include year-week fixed effects. Column 1 employs neighborhood fixed effects. Column 2 moves to block fixed effects applied to the same sample. In column 3 the sample changes to properties for which we observe repeated sales, but the specification again includes block fixed
effects. Finally column 4 adds lot fixed effects, using only repeated sales of the same property to identify
treatment effects. Only one thing–either specification or sample–changes across adjacent columns. Standard
errors are clustered at the Census tract level, allowing for arbitrary covariances of $\varepsilon_{nblwt}$ across properties
and over time within a tract. There are 24,545 clusters in columns 1-2 and 20,749 clusters in columns 3-4.
The average number of observations per cluster is 13.9 in columns 1-2 and 8.8 in columns 3-4.

The estimated effect of the Biggert-Waters Act is relatively stable and statistical significant in the more
tightly controlled specifications. Estimates in columns 2-4 are surround -5 percent and statistically significant
at conventional levels. As mentioned in Section 5, if the effects of Biggert-Waters had not fully realized by
the time Sandy hit in late October 2012, then this estimate represents a lower bound on the magnitude of the
true response. The estimate reflects at least two mechanisms. First, treated properties face a higher stream
of future premiums. Second, those higher premiums may alter the marginal buyer’s beliefs over the risk to
the uninsured value of a property. Recall that NFIP coverage is capped at $250,000, so for many properties
this uninsured value is considerable. The relative importance of these two mechanisms is discussed in Section
6.2. Incumbent property owners suffer welfare losses through both mechanisms: 1) diminished property value
from new information; and 2) loss of premium subsidies. Losses through the first mechanism are social losses,
while losses through the second are offset by gains to taxpayers from the removal of premium subsidies when
insurance is purchased. The net effect on social welfare depends on the distribution of marginal utility of
income among winners and losers.

The estimated effect of Sandy is stable in magnitude at -2.5 to -5.3 percent, but the statistical significance
of the estimate varies across specifications. In column 1 it is significant at the 5 percent level and column 2
at the 1 percent level, but the standard errors grow considerably when the smaller sample is relied upon and
the estimates are not statistically significant for any reasonable test size. The loss of precision may reflect
heterogeneity in inundation, which we explore below. This estimate reflects both any storm damage not
repaired at the time of sale and changes in the marginal buyer’s beliefs as a result of flooding. The welfare
effect of Sandy is unambiguously negative.

The estimated effect of the new floodplain maps is stable in magnitude between -7 to -8.2 percent. In
columns 1-3 it is statistically significant at the 1 percent level, and in column 4 at the 5 percent level. Again
this decrease in precision may reflect heterogeneity, explored below. The estimate reflects both the expected
stream of future premiums–recall that most properties in the floodplain will be required to purchase a NFIP
policy once the new FIRMs become official–and the marginal buyer’s updating over flood risk to the uninsured
value of the property. Again losses from new information are social losses, while losses from the insurance
mandate depend on property owners’ risk aversion (for risk-neutral property owners the insurance mandate
produces no welfare change) and whether their previous decisions not to purchase insurance reflected an
optimization failure.

It is reasonable to believe that these three flood risk signals convey more new information about some properties than others. Insofar as our estimates reflect new information, we can test versions of this hypothesis by comparing treatment effects for different groups of properties. Table 6 presents estimates corresponding to equation 11. The dependent variable, samples, year-week fixed effects, and clustering of standard errors are all identical to those in Table 5. The estimated effect of Biggert-Waters disappears in this specification, likely because the relevant group of properties (i.e.: properties in the old floodplain) is mostly included in the group of properties in the old floodplain that were flooded by Sandy.

This specification interacts the Sandy treatment variable $Sandy\_flooded_t \times Post\_Sandy_t$ with dummies for being in or out of the old (1983) floodplain and a continuous measure of Sandy inundation. That is, we allow the slope and intercept of the Sandy treatment function to depend on whether or not a property was in the old floodplain (which was, and still is, the active, floodplain designation at the time). We interpret the intercepts (“Sandy*in old FP” and “Sandy*not in old FP”) as effects on properties that were flooded by Sandy ($Sandy\_flooded_t = 1$), but for which the level of inundation was near zero. The inundation slopes (“Sandy*in old FP*depth” and “Sandy*not in old FP*depth”) potentially reflect both unrepaired damage and updating of beliefs by the marginal buyer. While the slope and intercept estimates vary between specifications and samples, the slope coefficient for the inundation depth among properties designated as within the floodplain is consistently in the -2 to 3 percent range, and remains statistically significant across models. The intercept coefficient for this group is not significantly different from zero in any specification. Taken together, these estimates suggest that - for properties in the designated 100-year floodplain - reductions in property values were primarily driven by the level of physical damage experienced by the property.

The opposite pattern emerges for properties that were flooded by Sandy but which were not in the officially designated 100-year floodplain. In both columns 2 and 4, the estimates suggest that such properties suffered significant price drops associated with any amount of flooding, while the depth of inundation (proxying for level of physical damage) is smaller in magnitude or insignificant altogether. While the variability in estimates across samples and specifications makes precise interpretation difficult, these results are generally consistent with a model in which flooding provided more information about properties which had not been previously identified as within the 100-year floodplain than about properties previously labeled as within the floodplain.

In a similar spirit, this specification interacts the new map treatment with dummies for being flooded or not during Sandy. Inclusion in the new floodplain plausibly conveys more information about properties that were not flooded by Sandy than about properties that were flooded by Sandy (only 3 months earlier). The estimates are consistent with this hypothesis. In columns 2-4 the estimated effect of new maps on properties
flooded by Sandy is small in magnitude (< 2.5 percent) and not statistically distinguishable from zero in the most saturated specification. The estimated effect of new maps on properties not flooded by Sandy, in contrast, ranges from -12 to -22.6 percent in these specifications with significance at the 1% level maintained throughout.

In the following section we decompose the reduced-form estimates into expected future premiums and updating of beliefs by the marginal buyer.

6.2 Inferring belief updating

Equations 5, 7, and 9 characterize the marginal effects on property values of changes in insurance premiums, flood experience, and official flood zone designation respectively. Values for each of these marginal effects have been empirically estimated in the prior section and are reported in Table 5 or 6. Using the marginal effects equations, these empirical effects can be decomposed as a means of estimating the magnitude of the changes in flood risk perceptions driven by each of our three information signals (\( \frac{\partial p}{\partial I} \), \( \frac{\partial p}{\partial E} \), and \( \frac{\partial p}{\partial F} \) respectively).

The equations above assume some level of insurance coverage (and associated premium costs), but empirically, uptake of flood insurance has been quite low. A study by Rand found that “55 percent of the one-to-four-family homes in” the 1/100 year floodplain “had federal flood insurance on the eve of Hurricane Sandy” (RAND, 2013). Thus, while the valuations of ñ55% of residential property holders (or potential holders) in the floodplain are well-characterized by the presented equations, the valuations of the other 45% will be simpler because an increase in premiums would not be anticipated in response to the passage of the Biggert-Waters Act (and thus \( \frac{\partial I}{\partial F} = 0 \)), and the change in flood zone status due to the release of new flood maps would not have impacted property valuations through increased expected premiums for those that were likely to be non-purchasers of insurance (i.e.: \( \frac{\partial I}{\partial F} = 0 \)). Also, for non-insurance-holders, \( V - L = -L \).

6.2.1 Biggert-Waters

As reported in Column 4 of Table 5, we estimate an average effect of the passage of the Biggert-Waters Act of -6.15% on the sale prices of properties designated as within the 100-year floodplain. We assume that 55% of such properties hold NFIP insurance (and similarly that 55% of expected buyers will plan on holding flood insurance) and rely on a City of New York estimate that 75% of “NFIP policies in effect during Sandy were eligible for” NFIP subsidies (as much of the building stock predated the first published flood maps, and was therefore not subject to the mandate to carry flood insurance NYC, 2013). Since neither insured properties, nor those which received zero subsidy prior to BW12, would be expected to experience a shock

\(^{13}\text{BW12 also included some provisions to increase enforcement of NFIP coverage mandates on federally backed mortgage, but it is not clear that such provisions would significantly change the expected rate of uptake.}\)
to insurance premiums following the passage of BW12, we introduce the following adaption of Equation 5:

$$\frac{\partial H}{\partial I} = 0.55 \times \left[ 0.75 \times \left( \frac{\partial p}{\partial I} \times (V - L) + p \times \frac{\partial L}{\partial I} - 1 \right) + 0.25 \times (0) \right] + 0.45 \times 0.$$ 

As noted by Kousky [2010], we cannot separately identify the effects of changes in the perceived likelihood of a flood event from the effects attributable to changes in the level of anticipated damages associated with the occurrence of such an event. We therefore allow information to impact subjective probabilities while assuming that anticipated losses, conditional on a flood occurring, are fixed at the value of the property. Thus, $\frac{\partial L}{\partial I} = 0$ and $V - L$ is both the expected losses from a flood event and the total value of the property which is not covered by flood insurance.

Prior to the passage of the Biggert-Waters Act, the mean sale price of properties in the 100-year floodplain - i.e.: those impacted by the changes of the Biggert-Waters Act - was approximately $492K. As of 2012, NFIP policies in New York City covered an average of $231k in damages [FEMA, 2012], so we assume that $V - L$, the uninsured, flood losses anticipated for the average affected (and insured) property in the sample is $231K-$492K=$261K. Based on the lot fixed-effects specification, we estimated: $\frac{\partial H}{\partial I} = -6.15\%$, or a reduction of $30,258 due to the premium increase under the Biggert-Waters Act. Using a 2.6 percent discount rate (following Giglio et al., 2016), this is equivalent to an $787 loss to the expected annual flow of hedonic value, thus $\frac{\partial H}{\partial I} = -$787.

Rather than a 1 unit change in insurance premiums, we are interested in examining a change in premiums reflective of that imposed on the market by the passage of the Biggert-Waters Act, which removed (over time) subsidies for NFIP insurance.\textsuperscript{14} FEMA estimated that on average, subsidized premiums were 60\% of the actuarially fair level (FEMA 2010), so by eliminating these subsidies, Biggert-Waters led to 66\% premium increases. The City of New York estimated that “the average NFIP premium paid on 1- to 4-family residential policies in New York City” was approximately $1000 in 2012 [NYC, 2013]. The increase in annual premiums is thus: $0.66 \times $1000 = $660.

Taken together, we now have:

$$\frac{\partial H}{\partial I} = 0.55 \times 0.75 \times \left[ \frac{\partial p}{\partial I} \times (V - L) + p \times \frac{\partial L}{\partial I} - 1 \right] \Rightarrow$$

$$-787 = 0.55 \times 0.75 \times \left[ \frac{\partial p}{\partial I} \times (-261K) + p \times 0 - 660 \right] \Rightarrow$$

$$\frac{\partial p}{\partial I} = 0.48$$

Thus, we estimate that a 66 percent increase in future flood insurance premiums led to an increase in the

\textsuperscript{14}In addition to the simplifying assumptions already imposed, we are now using derivatives to investigate non-marginal changes in the values of interest. While we believe the resulting estimated marginal effects contain useful information, we are under no illusions that they represent precise structural parameter estimates.
subjective annual flood risk of 0.48 percentage points for properties faced with higher future premiums. If we assume that prices of all properties in the 100-year floodplain were impacted (not only those that carried flood insurance and had subsidized rates), then the estimated impact on subjective annual flood risk is 0.05 percent. If we assume that all purchasers of properties in the 100-year floodplain subsequent to the passage of the Biggert-Waters Act internalized the higher costs of flood insurance, but only for property that were previously eligible for subsidies, then the estimated change in subjective flood probability is 0.15 percent.

### 6.2.2 Hurricane Sandy

The estimated average effect of flooding by Hurricane Sandy on home prices is not significant in our preferred specification (Column 4 of Table 5), suggesting that Hurricane Sandy did not have a discernible impact on the average flooded property’s value. Given that any effect from Sandy flooding could act through physical damage, informational channels, or some combination of the two, these estimates imply that, on average, flood damage from Sandy did not endure or remain unaddressed to the extent that it was capitalized into property values, and that updating of flood risk perceptions in response to Sandy flooding did not lead to significant changes in property values on average.

As was shown previously however, the information effects of experiencing a flood event are heterogeneous depending on the priors regarding flood risk for a property. We therefore anticipate larger effects on price through the information channel for properties that were flooded by Hurricane Sandy but which had not been previously identified as lying within the 100-year floodplain than among those properties situated within designated floodplains at the time of flooding. The estimates in Table 6 suggest this is the case in New York City following Hurricane Sandy as both the intercept and slope terms contribute significantly to the Sandy effect for properties not in the floodplain, while only the depth of inundation is significant in determining damages among properties designated as within the floodplain.

We therefore seek to characterize the information effects of Sandy among properties outside the officially designated 100-year floodplain at the time of flooding. Average inundation depth among such properties was 2.22ft (versus 4.69ft for properties within the designated floodplain), thus the average effect of Sandy flooding on the values of non-floodplain properties is estimated to be $-7.45\% + 2.22\%(-0.23\%) = 7.96\%$. (if we instead use estimates from column 2 the average total effect is: $-4.20\% + 2.22\%(-1.68\%) = 7.93\%$). The average property price in the areas flooded by Sandy but outside the 100-year floodplain prior to Hurricane Sandy was approximately $540K$, so the change in annual hedonic flow from such properties is $\frac{\partial H}{\partial E} = -0.0796 * 540K * 0.026 = -$1118. We again assume expected losses are fixed and thus $\frac{\partial L}{\partial E} = 0$, and rely on $V - L = $231K $- 540K = -$309K. This yields:
\[
\frac{\partial H}{\partial E} = \frac{\partial p}{\partial E} \cdot (V - L) - p \cdot \frac{\partial L}{\partial E} \Rightarrow \\
-1118 = \frac{\partial p}{\partial E} \cdot (-309K) - 0 \Rightarrow \\
\frac{\partial p}{\partial E} = 0.36
\]

which is the estimated change in the subjective flood risk for a property that was not in the officially designated floodplain, but was inundated by 2.22 ft of water during the Hurricane Sandy surge tide. Following a similar procedure based on the (insignificant) estimate of the average effect of Sandy on all flooded properties (from column 4 of Table 5) leads to an estimated \( \frac{\partial p}{\partial E} = 0.14 \).

### 6.2.3 Updated Flood Maps

While the estimates in the last two rows of Table 6 suggest that the FIRM updates most dramatically impacted properties that had not been recently flooded by Sandy (as assignment of such properties to the floodplain was truly new information), we will focus our investigation of the informational impacts on property values across all properties designated as within the 100-year floodplain by the updated flood maps. The mean pre-treatment sale prices of such properties was $524k. Again pulling from column 4 of Table 5 yields:

\[
\frac{\partial H}{\partial F} = -0.0721 \cdot 524K \cdot 0.026 = -982. V - L = 231k - 524K = 293k.
\]

The expected change in insurance premiums associated with an assignment to the 100-year floodplain depends on each property’s previous designation status. In September 2012, $250,000 of building coverage within a Standard-Rated Policy Zone was 72.6% more for properties in the 100-year floodplain than for those outside of it [FEMA, 2012], meaning that a new 100-year floodplain designation would cost an additional $421 in annual insurance premiums (for a property that ended up paying the average $1000/year premium) while an unchanged floodplain status would impose no new costs. Of the 25,654 properties in the larger analytical sample that are designated as within the 100-year floodplain by the updated flood maps, ~15,000 are newly designated while ~11,000 were within the old floodplain designations. Thus the average expected change in insurance premiums for properties impacted by the updated flood maps would be 15,000/25,654 * $421 = $246. We again maintain a fixed level of expected damages such that \( \frac{\partial L}{\partial F} = 0 \).

Returning to Equation 9, and taking into account that a change in floodplain status is only relevant for the 55% of buyers who will purchase insurance, yields:
\[ \frac{\partial H}{\partial F} = 0.55 \left[ \frac{\partial p}{\partial F} \right] (V - L) + p \frac{\partial L}{\partial F} - \frac{\partial I}{\partial F} \right] + 0.45 \cdot [0] \Rightarrow \]

\[ -982 = 0.55 \left[ \frac{\partial p}{\partial F} \right] (-$293K) + p \cdot 0 - $246 \Rightarrow (14) \]

\[ \frac{\partial p}{\partial F} = 0.53 \]

We therefore find that the magnitudes of the price signal, information signal, and experience signal for those properties for which flooding conveyed novel information are quite similar. Given that that annual flood risks \( \geq 1\% \) are classified as high flood risks, the estimated changes in perceived risk levels of 0.3\% to 0.5\% are quite large.

### 6.3 Corroborating evidence from Google Trends

Risk signals can produce the sale price effects estimated above only if the marginal buyer receives them, i.e. if the marginal buyer obtains information about Biggert-Waters, Sandy flooding, and new map releases. We provide preliminary evidence in support of this hypothesis using data from Google Trends. Figure 6 plots Google searches for “floodplain” in New York City, residualized on month of year dummy variables 2004-2016. We limit the horizontal range of the plot in order to focus on the period in which the risk signals occurred. The global maximum of the series occurs in January 2013, the month in which the first updated FEMA maps, known as the ABFE maps, were released. This is consistent with the marginal prospective buyer of a property newly placed in the floodplain learning about the maps around this time. We do not observe the locations or identities of those searching for “floodplain,” however, so the correlation is merely suggestive; it does not provide evidence of a causal relationship. Later releases of the preliminary work maps (June 2013) and preliminary FIRMs (January 2015) do not produce discernible effects on the time series. This is consistent with later releases, which left the ABFE floodplain largely unchanged, conveying little new information to the marginal buyer. There is a large local maximum associated with Hurricane Sandy and a small one associated with the Biggert-Waters act, again consistent with transmission of information to the marginal buyer but merely suggestive. Search activity continues to rise during the period between Biggert-Waters and Sandy.

Analyzing one time series raises concerns about omitted confounders. To test for such confounders, in Figure 7 we plot a similar time series of Google searches for “floodplain,” again residualized on month of year dummies, for the entire United States. Of the flood risk signals we examine, only Biggert-Waters was national in scope. Therefore ex ante we expect to see no effect of the ABFE maps (or other map releases) on national searches for “floodplain.” Hurricane Sandy might have increased such searches at the national
level, given that it affected a reasonably large fraction of the US population directly and news coverage of the storm might have made flood risk more salient, even outside directly affected areas. Figure 7 shows no evidence of local maxima associated with any of the flood risk signals we study. This suggests that the maxima observed in Figure 6 do not arise from nationwide time-varying confounders. As in Figure 6, search activity increases between Biggert-Waters and Sandy. Together Figures 3, 6, and 7 suggest that knowledge of Biggert-Waters may have diffused more slowly than the other signals we study.

7 Conclusion

This study examines the effect of three different flood risk signals on sale prices in New York City. It finds the Biggert-Waters Act decreased sale prices by 3 to 6 percent, Sandy flooding decreased home values by 3 to 5 percent, and inclusion in the floodplain by new FEMA maps decreased sale prices by 7 to 8 percent. The effect of the new maps on properties flooded by Sandy is zero, while the effect on properties not flooded by Sandy is estimated between -12 and -23 percent. This is consistent with the hypothesis that updated maps provide no new information for properties previously flooded by Sandy.

Using insights from a theoretical model, we decompose the estimated effects into changes in expected future premiums and updating. We find that all three flood risk signals produce changes in beliefs of roughly similar magnitudes among the groups for whom the signals are informative. This is somewhat surprising, given the qualitatively different signals. In all cases the changes in beliefs are proportionally large, ranging from 36 to 53 percent of FEMA’s roughly 1 percent estimated annual risk for properties in the floodplain.

We also analyze flood-related Google search activity and find local maxima at the times of the flood risk signals studied in this paper. While this does not imply a causal relationship, it is consistent with our hypothesis that diffusion of flood risk information affects the sale prices of New York properties.

The welfare consequences of these price effects warrant additional future study. While Biggert-Waters and the new maps may be welfare-neutral at the social level, they plausibly produce large welfare losses among incumbent property owners. At the time of Biggert-Waters, New York City had roughly $59 billion in property in the old (1983) floodplain. Applying our estimated loss of approximately 6 percent to all floodplain property suggests incumbent property owners lost approximately $3.5 billion from premium reform. These concentrated losses may be one of the reasons why New York City, which has invested large sums in infrastructure and planning for climate change impacts, challenged the expansion of the floodplain proposed in FEMA’s updated flood maps. Understanding the distribution of such welfare changes, and their political consequences, is broadly important to policy design around sea-level rise and flood risk from climate change.
References


Cara Buckley. Twice as Many Structures in FEMA’s Redrawn Flood Zone, jan 2013.


Stefano Giglio, Matteo Maggiori, Johannes Stroebel, and Andreas Weber. Climate change and long-run discount rates: evidence from real estate. 2016.


8 Figures

Figure 1: Sales by Year and Borough

Transaction data are from the New York City Department of Finance 2003-2016. Figure includes properties from all tax classes.
Notes: Maps depict Coney Island in south Brooklyn (Kings County). Floodplain and inundation maps are from FEMA. Black dots represent properties for which sales are observed in the transaction data from the New York City Department of Finance 2003-2016. Floodplain and inundation maps are from FEMA. The 100-year floodplain consists of flood zones A and V. Zone “Shaded X” is the 500-year floodplain, and zone X is not considered to be within a floodplain as the annual flood risk is deemed to be less than 0.2%.
Transaction data are from the New York City Department of Finance 2003-2016. Floodplain and inundation maps are from FEMA. Sample is restricted to properties in tax class 1 with a sale price from $100,000 to $6.75mn (99th percentile) in 2010 dollars. The dependent variable is log property value, residualized on block fixed effects. "Not in old floodplain" denotes properties not in the 1983 floodplain. "In floodplain" denotes properties in the 1983 floodplain.
Figure 4: Effect of Sandy

Transaction data are from the New York City Department of Finance 2003-2016. Floodplain and inundation maps are from FEMA. Sample is restricted to properties in tax class 1 with a sale price from $100,000 to $6.75mn (99th percentile) in 2010 dollars. The dependent variable is log property value, residualized on block fixed effects. "Not flooded" denotes properties not flooded by Sandy. "Flooded, in old floodplain" denotes properties in the 1983 floodplain (which was in effect when Sandy struck) and flooded by Sandy. "Flooded, not in old floodplain" denotes properties not in the 1983 floodplain and flooded by Sandy.
Figure 5: Effect of new floodplain maps

Transaction data are from the New York City Department of Finance 2003-2016. Floodplain and inundation maps are from FEMA. Sample is restricted to properties in tax class 1 with a sale price from $100,000 to $6.75mn (99th percentile) in 2010 dollars. The dependent variable is log property value, residualized on block fixed effects. "Not in new FP" denotes properties outside the 2013 floodplain. "In new FP, flooded" denotes properties in the 2013 floodplain that flooded during Sandy. "In new FP, not flooded" denotes properties in the 2013 floodplain that did not flood during Sandy.
Figure 6: Google searches for “floodplain” in New York City

Data from Google Trends for the search term “floodplain” in New York City 2004-2016. Google normalizes these data such that the maximum search volume over the period equals 100. The vertical axis reflects residuals from a regression of the full time series on month-of-year dummies. Dashed vertical lines correspond to flood risk signals.
Data from Google Trends for the search term “floodplain” in the United States 2004-2016. Google normalizes these data such that the maximum search volume over the period equals 100. The vertical axis reflects residuals from a regression of the full time series on month-of-year dummies. Dashed vertical lines correspond to flood risk signals. Only the Biggert-Waters Act was a nationwide signal.
9 Tables

Table 1: Timeline

<table>
<thead>
<tr>
<th>Event</th>
<th>Date</th>
</tr>
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<tbody>
<tr>
<td>Biggert-Waters Act</td>
<td>July 6, 2012</td>
</tr>
<tr>
<td>Hurricane Sandy</td>
<td>October 29-30, 2012</td>
</tr>
<tr>
<td>ABFE Map Release</td>
<td>January 28, 2013</td>
</tr>
<tr>
<td>Preliminary Work Maps</td>
<td>June 10, 2013</td>
</tr>
<tr>
<td>Homeowner Flood Insurance Affordability Act</td>
<td>March 21, 2014</td>
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<tr>
<td>Preliminary FIRMs</td>
<td>January 30, 2015</td>
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<tr>
<td>NYC Appeals Preliminary FIRMs</td>
<td>June 26, 2015</td>
</tr>
<tr>
<td>FEMA Agrees to further Revise Preliminary FIRMs</td>
<td>October 17, 2016</td>
</tr>
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</table>

Table 2: Properties by flood zone and map, all tax classes

<table>
<thead>
<tr>
<th>Map:</th>
<th>Original FIRM</th>
<th>ABFE</th>
<th>Prelim Work Map</th>
<th>Prelim FIRM</th>
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<tr>
<td>Date:</td>
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<td>1/2013</td>
<td>6/2013</td>
<td>1/2015</td>
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<tr>
<td>VE</td>
<td>222</td>
<td>2,090</td>
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<td>A</td>
<td>22,637</td>
<td>43,603</td>
<td>42,176</td>
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<tr>
<td>X500</td>
<td>24,989</td>
<td>27,646</td>
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<tr>
<td>X</td>
<td>558,054</td>
<td>532,563</td>
<td>533,480</td>
<td>533,356</td>
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Notes: Counts include all 605,902 unique properties which sold between 2003 and June 2016. Subcategorizations have been dropped for simplicity.

Table 3: FEMA flood risk groups

<table>
<thead>
<tr>
<th>Description</th>
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</thead>
<tbody>
<tr>
<td>VE: ≥1% annual flood risk and risk of wave action (also called “velocity hazard”)</td>
</tr>
<tr>
<td>A: Within the 100 year floodplain, ≥1% annual flood risk</td>
</tr>
<tr>
<td>X500: Within 500 year floodplain, but outside 100 year floodplain, ≥0.2% annual flood risk</td>
</tr>
<tr>
<td>X: Area outside the 500 Year floodplain, &lt;0.2% annual flood risk</td>
</tr>
</tbody>
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Notes: Descriptions taken from http://www.mass.gov/anf/docs/itd/services/massgis/q3floodzonescodetable.pdf. Subcategorizations have been dropped for simplicity.
<table>
<thead>
<tr>
<th></th>
<th>Mean</th>
<th>Stdev</th>
<th>Min</th>
<th>Max</th>
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</thead>
<tbody>
<tr>
<td><strong>Sale price (2010USD)</strong></td>
<td>582104.83</td>
<td>443155.15</td>
<td>85565.49</td>
<td>8344867.33</td>
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<tr>
<td>Old floodplain</td>
<td>0.03</td>
<td>0.18</td>
<td>0.00</td>
<td>1.00</td>
</tr>
<tr>
<td>Post Biggert-Waters</td>
<td>0.26</td>
<td>0.44</td>
<td>0.00</td>
<td>1.00</td>
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<tr>
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<td>0.09</td>
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<td>Flooded by Sandy</td>
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<td>0.27</td>
<td>0.00</td>
<td>1.00</td>
</tr>
<tr>
<td>Post Sandy</td>
<td>0.24</td>
<td>0.43</td>
<td>0.00</td>
<td>1.00</td>
</tr>
<tr>
<td>Flooded by Sandy*Post Sandy</td>
<td>0.02</td>
<td>0.14</td>
<td>0.00</td>
<td>1.00</td>
</tr>
<tr>
<td>New floodplain</td>
<td>0.08</td>
<td>0.26</td>
<td>0.00</td>
<td>1.00</td>
</tr>
<tr>
<td>Post ABFE</td>
<td>0.23</td>
<td>0.42</td>
<td>0.00</td>
<td>1.00</td>
</tr>
<tr>
<td>Post prelim. work maps</td>
<td>0.21</td>
<td>0.41</td>
<td>0.00</td>
<td>1.00</td>
</tr>
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<td>Post prelim. FIRMs</td>
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<td>0.30</td>
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<td>1.00</td>
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<tr>
<td>New floodplain*post new maps</td>
<td>0.02</td>
<td>0.13</td>
<td>0.00</td>
<td>1.00</td>
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<tr>
<td><strong>Observations</strong></td>
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Transaction data are from the New York City Department of Finance 2003-2016. Floodplain and inundation maps are from FEMA. Samples is restricted to properties in tax class 1 with a sale price from $100,000 to $6.75mn (99th percentile). The first table includes property sales for which needed spatial, temporal, and control variables are available, and for which non-unique neighborhood classification exists. The second table summarizes sales observations of properties for which two or more transactions are observed in the data, and for which other needed spatial, temporal, and control variables are available. This second sample could alternatively be characterized as being composed of properties with repeated sales in the data.
Table 5: Effects of flood risk signals on log property values

<table>
<thead>
<tr>
<th>(1)</th>
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<th>(4)</th>
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</thead>
<tbody>
<tr>
<td>Neighborhood FE</td>
<td>Block FE</td>
<td>Block FE</td>
<td>Lot FE</td>
</tr>
<tr>
<td>Biggert-Waters</td>
<td>-0.0268</td>
<td>-0.0515***</td>
<td>-0.0416*</td>
</tr>
<tr>
<td>(0.0181)</td>
<td>(0.0160)</td>
<td>(0.0238)</td>
<td>(0.0296)</td>
</tr>
<tr>
<td>Sandy</td>
<td>-0.0424**</td>
<td>-0.0530***</td>
<td>-0.0322</td>
</tr>
<tr>
<td>(0.0171)</td>
<td>(0.0152)</td>
<td>(0.0225)</td>
<td>(0.0293)</td>
</tr>
<tr>
<td>Floodplain maps</td>
<td>-0.0813***</td>
<td>-0.0728***</td>
<td>-0.0820***</td>
</tr>
<tr>
<td>(0.0202)</td>
<td>(0.0162)</td>
<td>(0.0250)</td>
<td>(0.0331)</td>
</tr>
<tr>
<td>(N)</td>
<td>341996</td>
<td>341996</td>
<td>182276</td>
</tr>
</tbody>
</table>

\* \(p < .1\), \** \(p < .05\), \*** \(p < .01\). Transaction data are from the New York City Department of Finance 2003-2016. Floodplain and inundation maps are from FEMA. Sample is restricted to properties in tax class 1 with a sale price from $100,000 to $6.75mn (99th percentile) in 2010 dollars. Estimates correspond to equation 10. Dependent variable is log sale price. All columns include year-week fixed effects. Cross-sectional fixed effects are indicated in column headings. Standard errors, clustered at the Census tract level, in parentheses.

Table 6: Heterogeneous effects on log property values

<table>
<thead>
<tr>
<th>(1)</th>
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</tr>
</thead>
<tbody>
<tr>
<td>Neighborhood FE</td>
<td>Block FE</td>
<td>Block FE</td>
<td>Lot FE</td>
</tr>
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<td>Biggert-Waters</td>
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<td>(0.0525)</td>
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<td>Sandy*in old FP</td>
<td>0.0541</td>
<td>0.00365</td>
<td>-0.0740</td>
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<td>(0.0542)</td>
<td>(0.0492)</td>
<td>(0.0722)</td>
<td>(0.0940)</td>
</tr>
<tr>
<td>Sandy*not in old FP</td>
<td>0.0199</td>
<td>-0.0420**</td>
<td>-0.0102</td>
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<td>(0.0236)</td>
<td>(0.0198)</td>
<td>(0.0294)</td>
<td>(0.0407)</td>
</tr>
<tr>
<td>Sandy<em>depth</em>in old FP</td>
<td>-0.0302***</td>
<td>-0.0280***</td>
<td>-0.0216**</td>
</tr>
<tr>
<td>(0.00782)</td>
<td>(0.00673)</td>
<td>(0.00988)</td>
<td>(0.0120)</td>
</tr>
<tr>
<td>Sandy<em>depth</em>not in old FP</td>
<td>-0.0323***</td>
<td>-0.0168***</td>
<td>-0.0263**</td>
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<td>(0.00690)</td>
<td>(0.00607)</td>
<td>(0.0104)</td>
<td>(0.0170)</td>
</tr>
<tr>
<td>Floodplain maps*Sandy</td>
<td>-0.0619**</td>
<td>-0.0351*</td>
<td>-0.0231</td>
</tr>
<tr>
<td>(0.0262)</td>
<td>(0.0200)</td>
<td>(0.0304)</td>
<td>(0.0422)</td>
</tr>
<tr>
<td>Floodplain maps*no Sandy</td>
<td>-0.0511</td>
<td>-0.120***</td>
<td>-0.173***</td>
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<tr>
<td>(0.0342)</td>
<td>(0.0292)</td>
<td>(0.0450)</td>
<td>(0.0598)</td>
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<tr>
<td>(N)</td>
<td>341996</td>
<td>341996</td>
<td>182276</td>
</tr>
</tbody>
</table>

\* \(p < .1\), \** \(p < .05\), \*** \(p < .01\). Transaction data are from the New York City Department of Finance 2003-2016. Floodplain and inundation maps are from FEMA. Sample is restricted to properties in tax class 1 with a sale price from $100,000 to $6.75mn (99th percentile) in 2010 dollars. Estimates correspond to equation 11. Dependent variable is log sale price. All columns include year-week fixed effects. Cross-sectional fixed effects are indicated in column headings. Standard errors, clustered at the Census tract level, in parentheses.
A Appendix

This paper has focused on information signals that were anticipated to lead to increases in perceived flood risk levels and decreases in home prices. However, there is no reason to believe that information of a different sort wouldn’t lead to reductions in perceived flood risk levels, and in turn, increases in the values of impacted properties. Flood protection infrastructure could justify such reductions in perceived risk levels, and the announcement of such infrastructure could therefore impact property values through the expectation of reductions in future flood risks. There has been much discussion of such flood-protection infrastructure in New York City since Hurricane Sandy.

Unfortunately, in the four years since Sandy came ashore, very little additional protection has been put into place, and most proposals aimed at the installation of such additional protective measures are still in very early stages. The credibility and timing of any claims regarding protection provided through such programs is highly uncertain, and thus not yet expected to markedly impact future perceived flood risks. The only major flood-protection infrastructure proposal that appears to have gained significant traction is the “Big U”, which proposed a series of barriers be installed around the southern tip of Manhattan. Unfortunately, our focus on small residential properties in this investigation leaves us with very few observations in the potentially impacted area as there are very few small residential properties in Lower Manhattan. Nevertheless, this section applies our empirical strategy to the announcement of the Big U and provides descriptions and maps of other major flood-protective infrastructure projects in New York City.

As early as 2013, plans began to be put forth to defend New York City against future major flood events. Such plans can be divided into those that aim to provide harbor-wide protections and those through which local investments are intended to provide protection to specific areas considered to be especially at risk. Two primary harbor-wide protection alternatives have been proposed. The first involves three movable barriers, one each at the Narrows, Arthur Kill, and in the upper reaches of the East River. The second proposal relies on only two barriers, one in the upper reaches of the East River, and the second spanning from the Rockaway Peninsula to Sandy Hook, NJ (at ~5 miles, the widest proposed span by far, p. 49 PlaNYC, 2013). Any harbor-wide plan would be exceedingly expensive (estimates are on the order of $20 billion), need to overcome significant approval hurdles and environmental impact assessments, require fortification of coastlines adjacent to proposed barriers, and possibly exacerbate flood damage in nearby areas outside the protected areas (p. 49 PlaNYC, 2013). For these reasons and others, such harbor-wide protective plans have fallen out of favor, and recent activities have been focused exclusively on a diverse range of more localized coastal protective strategies (OncNYC Report, 2013).15

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15One exception to this trend is the Blue Dunes proposal which seeks to provide protection to a large section of the Mid-
The most prominent of the localized protection proposals is the the Big U, also known as the Dryline. This proposal was one of six winners of the 2014 Rebuild by Design competition sponsored by the U.S. Department of Housing and Urban Development (HUD) and intended to support innovative solutions to prepare communities impacted by Hurricane Sandy for future uncertainties. The competition awarded $930 million to six projects in the coastal regions impacted by Hurricane Sandy, of which $335 million was allocated to the Big U proposal. Put simply the Big U proposed the installation of a protective barrier along the waterfront from the southern tip of Manhattan to 42nd Street along the East River and up to 57th Street along the Hudson River (see Figure A1).

Since the competition, the Big U, has garnered further funding commitments from HUD and the City of New York. It has also been split up into a number of pieces, two of which have become active projects. The first has been titled the East Side Coastal Resiliency (ESCR) Project and is considered to be fully funded with $510 million budgeted (Mayor’s Office of Recovery & Resiliency Map, accessed 2/24/2017). The ESCR Project is currently in the design phase (OnceNYC 2016 Progress Report) with construction expected to begin in 2018 (Architects Newspaper, 2016). The second project that has thus far come out of the Big U proposal is known as the Lower Manhattan Coastal Resiliency (LMCR) Project and has been split further into two distinct project areas. Work in the Two Bridges area, on the East River between the Manhattan and Brooklyn Bridges, has been allocated $203 million and is in the planning phase, while studies are still underway and additional funding is being sought for coastal defenses of the waterfront extending from the Brooklyn Bridge, around the tip of Manhattan to the northern end of Battery Park City (Mayor’s Office of Recovery & Resiliency Map, accessed 2/24/2017).16 “Actionable concept designs” are expected for the LMCR in 2018 (Architects Newspaper, 2016).

The initial funding of the Big U proposal came on June 2, 2014, when it was announced as the largest winner of the Rebuild by Design competition.17 We will treat this date as the beginning of the period during which property prices may reflect the value of future flood protection provided under the proposal. We consider all properties behind the barriers described in the Big U proposal as potentially benefiting from reductions in perceived future flood risk, and thus increased property values. Table A1 presents the

16 Atlantic coastline through the construction of a chain of barrier islands ~10 miles off the coast to break large wave and surge events before they reach the populated coastline behind. This proposal has not garnered any serious funding, and while it has generated discussion, especially among the academic community, there is currently no plan or timeline for its implementation. See the proposal website for more information: http://www.rebuildbydesign.org/our-work/all-proposals/finalist/blue-dunes--the-future-of-coastal-protection.

17 The Big U proposes development along the East River from East River Park to Battery Park. The transformation of this “J” shape to a “U” through protecting the Lower West Side of Manhattan is never talked about, though the line of protection is often drawn all the way up the West Side. A single mention of the “Westside Highway as a “raised natural landscape” was found (in this video at 3:14), but this does not appear to be part of the Big U project (https://www.nytimes.com/2016/01/19/nyregion/new-york-city-to-get-176-million-from-us-for-storm-protections.html?r=0).
results of our main specification with the initial Big U funding added as an additional information signal. While the neighborhood fixed effects specification suggests large and significant effects in the anticipated direction, the better controlled specifications are unable to identify any significant effects of the Big U proposal on the sale prices of small-residential properties. Alternative specifications - for example using alternative announcement dates, considering only properties flooded by Sandy or in some definition of the 100-year floodplain as potentially benefiting from the the Big U proposal, or considering only properties in the areas behind the ESCR and LMCR Projects as impacted - yield similarly unconvincing results in focused specifications. It is worth noting that our analytical sample includes only 1,357 sales that fall behind the barriers proposed by the Big U, and only 286 are characterized as within the 100-year floodplain under the updated definitions.

Below we provide basic information on four other large-scale infrastructure projects that have been proposed and gained some level of official support or recognition. Figure A2 depicts the location of each of these proposals as well as that of the Big U.

- **The Living Breakwaters Project** was funded with $60M through the HUD Rebuilding by Design competition to install break waters off of Staten Island’s southern tip with the stated goal of reducing erosion and attenuating wave action (Project Web Page). Early design work is currently underway with a final design expected by early 2018, and construction slated to begin thereafter.

- **Red Hook Integrated Flood Protection System (IFPS)** is a project seeking to protect the Red Hook neighborhood in Brooklyn through a series of flood protection measures (gates, walls, raised roads, etc.). The initial announcement of the project was made December 14, 2014 (Governor’s Announcement), and the project has received $100M in funding commitments from City and Federal sources. Three possible plans have been put forth and a series of public meetings were held in 2016 to inform the community about the project and the possible plans (Project Website).

- **Atlantic Coast of New York: East Rockaway Inlet to Rockaway Inlet and Jamaica Bay:** The United States Army Corps of Engineers (USACE) has maintained Rockaway Beach since 1977. In 2003, a study was commenced to reevaluate the “long-term protection” of the area. Funding was inconsistent until the Disaster Relief Appropriates Act of 2013 (following Sandy). The new recommendations for the management of the area were released to the public in July 2016 focusing on expensive, long-term infrastructure construction ($3-4B over 50-year period) to provide “long-term coastal storm risk reduction for Rockaway and Jamaica Bay” [USACE, 2016c]. The recommended plan would provide some degree of coastal flood protection to Coney Island in addition to Jamaica Bay and the Rockaway Peninsula (see Figure A2). The recommended plan aims to provide protection with a height of 1 7feet
above average water levels with an estimated total cost of $3.78B (Study Report), but no funding source or time frame for the project have been identified.

- **South Shore of Staten Island, NY: Coastal Storm Risk Management**: The USACE released an Interim Feasibility Report in Oct 2016 (amended in Dec 2016) which recommended that barriers to address storm damages from water levels up to 15.6 feet about still water elevation (2 feet higher than Hurricane Sandy Storm tide) be constructed along the Southern Shore of Staten Island with an estimated total cost of $571M (ACE Interim Feasibility Report, 2016). The plan involves the construction of a series of levees, floodwalls, and seawalls spanning from Great Kills Park to Fort Wadsworth along the northern end of Staten Island’s southeast shore. Original funding for the study of coastal storm risk management in the area was set up in May 1999 and work on the assessment began in August of 2000. Funding ran out prior to the completion and release of a report. Additional funding was allocated in 2009 (part of the stimulus) and then again in the Disaster Relief Appropriates Act of 2013 (following Sandy). The Draft Feasibility Report was released in June 2015. While the design phase of the project is currently underway, no definitive schedule has been laid out or funding source identified (Fact Sheet and ACE Page).

Each of these projects has characteristics that inhibit the application of our empirical methods to estimate the effects their announcements might have had on property values. The Living Breakwaters Project has been very slow moving, will cover a fairly small region at the southern tip of Staten Island, and doesn’t seek to provide full protection, but only to mitigate damages. The Redhook IFPS project similarly seeks to protect a very small area, and the proposed plans vary significantly in the specifics of which areas might actually benefit. While the two USACE projects aim to provide protection to large areas (and many residential properties), their announcements simply come too late for us to provide useful assessments of their effects. Further, it is far from certain when and to what extent the protections outlined in these proposals might be implemented.
B Additional Figures
Data from NYC Map of Recovery and Resiliency (https://maps.nyc.gov/resiliency/, accessed 3/24/2017) and the Big U Design Proposal (https://portal.bud.gov/budportal/documents/buddoc?id=BIG_IP_Briefing_Book.pdf, accessed 3/24/2017). The Big U Proposal includes protection for the areas to be protected by the ESCR and LMCR Projects. Construction on the ESCR Project is slated to begin in 2018 while design and plan for the LMCR Project are also to be finalized in the same year (Wachs, 2016).
### C Additional tables

Table A1: Effects of flood risk signals including protective infrastructure

<table>
<thead>
<tr>
<th></th>
<th>(1) Neighborhood FE</th>
<th>(2) Block FE</th>
<th>(3) Block FE</th>
<th>(4) Lot FE</th>
</tr>
</thead>
<tbody>
<tr>
<td>Biggert-Waters</td>
<td>-0.0660***</td>
<td>-0.0944***</td>
<td>-0.0928***</td>
<td>-0.127***</td>
</tr>
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<td>(0.0187)</td>
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<td>(0.0199)</td>
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<td>341996</td>
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<td>182276</td>
</tr>
</tbody>
</table>

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