Preliminary Draft

Hurricanes and Sinkholes: Analyzing Real Estate Market Responses to Multiple Environmental Risks

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Abstract: Real estate purchase is a major transaction for many households in the USA and the price of real estate properties may or may not reflect a wide range of associated environmental risks (e.g., geological risk like land subsidence, sinkhole etc. and hydro-meteorological risks like hurricane, floods etc.). Hedonic price models have been frequently used to value environmental risks and amenities. It is assumed that, under a perfectly competitive market the implicit price of each attribute in the hedonic model is the price people are willing to pay for. Most earlies hedonic studies consider one or the other type of these risks and analyze how that affect the property values. But in this study, we consider both geological (sinkholes) and hydro-metrological risk (hurricanes) and analyze their impacts on property values. We are particularly interested in learning if information revealed through one type of risk triggers the impact of other type of risk. With that objective, we focus on Lake County in Florida which have large number of identified sinkholes and have also experienced a recent hurricane. First, we investigate how the location/proximity of sinkholes affect the housing price and if that effect changes following a hurricane event. Using real estate sales data of almost 35000 single family homes in Lake county from 2014 to 2018, an area that experienced significant damages during hurricane Irma in 2017, we find that houses that are near known sinkhole locations experience larger price discount following a hurricane event. We also analyze the effect of a new sinkhole insurance law on housing prices in Florida. We found that the houses that are located close to known sinkhole locations face significant price discount due to reduced sinkhole damage protection offered by the new sinkhole insurance law.

1 Introduction

As climate change progresses and the global average temperature rises, natural disasters are becoming more frequent and severe (Nakicenovic & Swart, 2000; Pachauri et al., 2014). There is a growing literature assessing economic vulnerability in the face of increasing disasters and how people adopt due to these disasters (Mechler & Bouwer, 2015). People's perceptions of risk from hazards and their relationship to the adoption of protective adjustments have long been issues of theoretical (Perry et al., 1990) and analytical (Leone et al., 1999) importance. The same aspects of risk perception were studied for different natural hazards (Bin et al.,2006; Harrison et al., 2001; Ewing et al.,2007) and technological hazards (Burton et al., 1993; Lindell et al., 2007).

Most of the frameworks that link hazard perceptions and other variables with people's protective behaviors are applied to single hazards. Some, like the Protective Action Decision Model, has been tested in multiple hazard settings (Perry et al., 2007), but in each case, decision-making is examined serially, one hazard at a time. This approach is conceptually reasonable because risk perceptions and hazard adjustments are known to change over time, and decisions about one hazard (hurricane) may consider slightly different issues than a different (sinkhole) hazard (Turner et al., 1986; Tierney et al., 2001). We also know, however, that people occupy environments characterized by many hazards that can impinge serially or simultaneously (Perry et al., 2008). As Slovic et al. (2004) point out, effect is essential in risk judgments, and the contents of one's hazard environment shape views of individual threats as well as the collectivity of threats. So, individuals living in a multi-hazard environment would consider the effect of multiple hazards simultaneously.

This study examines citizen risk perceptions and threat adjustments in a hazard environment composed of hurricanes and sinkholes. We use data from Lake County in Florida to analyze how sinkhole and hurricane interact with each other to change the risk perception of homeowners and how that changed risk perception affects the real estate market.

Sinkholes can be both a property characteristic and a negative externality (Dumn et al., 2018). Hurricanes negatively affect housing prices in the affected areas. Both events can adversely affect the property prices in the impacted and surrounding areas. Florida ranks highest in the USA as the sinkhole risk area (Florida Geological Survey, 2018) and suffers tropical storms almost every hurricane season. Sinkholes open in areas where there are some specific types of rock, such as limestone, carbonate rock, and salt beds that are dissolved by water flow. So, the probability of sinkhole opening may increase after a hurricane as increased rainwater could be one of the reasons for the occurrence of sinkholes as there will be more groundwater after increased rainfall during a hurricane (Florida Geological Survey, 2017).

In this study, we explore if the risk perception of the homeowners regarding sinkhole risk changes following a hurricane event, especially homeowners who live close to sinkholes. If the homeowners are aware of the increased probability of sinkhole opening following a hurricane, the real estate market should reflect this changed risk perception. In this paper, we use a hedonic property price function to estimate the price discount of the houses located near known sinkhole locations following Hurricane Irma.

To the best of our knowledge, there has been no prior attempt to evaluate the combined effect of multiple hazards on property prices. Our results show that Hurricane Irma changed the risk perception of the homeowners who live close to known sinkhole locations, and we observe a price discount for those houses after the hurricane, reflecting that changed risk perception. This significant combined effect of multiple hazards on the real estate market is a novel finding in the literature. However, the price discount depends on the proximity of the house to a known sinkhole location. The negative effect decreases with increased distance from a sinkhole, and after a specific range, the effect disappears.

We also analyze the effect of the new sinkhole insurance law in Florida that was effective from July 1, 2016. This law drastically reduced the sinkhole damage coverage offered to the homeowners by the insurance companies. For this change in insurance law, the risk homeowners face from sinkhole related hazards has increased as the proximity of a sinkhole to the property would make them less likely to receive compensation from the insurance companies for structural damages. We also analyze the effect of this new insurance law on real estate prices and if this increased risk is reflected in the real estate market. We then compare the price effect of a natural event like Hurricane Irma and an institutional change like a new insurance law on housing prices and observe similar reactions by the real estate market to these different types of shocks.

2 Background

There is considerable research on the effects of natural (Harrison et al., 2001; Ewing et al., 2007) and technological hazards (Adeola, 2000; Lee et al., 2008) on real estate pricing. But the conclusions from these researches were inconsistent as some of them found a negative effect on property prices, some found no effect, and some of them even found a positive impact on property prices from these hazards. Compared to some of these studies, such as Bin et al. (2008), our dataset is much larger, and we find a significant negative effect of natural hazards in our study, and the results are robust to different specifications.

There is little evidence showing the effect of sinkholes on housing prices. And the findings from these studies are not consistent. Yoo and Frederick (2017) uses quantile regression to examine the impact of land subsidence and earth fissures on residential property values across different quantiles of distribution in housing prices in Maricopa County, Arizona. Using 82,716 arms-length property sales between 2004 and 2010, they found that both land subsidence and earth fissures had a negative impact on property values. Fleury (2007) studied the effect of sinkholes on housing prices using census data from 1990. He used data from Tampa Bay and used OLS and probit models to see the impact of sinkhole proximity/density on median home prices by census block. But he found no significant effect of sinkholes on home values and concluded that maybe the homebuyers are not aware of the risk that sinkholes pose to their houses. But another explanation might be, according to Dumm et al. (2018), is that using census level data, such as median home value by census block, obscures the true price variation across properties that are affected by sinkholes and those are not. But as we are using individual property transaction price data in our study, we don't have that issue.

Our analysis is particularly related to two recent studies. Dumm et al. (2018) studied property data from 2010 to 2014 of Hernando county in Florida and sinkhole data from Florida Geological Services (FGS) to examine the effect of sinkhole presence, proximity, and density on the housing sale price. Using a spatial regression model, they show that sinkhole proximity and exposure create a negative externality, and both have a significant adverse effect on housing prices. In our study, we not only analyze the effect of sinkholes on property prices but also explore the added impact of Hurricane Irma and the new insurance law on properties that are located near the sinkhole.

Moreover, Hallstrom and Smith (2005) explored the effect of risk information conveyed by Hurricane Andrew using a difference in differences framework and their findings indicate at least a 19 percent decline in property values following Hurricane Andrew. We also use a difference in differences (DID) framework in our analysis to explore price differentials following a hazard, but we analyze to effect of multiple hazards together instead of a single hazard.

There can be many factors that might amplify or attenuate people's risk perception regarding environmental risk when they are making a real estate purchase decision (Kasperson et al., 1988; Perry et al., 2008). Recent experience with a natural disaster such as flooding or hurricane or a sinkhole opening nearby raises the discount rate of living in the disaster-prone areas. Several studies documented the price reduction from locating in a floodplain and compared the price reduction with the capitalized flood insurance premiums (Donnelly, 1991). They found that location within a floodplain lowers property value between 4% to 12%. They hypothesize that there is a change in risk premium after a natural hazard in the affected area. So, the buyer's and seller's risk perception were changing with the prevalence of hazard events, and the home buyers are unaware of flood risks and insurance requirements when bidding on properties. We also assume that the price differential of the properties following a hurricane event can be rationalized through a model of changing risk perception, responding to a rare, extreme event.

Several hedonic studies analyze the value that the homeowners attach to the reduction of the probability of loss from a natural hazard (self- protection). Brookshire et al. (1985) studied the effect of living in an earthquake zone. Like our analysis, they also used real estate transaction data from San Francisco and Los Angeles and found that homes that are in earthquake risk zone suffer price discounts compared to the houses that are outside the earthquake risk zone.

Finally, most of the studies that have studied the effect of a natural hazard on property prices tried to examine the impact of a single natural hazard. Few studies investigated the effect of multiple natural hazards on property prices and how one hazard can trigger or increase risk perception about another hazard. Perry et al. (2008) gathered data from two northern California

(USA) communities that are exposed to wildfires, earthquakes, and volcanic activity, and they found that risk perception was not a statistically significant predictor of the number of adjustments for any of the three hazards. But they don't consider the effect of the three hazards together for their analysis.

In contrast to the research described previously, our study examines two natural hazards together and how two different kinds of environmental risks can combine and affect the real estate market. In this study, we analyze how two different types of natural hazards like hurricane and sinkhole interact with each other and affect the real estate prices that face the dual threat of sinkhole damage and hurricane event. We also analyze the effect the effect of the new sinkhole insurance law on property prices near sinkholes and compare the effect of the insurance law and Hurricane Irma to differentiate between hazard effect and institutional effect on property prices.

3 Sinkhole Risk

3.1 What is sinkhole?

A sinkhole is a ground depression with no natural external surface drainage capability. Sinkholes are most common in areas of ‘karst terrain.’ A karst terrain is an area where the rocks below the land surface can naturally be dissolved by groundwater circulating through them. Dissolvable types of rocks include salt beds and domes, gypsum, limestone, and other carbonate rocks. As water soaks into the ground, these karst terrain rocks dissolve, creating underground caverns and spaces. At some point, the subterranean space becomes too big for the ground cover to support, causing the surface land to collapse and a sinkhole results. About 20% of the U.S. sits atop karst terrain, and most states have some areas with karst terrain (US geological Survey, 1999).

Although most sinkholes are ‘natural’ phenomena, some sinkholes are correlated with events such as flooding and land-use practices such as groundwater pumping and construction, which may lower the water table. Real estate development such as buildings and parking lots can divert rainwater runoff and result in concentrated weight that causes the ground cover to collapse. As Sinclair (1982) points out, sinkholes may occur along with certain joint patterns in the underlying bedrock. Pumping of large-capacity wells along these joint patterns could increase the probability of sinkhole development. Natural events like excessive rainfall or flood after a dry season can lead to sinkhole outbreak in an area that is rich with dissolve type of rocks such as salt beds and domes, gypsum, limestone, and other carbonate rocks (Florida Geological Survey, 2018).

3.2 Sinkhole Risk in Florida

Sinkhole damages over the last 15 years cost on average at least $300 million per year (US geological Survey, 2018). Since there is no national tracking of sinkhole damage costs, this estimate is probably much lower than the actual number, according to United States Geological Survey (US geological Survey, 2018). According to them, that damage could escalate as climate change intensifies. For example, as sea level rises in response to climate change, groundwater levels in near-coastal areas will also rise and result in increased flooding of sinkholes.

In theory, the entire state of Florida is susceptible to sinkholes since it sits on porous carbonate rocks such as limestone. The normally moist soil of Florida has a stabilizing effect on karst. But during a drought, cavities that were supported by groundwater empty out and become unstable. During a heavy rainstorm, the weight of pooled water can strain the soil, and the sudden influx of groundwater can wash out cavities (Xiao et al., 2016). Central Florida was in a severe drought at the beginning of 2017, followed by the intense rainfall of Hurricane Irma that hit many parts of

Florida in September, and “a deluge after a drought is the optimal condition for a sinkhole outbreak” (Florida Geological Survey, 2018). A proof of this mechanism was evident in 2017 when at least 400 new sinkholes were reported after Hurricane Irma (FGS).

3.3 Sinkhole Insurance in Florida

Central to the fear factor for sinkholes is how unpredictable they are. They usually form without warning, and it’s difficult to detect weak spots in the ground. Ground-penetrating radar (GPR), is the best way to detect cavities that cause sinkholes in the ground. But Florida law doesn’t require to use GPR before selling or buying a property, and due to the high cost of using GPR, people are not interested in using it. Even when a site is surveyed and deemed safe from sinkholes, one can still form a few years later, given the precarious nature of karst. So, one of the few ways homeowners can have peace of mind about sinkhole risk is by buying insurance.

Due to high sinkhole risk, Florida law used to require insurers to include sinkhole activity coverage in homeowners’ insurance policies until 2007 (Florida Office of Insurance Regulation, 2010). But sinkhole insurance coverage in Florida was very broad. In 2007, a new legislature passed, which required insurance companies to provide all homeowners with coverage for catastrophic ground cover collapse. There was not a clearly defined threshold for what structural damage was covered. So, property owners were filing for sinkhole damage even when the damage was not related to sinkholes. So, insurance companies faced significant losses.

In a 2011 report, the Florida Office of Insurance Regulation (OIR) reported that the number of sinkhole claims increased from 2,360 in 2006 to 6,694 in 2010 (a total of 24,671 claims). The approximate dollar amount of these claims was $1.4 billion (OIR, 2011). In 2011, Florida Senate passed a new legislature, narrowing the scope of qualifying damage and includes other provisions. The new law was applicable from July 2016. This law states that the insurance companies may require an inspection before extending coverage and they can decline coverage for a property if sinkhole activity is present on the property or within a certain distance of the property to be insured. According to this law, homeowner’s insurance only covers ‘catastrophic ground collapse’ when a sinkhole makes a home uninhabitable. Any damage just short of that must be covered by sinkhole insurance, whose deductible is very high in Florida and is typically 10 percent of the home’s value. So, it is relatively costly for the homeowners to have sinkhole insurance. And even when they buy sinkhole insurance, in the event of sinkhole damage, they must pay a large portion of the repair cost.

4. Data and Study area

Hurricane Irma, one of the most devastating and powerful hurricanes in recent memory, hit the state of Florida on September 10, 2017. The storm, which came ashore south of Tampa, veered east, landing a direct blow on Lake County in the early morning hours on September 11 (National Oceanic and Atmospheric Administration, 2017). By that time, the eye of the once-Category five storm had eroded, and the winds had significantly diminished, although not enough to head off significant tree damage there. Some roads were rendered impassable when large oaks were uprooted or splintered from sustained winds that reached as high as 76 mph (FEMA, 2017). Irma was the fifth most expensive tropical cyclone to hit the USA, and the estimated damage from Hurricane Irma in Lake County was at least $36 million (FEMA, 2019). As Lake County is one of the major counties that have sinkhole risk, there was a high chance of new sinkholes opening in lake county after the hurricane. We capture the homebuyers and home sellers’ modified risk perception about sinkhole risk after the hurricane event from their real estate purchase decision.

Multiple data sources were used for the study. Property parcel data, GIS data of the parcels, and the real estate purchase records were collected from the property appraiser's office. The data include structural characteristics such as year built (used to calculate age), number of bedrooms, flooring, and lot size. Supplementary property characteristics such as fireplace, swimming pool, central air conditioning, and building construction quality are also available. Some of these are converted to binary variables with a value of one to indicate the existence of the specific characteristic or superior condition and zero otherwise. Structural characteristics were linked to the sales database using the unique property identification number for each parcel. During the observation period, some properties sold multiple times, and the duplicate sales have been removed from the sample. The year-built variable was used to delete any sales where a house had been rebuilt. That is, if the year built is more recent than the sale year, we assume that the original house was torn down. In that case, the observation is deleted as structural data are only available for houses that are currently standing. All sales in our data are qualified sales or arm's length transactions. All non-qualified sales (such as purchase by a relative, foreclosure, or any other non- arms-length transaction) were deleted from the sample. Binary variables are used to represent the quarters from 2014 to 2018, with the first quarter of 2014 as the base quarter. We also tried to establish the effect of various amenities such as lakes, libraries, and hospitals. We calculated the distance of the nearest known amenity from the sold house and determined its effect on the price of the house. Then these data sets were combined with unique parcel id.

Additionally, a file with the location of known sinkholes in the State of Florida was obtained from the Florida Geological Survey (FGS) office. The FGS is the premier state government institution in Florida, specializing in geoscience research and assessments to provide objective quality data and interpretations. They maintain and update databases as part of the statewide geomorphic mapping project and provide a mapping of the state relative to sinkhole risk and likely occurrence. We utilized GIS to identify properties that contain reported sinkhole activity and to calculate the proximity of properties without sinkholes to the nearest property with a sinkhole. GIS spatial queries were performed to calculate sinkhole proximity and density within different distance bands such as ¼ mile, ½ mile, ¾ mile, 1 mile, and 2 miles. Finally we used a total of 35000 single-family residential homes from Lake county, Florida, that were sold between 2014 and 2018. Lake County is approximately 1157 square miles, with a population of roughly 3,46,017 and a population density of 369/sq. miles.

5. Theory of hedonic property prices, hazards, and insurance

Bin and Landry (2012) showed the relationship between marginal implicit hedonic prices, incremental option value, and insurance costs. We add a minor alteration to their theory to explicitly account for the sinkhole effect and how that effect interacts with a hurricane event.

Let the subjective probability of sinkhole damage (state 1) be given by p(i), where i denotes the information set. Conditional property loss is L ϵ (0, S), with density f(L) (where S is the structure replacement/repair cost). The probability of no sinkhole damage (state 0) is then 1-p(i). Information(i) can change due to education programs, media coverage, or the occurrence of catastrophic events. Indirect utility V(.) is defined over a vector of housing attributes, a and income, y and is quasi-concave, bounded, and continuously differentiable. Uninsurable losses such as the hassle of being displaced by sinkhole damage, the possibility of injury and death, damage to community infrastructure, and loss of personal items with sentimental values are introduced by a state-contingent utility function, with $V_j(a, y)$ representing utility in state $j = 0,1$. Assume $V_0(a, y) > V_1(a, y)$ for any a, y. Let the hedonic property price schedule be represented by R (a, p(i)), which is exogenous to individual buyers and sellers, but reflects subjective risk perceptions, p(i).

If we assume the homebuyers are buying sinkhole insurance because the location of the houses is in a sinkhole risk zone, the expected utility for the homebuyers is given by:

$$EU = p(i)\int_0^S V_1(a, y - R(a, p(i)) - I(p, C) - L + C)f(L)dL + (1 - P(i))V_0(a, y - R(a, p(i) - I(p, C)) \ldots\ldots\ldots\ldots\ldots(1)$$

Where, C ϵ (0, S) is the insurance cover on the property, and I (p, C) is the insurance premium (which depends on the objective risk as well as the level of cover). Given state-contingent utility, optimal cover in (1) depends on the relationship between insurance price and perceived risk. For fair insurance or insurance price with a loading (to cover administrative and capital costs), optimal cover can be less than or equal to S. For simplicity, we assume that if insurance is purchased, full cover is chosen so that L=C, and Eq. (1) simplifies to

$$EU = p(i)V_1(a, y - R(a, p(i)) - I(p, C) + (1 - p(i))V_0(a, y - R(a, p(i)) - I(p, C) \ldots\ldots\ldots(2)$$

For homebuyers outside the sinkhole risk zone or further away from sinkhole prone areas, the probability of buying sinkhole insurance is lower. Equation (1) and (2) hold for the people who live outside the sinkhole risk zone but buy sinkhole insurance. For those that do no purchase sinkhole insurance, I (p, C) and C terms do not appear in (1), and the EU is given by

$$EU = p(i)\int_0^S V_1(a, y - R(a, p(i) - L)f(L)dL + (1 - p(i))V_0(a, y - R(a, p(i)) \ldots\ldots\ldots(3)$$

Following Smith (1985), we define incremental option value as the maximum payment that an individual would make (under uncertainty) to increase the probability of the desirable state. In our framework, incremental option value (OV) can be implicitly defined as follows.

$$[p(i) - \sigma]V_1(a, \hat{y} - OV) + [1 - p(i) + \sigma]V_0(a, \hat{y} - OV) = EU \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (4)$$

With the full insurance cover, where $\hat{y} = y - R(a, p(i)) - I(p, C)$ is residual income after housing and insurance payments; σ is the increment in probability to the favorable state, and EU is given by Eq (2). Employing the implicit function theorem, we can derive the gradient of incremental option value in the case of full insurance cover as:

$$\frac{dOV}{d\sigma} = \frac{V_0(a,\hat{y}-OV)-V_1(a,\hat{y}-OV)}{[1-p(i)+\sigma]\frac{\partial V_0}{\partial y}+[p(i)-\sigma]\frac{\partial V_1}{\partial y}} \ldots\ldots\ldots\ldots\ldots\ldots (5)$$

Which defines incremental option value as a direct reflection of the expected value of the incremental change in utility. A similar expression can be derived for the case of no insurance.

Macdonald et al. (1987) show that the maximization of EU in (2) implies the following equality in equilibrium:

$$\frac{\partial R}{\partial P} = \frac{V_1(a,\hat{y}- V_0(a,\hat{y})}{[1-p(i)]\frac{\partial V_0}{\partial y}+[p(i)]\frac{\partial V_1}{\partial y}} - \frac{\partial I(p)}{\partial P} = -\frac{dOV}{dp} - \frac{dI(p)}{dp} < 0 \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (6)$$

Thus, the marginal implicit hedonic price for a change in a risk factor that affects the probability of loss is the sum of the option value for residual risk (reflected in the state-contingent utility difference in the numerator of the first term) and marginal insurance cost. We assume, with the occurrence of a hurricane event, the risk factor of a sinkhole event happening will increase for the homebuyers who are buying or selling homes in a sinkhole risk zone, and we will see the reflection of that changed risk factor in the marginal implicit hedonic price in (6). The formulation clearly shows that under conditions of perfect information and full insurance, the hedonic price function capitalizes insurance cost and residual risk of non-insurable losses. In the case of no insurance, the marginal implicit price of a risk factor that affects the probability of loss reflects only the expected value of lost utility associated with the incremental change in risk (the first term in (6) above, but also evaluated at different income levels associated with and without loss). In either case, well-informed buyers and sellers that associate higher utility with the no-loss state will give rise to a gradient in the price-risk dimension that is determined by the expected value of lost utility associated with sinkhole event and marginal insurance costs.

Lastly, consider how a change in the information set [i] could affect marginal implicit prices. Assume $\frac{\partial p(i)}{\partial i} > 0$, so that information conveyed by educational programs, media coverage or in our case, a hurricane event heightens the subjective perception of risk because now the probability of a sinkhole opening is higher.

Differentiating (6) with respect to i shows that the implicit price of risk factors is decreasing in information that heightens perception in risk (i.e. becomes more negative) if $\frac{\partial V_0}{\partial y} > \frac{\partial V_1}{\partial y}$, while the effect is indeterminate if $\frac{\partial V_1}{\partial y} > \frac{\partial V_0}{\partial y}$. Here we use occurrence and non-occurrence of hurricane events to test for such effects in marginal implicit housing prices. So, after a hurricane, people who live close to a sinkhole location update their risk perception, and the sinkhole risk gets triggered by hurricane risk, and there would be a price discount for such properties. If there is an increase in insurance cost, the cost of living in the area will increase, and this will increase marginal implicit price in (6), which will also cause a negative price premium.

6. Empirical Strategy

6.1 Empirical Model

Hedonic regression analysis is commonly used in real estate research to measure the marginal effects of housing characteristics and other factors on house prices. A review by Sirmans et al. (2005) of over 125 real estate studies that have used hedonic pricing models shows that many types of variables such as the age of the house, number of bedrooms, number of bathrooms, garages, pool, and fireplace have been included in these models. This study includes these variables and, additionally, variables to measure the price effect of having a sinkhole on the property or a sinkhole located within certain proximity as well as the changing effect of these sinkholes after a natural hazard event such as a hurricane that might be correlated with a new sinkhole opening nearby.

The general form of the hedonic pricing model is:

$$P_i = f(X_j, L_j, E_i) \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (7)$$

where P_i is the log of the transaction price of house i, X_j is a vector of j structural housing characteristics, L_j is vector of location variables, and E_i is a vector of externalities affecting the transaction price. The semi-log model is generally preferred since the coefficients provide semi-elastic, i.e., the coefficients are interpreted as the percentage change in price relative to one-unit change in the explanatory variable (Sirman et al., 2005). The method typically used to measure the marginal effect of the explanatory variables on the house price is OLS regression which minimizes the sum of squared residuals (Sirman et al., 2005).

Our first model estimates the effect of the presence and proximity of sinkhole on housing value using the log of the sales price of the houses as the dependent variable. We use binary variables for quarters between 2014 to 2018, using the first quarter of 2014 as the base quarter. With these additional variables, our first model can be written as:

$$log\ (price)_{i,t} = \alpha_0 + \beta_i\, X_{ij} + \ \varphi_i\ \ sinkhole_i + \mu_i\, Distance_{sinkhole\ ij} + \theta_i\ time_i \\ + \varepsilon_i \ldots\ldots\ldots\ldots\ldots\ldots (8)$$

Where $price_i$ is the selling price of the house, i, X_{ij} is the matrix of explanatory variables j for the house i, $Sinkhole_i$ is a binary variable for house i with a value of one if a sinkhole is located within a specific distance band and zero otherwise.

$Distance_{sinkhole\ ij}$ is a set of j variables that capture the proximity of the nearest sinkhole to house i. $Time_i$ is a vector of binary variables indicating the quarter that property i was sold and ε_i is the error term.

To estimate the combined effect of hurricane and sinkhole on the property value, we use a difference-in-differences (DID) framework with a hurricane event. We compare the price differentials of the houses located near sinkholes with price differentials of the houses that are not close to sinkholes from a sample of housing sales data. We use the log of the sales price of the houses as dependent variable to estimate our model:

$$log(price_i) = \alpha_1 + \beta_i X_{ij} + \varphi_i\ sinkhole_i + \gamma_t\ irma_t + \delta_{irma}\ (sinkhole_i * irma_t) + \varepsilon_{i,t} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (9)$$

Where $price_i$ is the selling price of the house, i, X_{ij} is the matrix of explanatory variables j for the house i, $sinkhole_i$ is a binary variable for house i with a value of one if sinkhole is located within a certain distance band for the sold property and zero, if it is located further than the distance band. The variable, $irma$ is binary which takes the value of one if the house is sold after Hurricane Irma and zero if the house is sold before hurricane Irma. The δ_{irma} represents the effect of hurricane Irma on the value of the houses that are close to known sinkhole locations. From δ_{irma} we can estimate the changing risk perception of the homebuyers and sellers.

The Model (8) is designed to test two hypotheses. First, the presence of a sinkhole near a property has a negative effect on the selling price of the property. According to this hypothesis, the φ_i on the sinkhole would be negative. We will try to prove this hypothesis using different distance bands such as ½ mile, 2/3 mile, 1 mile and 2 miles. The second hypothesis is that sinkhole proximity has a negative effect on selling price (i.e., the closer the sinkhole, the lower the selling price) and we will try to prove this hypothesis for the continuous case. So, the μ_i for the $Distance_{sinkhole\ ij}$ would be negative. The Model (9) is designed to test the third hypotheses: After hurricane Irma, the negative effect of close sinkhole proximity to the property will be exacerbated and we will see more price discount for the houses that are located close to known sinkhole locations. So, our δ_{irma} will be negative.

6.2 Threats to identification

It is possible that some households favor places that were hit by Hurricane Irma in order to take advantage of a decline in housing prices, while others move to nearby locations without a previous disaster to avoid future losses. This would suggest a positive impact of natural disasters on the price of the homes, which would bias the estimate (Sheldon et al., 2019). If more risk-averse households are less likely to buy houses, the self-selection of locations of the latter group would also produce a positive bias and reduce the magnitude of the estimate. Therefore, neither case would impose a serious threat to the identification of the impact of disasters via risk updates as long as a negative effect of Hurricane Irma is found.

7 Estimation Results

7.1 Baseline Estimates

The definitions of the variables that we have estimated are given in Table 1, and the descriptive statistics of the variables are given in Table 2. As shown in Table 2, the average price of the houses sold between 2014 and 2018 is \$227118.3, the average age of the sold houses is 22.3

years, and the average lot size is 0.66 acres. There are 3.02 bedrooms per house on average, and almost all the houses have central heating. Regarding the distance of the nearest sinkhole from the sold houses, 18% of the houses have the nearest sinkhole within ½ mile, 27% of the houses have the nearest sinkhole within 3/4 mile, 50% of the houses have the nearest sinkhole within 1.5 miles and 70% of the houses have the nearest sinkhole within 2 miles.

We collected the geographic location data for all the houses in the data set as well as the location data for the sinkholes in Lake County from Florida Geological Survey (FGS) website. Using *ArcGIS*, we calculated the shortest distance between each house and nearest known sinkhole location using their geocoded location. In Figure 2, we have shown the locations of the geocoded houses in Lake County and known sinkhole locations in Florida. In Figures 3, 4 and 5, we have shown the price trend of the houses that have a sinkhole within ½ mile, and 1 mile and 2 miles respectively and observed that the houses that are located close to the sinkholes have a negative price premium compared to the houses that are not close to sinkholes. It can also be seen that the price discount increases after Hurricane Irma. This indicates the risk perception of the homebuyers who are buying houses near sinkhole locations changes following a hurricane event.

From Figures 3, 4, and 5, we can also see the effect of the new sinkhole insurance policy rule on housing prices. There is a slight downward shift in the price trend of the houses that are close to sinkhole locations compared to the houses that are located far from known sinkhole locations following the implementation of the new policy. This shift is reflecting the real estate market response to the new insurance policy.

The focus of this study is to analyze three primary effects: (1) the price effect of being within proximity of a sinkhole, (2) the change in risk perception about sinkhole risk following a hurricane event and the effect of that changed risk perception on real estate market, and (3) real estate market response following the new sinkhole insurance policy rule in Florida. These effects are measured by analyzing both sinkhole and non-sinkhole properties.

7.2 Effect of sinkhole on housing price

We estimate the Ordinary Least Squares (OLS) regression model to calculate the effect of sinkholes on housing prices. As there can be some spatial effect present in the data, we also estimate the spatial error regression model to account for the spatial autocorrelation among the houses that are located close to each other. We use the log of the sales price as the dependent variable in all of our regression models.

We report the result for the OLS regression in Table 3, where we estimate the percentage change in prices for the houses that are located close to sinkhole locations. We find that sinkholes have a significant effect on housing prices from our OLS regression. We run the regression using different dummy variables covering the distance of sinkholes as well as continuous distance variable from the nearest sinkhole location. We also control for time trend by using quarterly dummy variables from the 1st quarter of 2014 to the last quarter of 2018, using the 1st quarter of 2014 as the base quarter. In the OLS regression, all the structural variables such as the number of bedrooms (Bedrooms), number of bathrooms (Bathrooms), land size of the house (Acres), and age of the house ($\text{House}_{\text{Age}}$) have expected signs and are significant at 1% level. Amenities such as pools (Pool), fireplace (Fireplace), and having central air-conditioning (Central air) also significantly affect the housing values, and they are also significant at 1% level. We find a significant price discount for the houses due to proximity to sinkhole locations. We find that houses that are within ½ mile of a known sinkhole location suffer an 8.2 % price discount compared to other houses, and it is significant at 5% level. The price discount falls to 7% when the house is within ¾ mile of a known sinkhole location, and it is significant at 1% level. We find that the price discount remains 7% for the properties that have a known sinkhole location within 1 mile and this negative premium is significant at 1% level. When the house is located further than that, for example, when the house is 2 miles away from a sinkhole location, price discount falls to 5%, and this discount is also significant at 1% level.

As the houses are sometimes clustered together in our sample, and sinkhole exposure may show spatial trend, we run different spatial error models to explore the effect of sinkholes on housing prices further. Our estimation results from the spatial error model are given in Table 4. In Table 4, we show the effect of structural and neighborhood variables such as the number of bedrooms (Bedrooms), number of bathrooms (Bathrooms), land size (Acres), pools (Pool), fireplaces (Fireplace), etc. on sales values. The coefficients of the structural variables all have expected signs and are statistically significant at 1% level. In the spatial error model, the price discount is even higher for different distance bands compared to the OLS model. Here, after controlling for spatial autocorrelation, houses that are within ½ mile of a known sinkhole location suffer an 6% price discount compared to other houses, and it is significant at 1% level. The price discount increases to 8% when the house is within ¾ mile of a known sinkhole location and this discount is also significant at 1% level. When a house has a known sinkhole location within 1 mile, the price discount increases to 8.9%, and it is significant at 5% level. After controlling for spatial autocorrelation, even when the house is 2 miles away from a sinkhole location, there is a 2.3% price discount due to sinkhole proximity, and it is significant at 1% level.

Overall, we can say that there is a significant price discount if the house is located close to a known sinkhole location and from different estimated models, the price discount for being in proximity to a known sinkhole location varies from 8.9% to 2.3% and almost all of these negative price premiums are significant at 1% level.

7.3 Effect of Hurricane Irma on houses close to known sinkhole locations

To analyze the effect of a hurricane event on housing prices that are located close to sinkholes, we estimate the difference in differences (DID) model. Hurricane Irma is used as a natural experiment to capture how the risk from Hurricane Irma triggers the risk from sinkhole among the homebuyers and homeowners who live close to sinkhole locations. The natural experiment happened on September 10, 2017, when Hurricane Irma passed over Lake County. This hurricane event made homeowners of the hurricane-affected areas aware of the hurricane risk, and it had an added effect for the homeowners who lived near a known sinkhole location and made them aware of the increased possible risk of a sinkhole in the near future. The homeowners who live far away from any known sinkhole location, are exempt from this added effect. We establish them as control group and applied a difference in difference estimator (DID) to quantify the added risk for living near a sinkhole location. The results of the difference in difference estimation are reported in Table 5.

We use the log of the sales price as the dependent variable in Table 5. We control for household characteristics (e.g., number of bedrooms (Bedrooms), number of bathrooms (Bathrooms), land size (Acres), etc.) along with quarter fixed effects. We also use the squared value of the number of bedrooms (Bedrooms Sq.) and bathrooms (Bathrooms Sq.) as control variables following Bin and Polasky (2004). We find that there is an additional price discount for the houses that are located close to sinkholes after Hurricane Irma. We calculate the effect of Hurricane Irma for houses that are located within different distance bands from known sinkhole locations. We find an additional price discount when the houses are located within ½ mile, ¾ mile, and 1 mile of a known sinkhole location. When the house has a known sinkhole location within ½ mile distance, that house faces an extra 2% price discount compared to the houses that are not close to sinkholes, and it is significant at 10% significance level. When the house is located ¾ mile away from the nearest sinkhole location, that house suffers 3% extra price discount, and it is significant at 5% level. If the nearest sinkhole is located within 1 mile of the house, we again find a 2% price discount compared to other houses, and it is significant at 5% level. But as before, the effect disappears when the distance increases to 2 miles. So, people who are buying houses that are at least 2 miles away from the nearest sinkhole location, their perception of sinkhole risk after a hurricane is unlikely to change.

We find clear evidence that a hurricane event is likely to change people's risk perception about sinkhole. People have increased risk perception of sinkholes after a hurricane event, and due to that increased risk perception, the houses located close to sinkhole suffer a price discount of around 2% to 3% compared to similar houses that are not close to sinkholes. As seen from Table 5, buyers will count the fact that after a hurricane, there is an increased risk of a sinkhole opening nearby due to the presence of an already open sinkhole and that increased risk factor is represented in their purchase decision. There can also be a supply-side effect present in the increased price discount for sinkholes after a hurricane event. People who are already living in a house that is close to a sinkhole, might also think about this increased risk of a new sinkhole opening, and they will try to move to some other place where the risk is lower. So, the supply of housing units that are available for sale will increase, and this increased supply will further reduce the prices of the houses, exacerbating the price discount. So, the overall price discount observed in Table 5 can be considered as the combined effect of demand-side and supply-side responses to increased risk perception for sinkholes after a hurricane event.

We show the treatment effect of Hurricane Irma in figures 6, 7 and 8. We observe that following the hurricane, the houses that are within 0.25-mile face significant price discount as they think that they are in danger of increased activity due to the hurricane. When the distance increase to 0.50 mile, we again observe a significant price discount for the houses that are within 0.50 mile of a sinkhole. But when the distance increase to 2 miles, the price discount diminishes, as people who live this far from a sinkhole might think that they are not in increased danger of suffering sinkhole damage due to the hurricane as they are far away from any sinkhole activity and so, Hurricane Irma doesn't affect their risk perception.

7.4 Effect of the new sinkhole insurance law on housing prices

To analyze the effect of the new insurance law that was effective from June 1, 2016, on housing prices that are located close to sinkholes, we estimate the difference in differences (DID) model. Here, we use the new insurance law as a natural experiment. This new insurance law should influence the homeowners who live close to a known sinkhole location as this new rule will increase their insurance cost, and the more limited sinkhole coverage will increase the risk of living in a sinkhole prone area. The homeowners who live far away from any known sinkhole location, are exempt from this effect. We establish them as control group and apply a difference in differences estimator (DID) to quantify the added risk for living near a sinkhole location. We compare the price differentials of the houses located near sinkholes with price differentials of the houses that are not close to sinkholes from our sample of housing sales data.

We use the log of the sales price of the houses (Log (price)) as the dependent variable to estimate our model (10):

$$log\ (price)_{i,t} = \alpha_2 + \beta_i X_{ij} + \varphi_i\ Sinkhole_i + \gamma_t\ insurance_t + \delta_{insurance}\ (sinkhole_i * insurance_t) + \varepsilon_{i,t} \ldots\ldots\ldots\ldots\ldots\ldots\ldots (10)$$

Where $price_{i,t}$ is the selling price of the house, $i\ at\ time\ t,\ X_{ij}$ is the matrix of explanatory variables j for the house i, $Sinkhole_i$ is a binary variable for house i with a value of one if the sinkhole is located within a certain distance band for the sold property and zero, if it is located further than the distance band. $insurance$ is a binary variable taking the value of one if the house is sold after June 1, 2016, and zero if the house is sold before June 1, 2016. $\delta_{insurance}$ represents the effect of the new insurance law on the value of the houses that are close to known sinkhole locations. From δ we can estimate the changing risk perception of the homebuyers and sellers due to insurance policy change.

We analyze the effect of the new insurance policy for the houses located within different distances from the nearest known sinkhole location to explore the spatial nature of the effect as well as to check the robustness of our analysis. To isolate the effect of the new insurance law from the hurricane effect, we used sales data of the properties that were sold before hurricane Irma. So, we use data from January 1, 2014, to September 1, 2017, for our analysis.

Our results are presented in Table 7. We estimate the effect of the new insurance law on houses that are within ½ mile, ¾ mile, 1 mile, and 2 miles of a known sinkhole location. When the house has a known sinkhole location within ½ mile distance, we find that following the new insurance law, the houses that are within ½ mile of a sinkhole suffer a 2% price discount, and this is significant at 10%. When the property is located ¾ mile away from the nearest sinkhole location, that house suffers a 4% extra price discount after the new insurance law, and it is significant at 1% level. If the nearest sinkhole is located within 1 mile of the house, we find a 3.2% price discount compared to other houses, and it is significant at 1% level. When the distance of the property is increased to 2 miles from the nearest sinkhole location, there is still a significant price discount of 3% compared to the properties that are located further than that.

We also observe that the change in insurance law does not have any significant effect on housing prices by themselves. Only when the new insurance law interacts with sinkhole presence, then the new insurance law has a significant impact on housing prices. So, after the change in insurance law, only people who live close to sinkholes react to the new law and their risk perception regarding sinkholes increases due to their increased exposure to sinkhole damage as they have less protection by insurance now. And that increased risk perception is reflected in property price.

Also, properties that are located at least 2 miles away from a sinkhole don’t face price discounts due to sinkhole presence. Only after the change in insurance law, these properties face a 3% price discount due to sinkhole presence. Maybe because, with more protection from the previous insurance policy, they didn’t care about sinkhole risk. But after the new insurance law was passed, which offered less protection from sinkhole damage, they became more aware of sinkhole risk, and that change in risk perception is reflected in property price.

We show the treatment effect of this new insurance law in Figures 9,10 and 11. We observe that following the new insurance law, the houses that are within 0.25-mile face small but significant price discount. When the distance increase to 0.50 mile, we observe a significant price discount for the houses that are within 0.50 mile of a sinkhole. When the distance increase to 2 miles, the price discount diminishes greatly but we still observe some price discount following the new insurance policy.

7.5 Event study of the effect of hurricane and the new insurance law on houses close to sinkholes

When trying to identify the effect of a reform or an event, it is imperative to differentiate the effect of interest from other irrelevant effects (Olsson, 2008). In an ideal situation, one would prefer to estimate the outcome for an individual or for one unit of the variable of interest that is both treated and untreated at the same point in time. But unfortunately, that is not possible. So, the closest to the ideal situation one researcher can come to is to find a feasible control group that, in the absence of treatment, is on average the same as the treatment group, and that way, the average treatment effect be correctly estimated. All of the time effects should thereby be common across the two groups, that is, the average outcome for the two groups should be parallel over time in the absence of treatment (Greene, 2009). We can assume that this assumption is fulfilled if we can establish that the parallel trend assumption is fulfilled.

In Figures 3, 4 and 5 below, we presented a visual analysis of the effect of Irma and the new insurance law on the selling price of the houses that are located within ½ mile,1 mile, and 2 miles respectively to known sinkhole locations. These figures also visually present the parallel price trend for houses that are close to the sinkholes and the houses that are not. This trend comparison is crucial and is helpful to visually inspect the parallel trend assumption for the difference in differences model reported in Tables 5 and 7. We can see that parallel trend assumption is fulfilled for the houses that are located closer than 2 miles within a sinkhole. But if the distance increase to 2 miles, the price trends are not parallel.

These diagrams also help to show the change in price trends following Hurricane Irma on housing prices that were close to sinkholes. From Figures 3 and 4, we can see that there is a price discount for houses that are located close to sinkholes compared to the houses that are far away from known sinkhole locations.

After Hurricane Irma, we can see that there is an increase in price discounts for houses that are close to sinkholes due to the changed risk perception. In Figure 5, we see that the price trend of the houses that are located more than 2 miles away from the nearest sinkhole location does not show the price discount.

We can also see the change in price trends following the new insurance law in Figures 3, 4, and 5. We observe a price discount following the new insurance rule for houses that are located within ½ mile and 1 mile of a known sinkhole location. But when the distance increase to 2 miles within a sinkhole location, we don't observe any price discount for the properties.

7.6 Can we trust the estimated treatment effect?

Is the treatment effect estimated in Table 5 and Table 7 unique and attributable to the effect of Hurricane Irma and the new insurance law, respectively? An easy and straightforward way of testing the robustness of an estimated treatment effect is to estimate placebo effects at different points in time. If any of these placebo effects turn out to be significant, it can cast doubt on the treatment effect.

Table 7 shows that all the estimated treatment effects for the placebo regression models are insignificant and that the only DID estimator that is significant is that for 2016 and 2017. The significant placebo effect of 2016 is because of that insurance policy change with respect to sinkhole coverage.

The significant results in 2017, the actual year of our treatment, Hurricane Irma, indicates that the effect that occurred in 2017 is not random.

A common objection against the use of a difference in differences model for an event is that if individuals anticipate the event and begin to behave in a certain way before the event is implemented, it will bias the treatment effect. But for this case, as the shock is a hurricane event, the chance of people anticipating it ahead of time and adjusting their behavior is very low, and so, that possibility can be ruled out.

But for the new insurance law, as the effective date of the implementation of the new rule was announced about a year before, we can assume that people expected the change and had time to adapt to the new rule. But as we are attempting to capture the behavioral effect of the new rule, this change in behavior shouldn’t affect our analysis.

8 Conclusion

As climate change-induced natural disasters are projected to become more frequent and cause immense economic and human losses, there is a growing interest among both policymakers and researchers in the potential effects of these natural disasters on the real estate market. Real estate is one of the major investments by households, and any significant negative shock to the real estate market can cause a substantial negative shock to the economy. This study estimates the effects of sinkholes on residential property value using a hedonic property price approach. More specifically it analyzes the effects of sinkholes on residential property value before and after Hurricane Irma swept through Florida in September 2017.

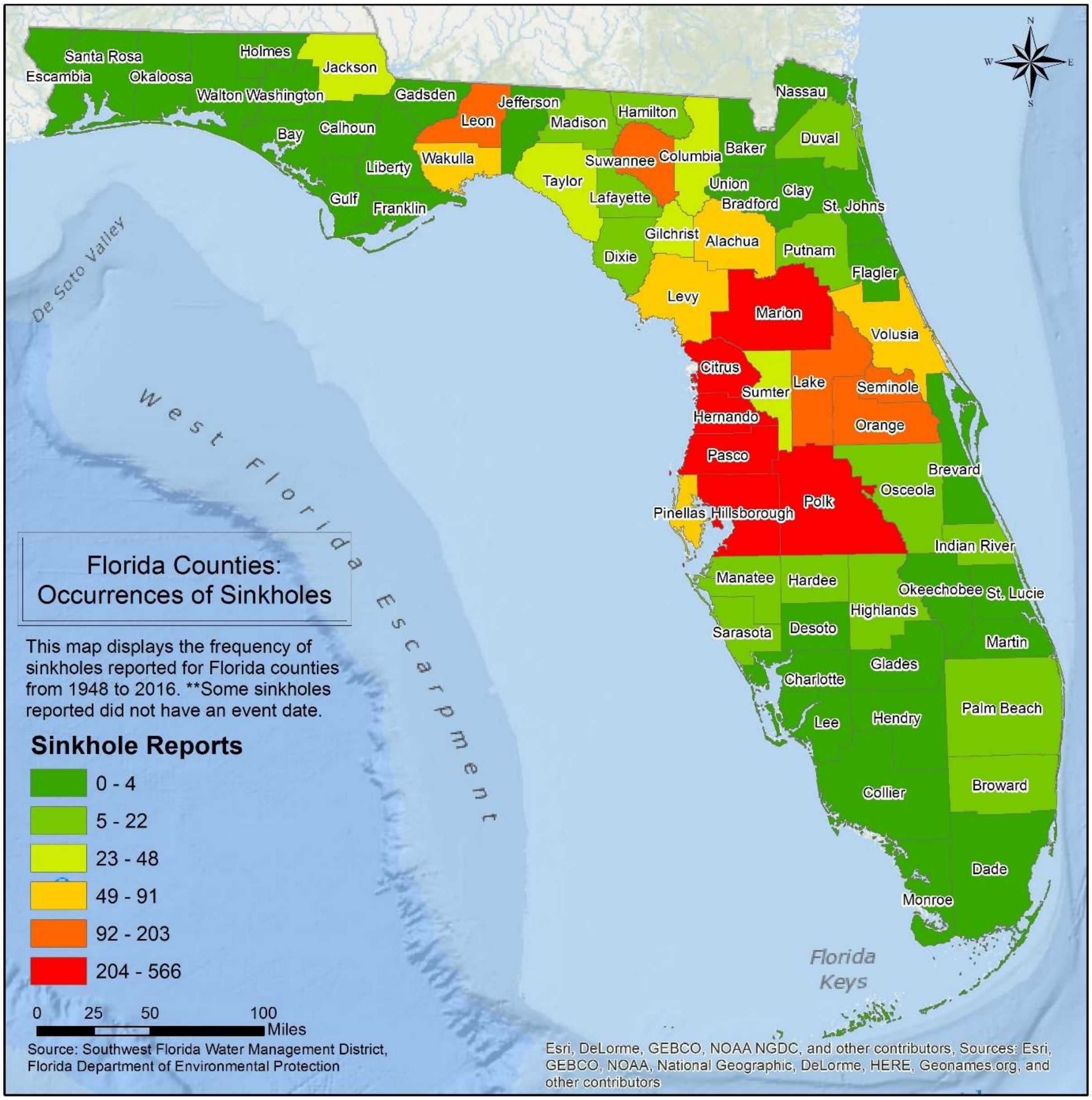
The estimation results from this study indicate that the price of a residential housing property located close to a known sinkhole location is lower than an otherwise similar house located far from a sinkhole location. Proximity to a known sinkhole location lowers estimated sales value for an average house by 2.3% to 8.9% of the average house sales price, and this discount gradually lowers with distance from the nearest sinkhole location. In nominal terms, this discount is from $4,309 to $23,702. All these price discounts are statistically significant. We also estimated the effect of the new sinkhole insurance law in Florida that was effective from July 1, 2016. According to our estimate, due to the new insurance law, the houses within 2 miles of a sinkhole face 2% to 4% price discount. That discount is around $4542 to $9085 on average in nominal terms.

Our estimation showed that after Hurricane Irma, the houses located close to sinkholes suffers a further 2% to 3% price discount compared to the houses that are located further away from known sinkhole areas, and these price discounts are statistically significant. This discount is approximately $4309 to $6464. This result shows that hurricane risk perception triggers people's risk perception of sinkholes. Homebuyers and sellers are aware of the increased risk of sinkhole occurrence following Hurricane Irma, and their increased risk perception is reflected in the housing prices. This price discount allows us to observe how one hydrological hazard like hurricane interacts with a geological hazard like a sinkhole and how that combined effect is reflected in the real estate market.

The evolution of the risk premium may be contingent upon various factors such as severity and frequency of hurricane events and sinkhole incidences and the occurrence of similar events in other places that receive extensive news coverage. We observed the increased risk premium due to Hurricane Irma even after one year. Further research is needed to see if the risk premium persists over a longer period, or it gets eroded shortly after one year. Also, the evolution of this risk premium with time is not clear, and people's reaction to the dual risk of sinkhole and hurricane might change as the memory of a major Hurricane recedes. This evolution of risk perception can be an important topic for future research.

Another interesting finding from this study is that we observe similar price discount due to the new insurance law and Hurricane Irma to the houses that are located close to known sinkholes. So, an institutional change had a similar effect as a natural hazard on the housing market. Government policies are supposed to be targeted towards stabilizing the real estate market, but in this case, the new law resulted in reducing the protection from sinkhole damage and this reduced protection caused price discount for the houses that are located close to sinkholes. This insight can be helpful for the policymakers when they are making or changing policies regarding real estate market in future.

Figure 1: Sinkhole locations in Florida counties.



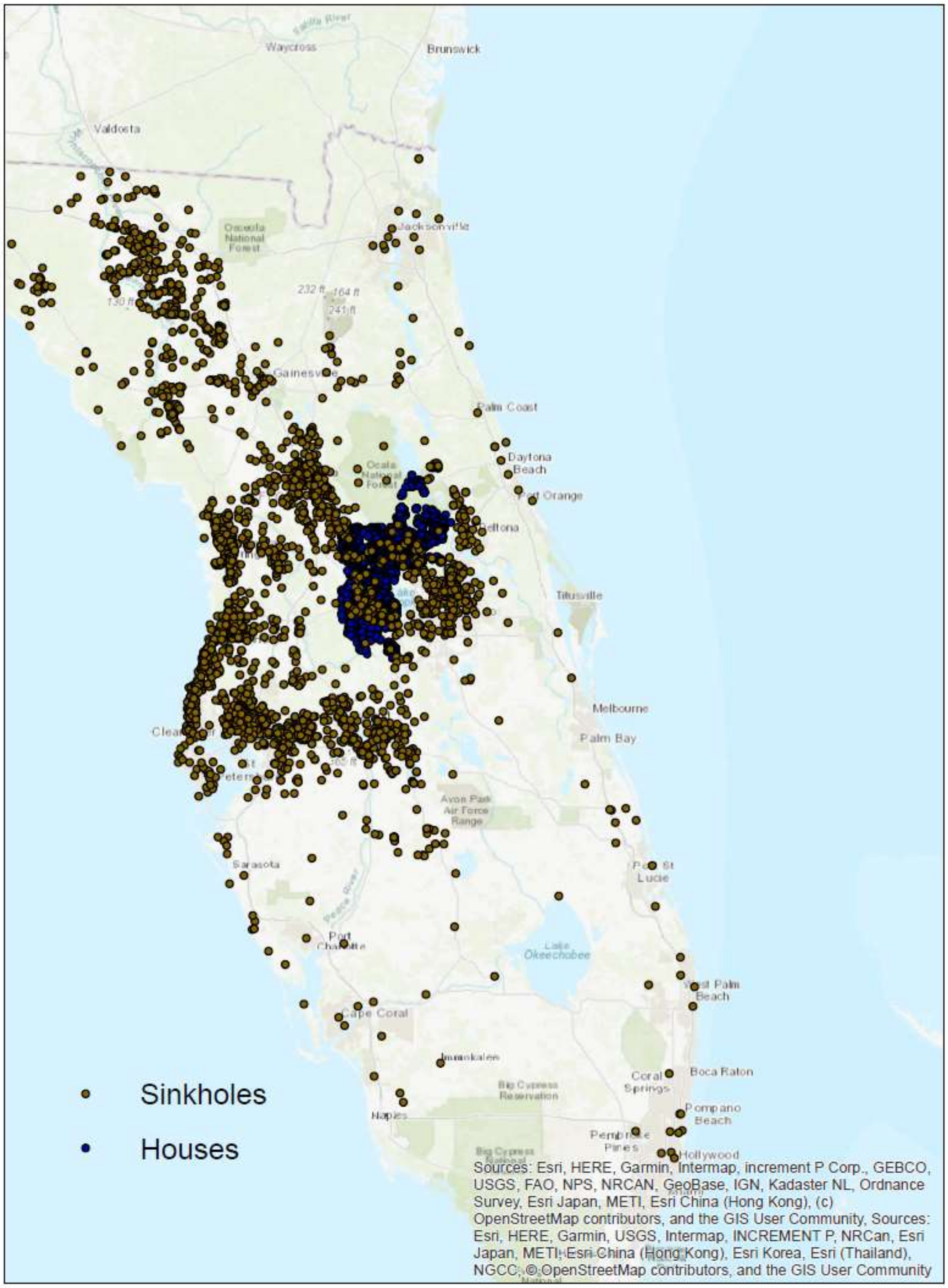
Florida Counties: Occurrences of Sinkholes

This map displays the frequency of sinkholes reported for Florida counties from 1948 to 2016. **Some sinkholes reported did not have an event date.

Source: Southwest Florida Water Management District, Florida Department of Environmental Protection

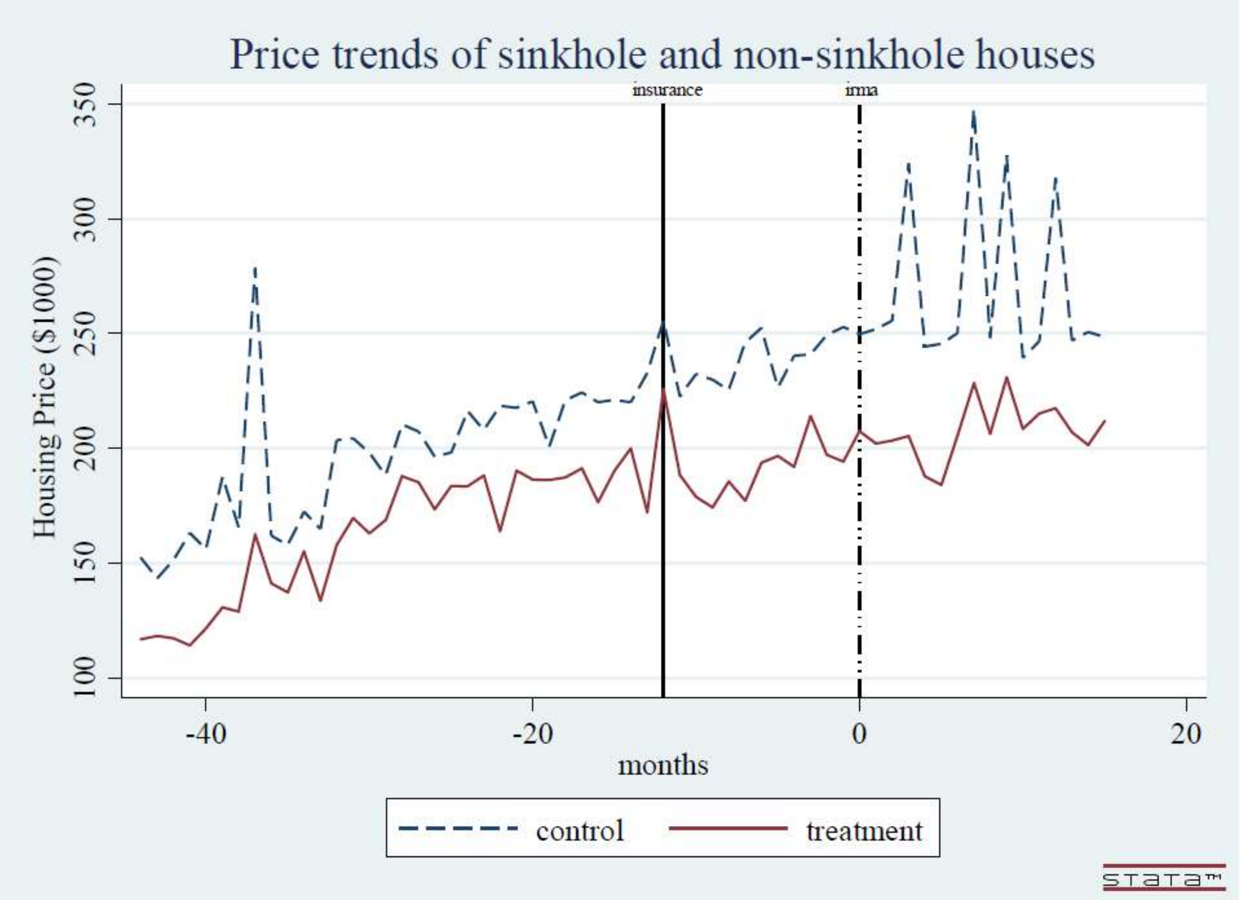
Esri, DeLorme, GEBCO, NOAA NGDC, and other contributors, Sources: Esri, GEBCO, NOAA, National Geographic, DeLorme, HERE, Geonames.org, and other contributors

Figure 2: Locations of the known sinkholes in Florida and sold houses in Lake County.



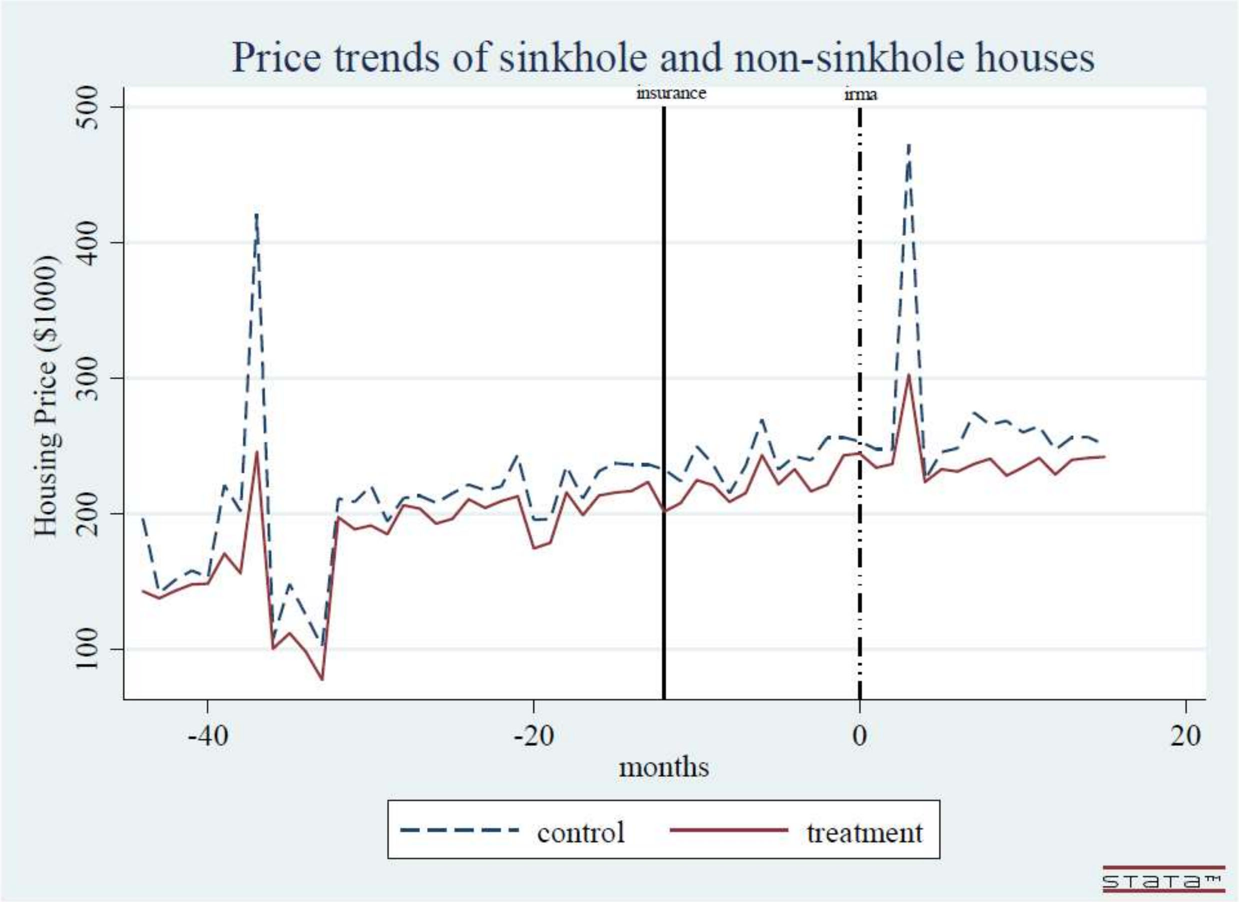
Sources: Esri, HERE, Garmin, Intermap, increment P Corp., GEBCO, USGS, FAO, NPS, NRCAN, GeoBase, IGN, Kadaster NL, Ordnance Survey, Esri Japan, METI, Esri China (Hong Kong), (c) OpenStreetMap contributors, and the GIS User Community, Sources: Esri, HERE, Garmin, USGS, Intermap, INCREMENT P, NRCan, Esri Japan, METI, Esri China (Hong Kong), Esri Korea, Esri (Thailand), NGCC, © OpenStreetMap contributors, and the GIS User Community

Figure 3: Price trend of houses sold within 1/2 mile of a known sinkhole location between 2014 and 2018.



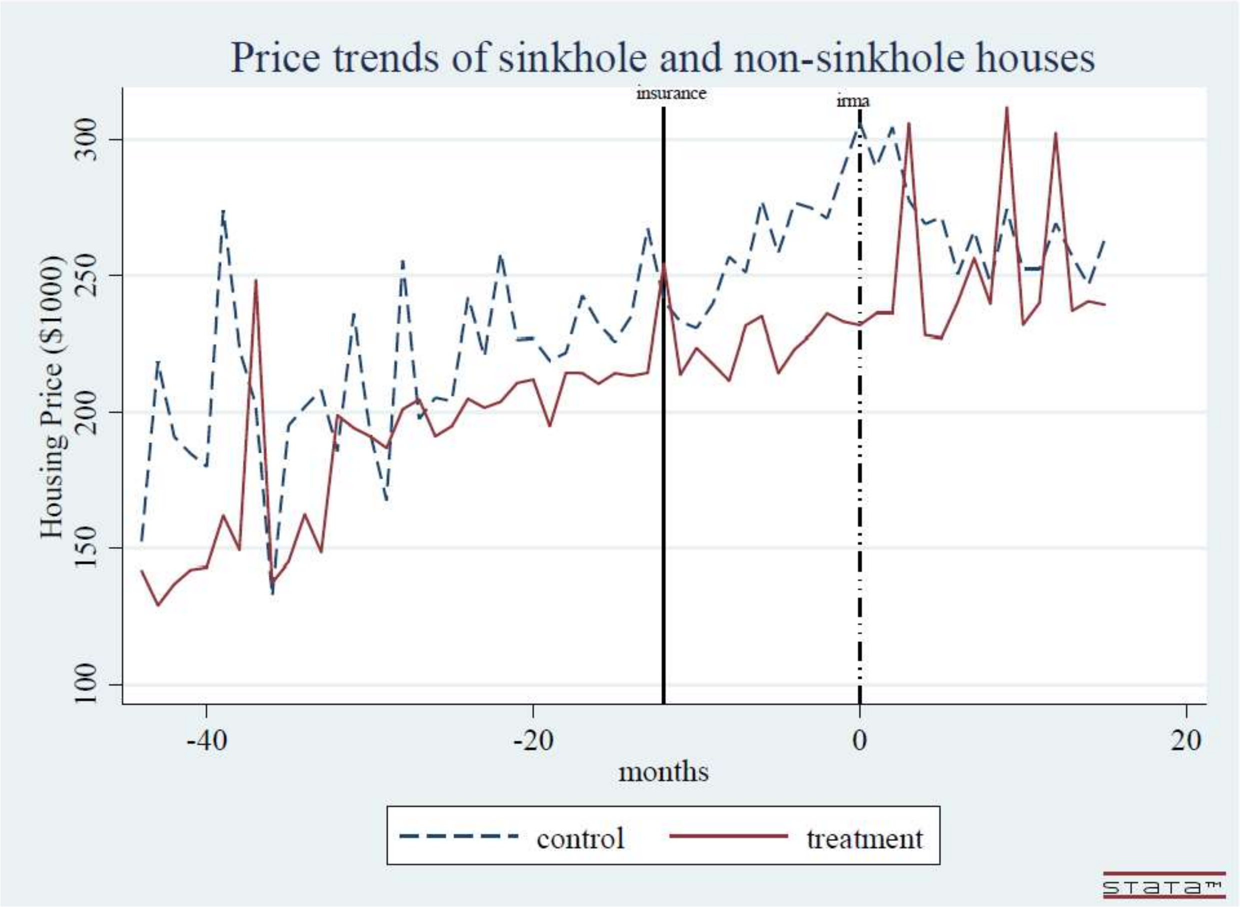
Notes: This figure depicts price trends before and after the new insurance law and Hurricane Irma for properties located within ½ miles of a sinkhole (treatment) and properties located beyond this distance from a sinkhole (control). Source: Authors.

Figure 4: Price trend of houses sold within 1 mile of a known sinkhole location between 2014 and 2018.



Notes: This figure depicts price trends before and after the new insurance law and Hurricane Irma for properties located within 1 mile of a sinkhole (treatment) and properties located beyond this distance from a sinkhole (control). Source: Authors.

Figure 5: Price trend of houses sold within 2 miles of a known sinkhole location between 2014 and 2018.



Notes: This figure depicts price trends before and after the new insurance law and Hurricane Irma for properties located within 2 miles of a sinkhole (treatment) and properties located beyond this distance from a sinkhole (control). Source: Authors.

Table 1: Variable definition.

Variable	Description
House $_{\text{Age}}$	Number of years since the house was built.
Bedrooms	Number of bedrooms in the house.
Acres	Lot size of the house.
Bathrooms	Number of bathrooms in the house.
Fireplace	1, If the house has a fireplace and 0 otherwise.
Pool	1, If the house has a pool and 0 otherwise.
Central air	1, If the house has central air and 0 otherwise.
Distance $_{\text{Airport}}$	Distance of the nearest airport from the house.
Distance $_{\text{Lake}}$	Distance of the nearest lake from the house.
Distance $_{\text{Flood zone}}$	Nearest distance of the flood zone from the house.
Distance $_{\text{Library}}$	Distance of the nearest library from the house.
Distance $_{\text{Sinkhole}}$	Distance of the nearest sinkhole from the house.
Irma	1, If the house was sold after Hurricane Irma and 0 otherwise.
Insurance	1, If the house was sold after June 1, 2016 and 0 otherwise.
Price	Sale price of the house.
Log (price)	Log of the sale price of the house.
Sinkhole $_{\text{1/2 mile}}$	1, if the house is located within ½ mile of a known sinkhole location and 0 otherwise.
Sinkhole $_{\text{3/4 mile}}$	1, if the house is located within 3/4 mile of a known sinkhole location and 0 otherwise.

Sinkhole $_{1\ mile}$	1, if the house is located within 1 mile of a known sinkhole location and 0 otherwise.
Sinkhole $_{2\ mile}$	1, if the house is located within 2 miles of a known sinkhole location and 0 otherwise.
Q1-2014 to Q4-2018	Quarterly time trend variables for the period 2014 to 2018 (Q1-2014 is the base quarter)

Table 2: Descriptive statistics.

Variable	Observations (N)	Mean	Min	Max	Standard deviation
Price	37,788	227118.3	50000	3500000	153004.2
House $_{\text{Age}}$	37,788	22.34	0	159	19.74
Bedrooms	37,788	3.02	1	6	0.81
Acres	37,788	0.66	0	517.1	4.78
Bathrooms	37,788	2.07	0	6	0.57
Fireplace	37,788	0.121	0	1	0.350
Pool	37,788	0.142	0	1	0.349
Central air	31,901	0.974	0	1	0.156
Distance $_{\text{Airport}}$	37,788	2.65	0.08	15.13	1.54
Distance $_{\text{Lake}}$	37,788	0.18	0.003	1.22	0.12
Distance $_{\text{Flood zone}}$	37,788	0.32	0.001	1.30	0.18
Distance $_{\text{Library}}$	37,788	2.92	0.37	12.21	1.66
Distance $_{\text{Sinkhole}}$	37,788	1.30	0.001	16.86	1.35
Irma	37,788	0.41	0	1	0.49
Insurance	37,788	0.66	0	1	0.47
Log (price)	37,788	12.02	8.51	18.07	0.76
Sinkhole $_{\text{1/2 mile}}$	37,788	0.18	0	1	0.38
Sinkhole $_{\text{3/4 mile}}$	37,788	0.27	0	1	0.44
Sinkhole $_{\text{1 mile}}$	37,788	0.50	0	1	0.49

Sinkhole $_{2\ \text{miles}}$	37,788	0.70	0	1	0.45
Q1-2014	37,788	.0081	0	1	0.09
Q2-2014	37,788	.0083	0	1	0.09
Q3-2014	37,788	.0084	0	1	0.09
Q4-2014	37,788	0.045	0	1	0.09
Q1-2015	37,788	0.051	0	1	0.20
Q2-2015	37,788	0.051	0	1	0.22
Q3-2015	37,788	0.048	0	1	0.21
Q4-2015	37,788	0.04	0	1	0.19
Q1-2016	37,788	0.051	0	1	0.22
Q2-2016	37,788	0.059	0	1	0.23
Q3-2016	37,788	0.06	0	1	0.23
Q4-2016	37,788	0.051	0	1	0.22
Q1-2017	37,788	0.068	0	1	0.25
Q2-2017	37,788	0.075	0	1	0.26
Q3-2017	37,788	0.063	0	1	0.24
Q4-2017	37,788	0.061	0	1	0.24
Q1-2018	37,788	0.07	0	1	0.25
Q2-2018	37,788	0.08	0	1	0.27
Q3-2018	37,788	0.07	0	1	0.25
Q4-2018	37,788	0.06	0	1	0.24

Table 3: Effect of sinkholes on housing prices. Ordinary Least Squares (OLS) regression.

	Model 1	Model 2	Model 3	Model 4
House $_{Age}$	0.01 *** (0.0002)	-0.01 *** (0.0002)	-0.01 *** (0.0002)	-0.01*** (0.0001)
Bedrooms	0.14 *** (0.004)	0.08 *** (0.004)	0.08 *** (0.004)	0.08 *** (0.004)
Acres	0.015 *** (0.0006)	0.03 *** (0.001)	0.03 *** (0.001)	0.03 *** (0.001)
Bathrooms	0.24 *** (0.006)	0.23 *** (0.006)	0.23 *** (0.006)	0.23 *** (0.006)
Fireplace (=1)	0.32 *** (0.009)	0.23 *** (0.008)	0.23 *** (0.008)	0.23*** (0.008)
Pool (=1)	0.25 *** (0.009)	0.2 *** (0.008)	0.19 *** (0.007)	0.19 *** (0.007)
Central air	0.48 *** (0.02)	0.48 *** (0.02)	0.48 *** (0.02)	0.48 *** (0.02)
Distance $_{Park}$	-0.02 *** (0.001)	-0.016 *** (0.001)	-0.02 *** (0.001)	-0.015*** (0.001)
Distance $_{Library}$	-0.005 *** (0.001)	-0.004 *** (0.001)	-0.005 ** (0.001)	-0.004** (0.002)
Distance $_{Sinkhole}$	0.02 *** (0.002)	0.015 *** (0.003)	0.01 *** (0.003)	0.01 *** (0.003)

Distance $_{\text{Airport}}$	-0.02 *** (0.002)	-0.01 *** (0.002)	-0.016 *** (0.002)	-0.018 *** (0.002)
Sinkhole $_{\text{1/2 mile}}$	-0.082 *** (0.008)			
Sinkhole $_{\text{3/4 mile}}$		-0.07 *** (0.007)		
Sinkhole $_{\text{1 mile}}$			-0.07 ** (0.006)	
Sinkhole $_{\text{2 miles}}$				-0.05 *** (0.008)
Constant	11.00 *** (0.04)	10.93 *** (0.04)	10.95 *** (0.04)	11.00 *** (0.04)
N	31,901	31,901	31,901	31,901
R^2	0.40	0.40	0.40	0.40

Note: Dependent variable is the log of sales price. All models are estimated with quarterly dummy variables. Robust standard errors are reported in parenthesis. *** significant at 1%, ** significant at 5%, * significant at 10%

Table 4: The effect of sinkhole location on housing prices. Spatial error regression.

	Model 5	Model 6	Model 7	Model 8
House $_{Age}$	-0.01 *** (0.0002)	-0.01 *** (0.0002)	-0.02 *** (0.0002)	-0.01*** (0.0001)
Bedrooms	0.07 *** (0.004)	0.07 *** (0.004)	0.07 *** (0.004)	0.05 *** (0.004)
Acres	0.03 *** (0.001)	0.03 *** (0.001)	0.029 *** (0.001)	0.03 *** (0.001)
Bathrooms	0.18 *** (0.005)	0.17 *** (0.006)	0.18 *** (0.006)	0.22 *** (0.006)
Fireplace (=1)	0.15 *** (0.007)	0.16 *** (0.008)	0.15 *** (0.008)	0.21*** (0.008)
Pool (=1)	0.18 *** (0.007)	0.20 *** (0.007)	0.18 *** (0.007)	0.18 *** (0.007)
Central air	0.43 *** (0.01)	0.42 *** (0.02)	0.43 *** (0.01)	0.48 *** (0.02)
Distance $_{Park}$	-0.02 *** (0.001)	-0.006 *** (0.002)	-0.012 *** (0.001)	-0.02*** (0.001)
Distance $_{Library}$	0.002 (0.01)	0.002 (0.002)	0.003 (0.016)	-0.01*** (0.002)
Distance $_{Flood\ zone}$	0.025 (0.01)		0.03 (0.02)	-0.014 *** (0.009)

Distance $_{\text{Sinkhole}}$	0.01 ***	0.01 **	-0.003	-0.001 ***
	(0.003)	(0.004)	(0.003)	(0.10)
Distance $_{\text{Airport}}$	-0.01 ***	-0.003 **	-0.01 ***	-0.014
	(0.02)	(0.003)	(0.002)	(0.003)
Sinkhole $_{\text{1/2 mile}}$	-0.06 ***			
	(0.02)			
Sinkhole $_{\text{3/4 mile}}$		-0.08 ***		
		(0.01)		
Sinkhole $_{\text{1 mile}}$			-0.089 **	
			(0.010)	
Sinkhole $_{\text{2 miles}}$				-0.023 ***
				(0.008)
Constant	11.10 ***	11.32 ***	11.13 ***	11.36 ***
	(0.04)	(0.02)	(0.04)	(0.10)
R^2	0.51	0.49	0.49	0.46
Lamda	0.48 ***	0.47 ***	0.62 ***	0.61 ***
	(0.006)	(0.006)	(0.005)	(0.006)
AIC	39984	41419.3	39925	39938.3
Schwarz	40277	41544.9	40217.9	40231.2
Likelihood ratio	4709.19 ***	4618.41 ***	4697.32***	4691.8***

Note: dependent variable is the log of sales price. All models are estimated with time dummy variables. Robust standard errors are reported in parenthesis. *** significant at 1%, ** significant at 5%, * significant at 10%.

Table 5: The effect of Hurricane Irma on the sale price of houses that are close to sinkholes.

	Model 9	Model 10	Model 11	Model 12
House $_{Age}$	-0.02 *** (0.0003)	-0.03 *** (0.0003)	-0.02 *** (0.0003)	-0.02 *** (0.0002)
Bedrooms	0.18 *** (0.02)	0.64 *** (0.02)	0.18 *** (0.02)	0.64 *** (0.019)
Bedrooms $_{Sq.}$	-.011 *** (0.001)	-.011 *** (0.001)	-.011 *** (0.001)	-.011 *** (0.001)
Acres	0.03 *** (0.001)	0.016 *** (0.0006)	0.03 *** (0.001)	0.017 *** (0.0006)
Bathrooms	0.37 *** (0.02)	0.48 *** (0.014)	0.37 *** (0.01)	0.48 (0.014)
Bathrooms $_{Sq.}$	-0.023 *** (0.002)	-0.03 *** (0.0025)	-0.02 *** (0.002)	-0.02 *** (0.002)
Distance $_{Airport}$	-0.02 *** (0.002)	-0.02 *** (0.002)	-0.02 *** (0.002)	-0.02 *** (0.002)
Distance $_{Flood zone}$	-0.04 *** (0.014)	-0.04 *** (0.01)	-0.005 (0.01)	-0.007 (0.014)
Distance $_{Sinkhole}$	0.05 *** (0.003)	0.05 *** (0.003)	0.06 *** (0.003)	0.06 *** (0.003)
Hurricane	-0.10 (0.11)	0.033 (0.12)	-0.11 (0.10)	-0.11 (0.12)

Sinkhole $_{\text{½ mile}}$	-0.03 *** (0.009)			
Sinkhole $_{\text{¾ mile}}$		-0.01 (0.009)		
Sinkhole $_{\text{1 mile}}$			-0.01 (0.008)	
Sinkhole $_{\text{2 miles}}$				-.02 * (0.030)
Sinkhole $_{\text{1/2 mile}}$* Irma	-0.02 ** (0.01)			
Sinkhole $_{\text{3/4 mile}}$ * Irma		-0.03 ** (0.013)		
Sinkhole $_{\text{1 mile}}$ * Irma			- 0.02 ** (0.01)	
Sinkhole $_{\text{2 miles}}$ * Irma				-0.01 (0.01)
R^2	44	43	44	42
N	31,901	31,901	31,901	31,901

Note: dependent variable is the log of sales price. All models are estimated with time dummy variables. Robust standard errors are reported in parenthesis. *** significant at 1%, ** significant at 5%, * significant at 10%

Table 6: Difference in differences estimates for Hurricane effect on different sinkhole locations.

Distance to nearest sinkhole location	Hurricane Irma	Sinkhole	Diff-in-diffs estimation	Quarter fixed effects	Number of observations
½ mile	0.033 (0.12)	-0.03 (0.009)	-0.02 ** (0.01)	Yes	31,901
¾ mile	-0.10 (0.11)	-0.01 (0.009)	-0.03 ** (0.013)	Yes	31,901
1 mile	-0.11 (0.10)	-0.01 (0.008)	- 0.02 ** (0.01)	Yes	31,901
2 miles	-0.11 (0.12)	-.02 * (0.030)	-0.01 (0.01)	Yes	31,901

Note: dependent variable is the log of sales price. All models are estimated with time dummy variables. Robust standard errors are reported in parenthesis. *** significant at 1%, ** significant at 5%, * significant at 10%. All models include control variables for housing characteristics and quarter dummies.

Table 7: The effect of the new insurance law on the sale price of houses that are close to sinkholes.

	Model 13	Model 14	Model 15	Model 16
Bedrooms	0.08 *** (0.02)	0.08 *** (0.02)	0.08*** (0.02)	0.08 *** (0.01)
Acres	0.02 *** (0.001)	0.02 *** (0.001)	0.03 *** (0.001)	0.02 *** (0.001)
Bathrooms	0.29 *** (0.01)	0.29 *** (0.01)	0.30 *** (0.01)	0.30 *** (0.01)
House Age	-0.02 *** (0.0003)	-0.02 *** (0.0004)	-0.02 *** (0.0004)	-0.02 *** (0.0003)
Bathrooms $_{\text{Sq.}}$	-0.01 *** (0.001)	-0.01 *** (0.001)	-0.01 (0.002)	-0.01 *** (0.001)
Bedrooms $_{\text{Sq.}}$	-0.006 ** (0.002)	-0.006 *** (0.002)	-0.006 (0.003)	-0.006 ** (0.002)
Fireplace	0.21 *** (0.007)	0.21 *** (0.007)	0.21 *** (0.008)	0.21 *** (0.007)
Pool	0.23 *** (0.007)	0.23 *** (0.007)	0.23 *** (0.007)	0.23 *** (0.007)
Distance $_{\text{Sinkhole}}$	0.00003 (01.54e-06)	0.00003 *** (1.73e-06)	2.92E-05 *** (1.85E-06)	0.00002 (1.93e-06)
Distance $_{\text{Lake}}$	0.0001 *** (0.00001)	0.0001 *** (0.00001)	0.00014 *** (1.25E-05)	0.0001 *** (0.00001)
Central air	0.11 *** (0.02)	0.10 *** (0.02)	0.10 *** (0.02)	0.10 *** (0.02)

Sinkhole $_{\text{½ mile}}$	-0.0003 (0.009)			
Sinkhole $_{\text{¾ mile}}$		0.03 *** (0.008)		
Sinkhole $_{\text{1 mile}}$			0.02 *** (0.008)	
Sinkhole $_{\text{2 miles}}$				0.007 (0.01)
Insurance	0.05 (0.06)	0.06 (0.06)	0.06 (0.07)	0.90 (0.07)
Sinkhole $_{\text{½ mile}}$ # Insurance	-0.02 ** (0.01)			
Sinkhole $_{\text{¾ mile}}$ # Insurance		-0.04 *** (0.01)		
Sinkhole $_{\text{1 mile}}$ # Insurance			-0.032 *** (0.01)	
Sinkhole $_{\text{2 miles}}$ # Insurance				0.03 *** (0.01)
Constant	11.29 *** (0.05)	11.27 *** (0.04)	11.27 *** (0.05)	11.30 *** (0.05)
R^2	0.50	0.50	0.50	0.50
N	18,933	18,933	18,933	18,933

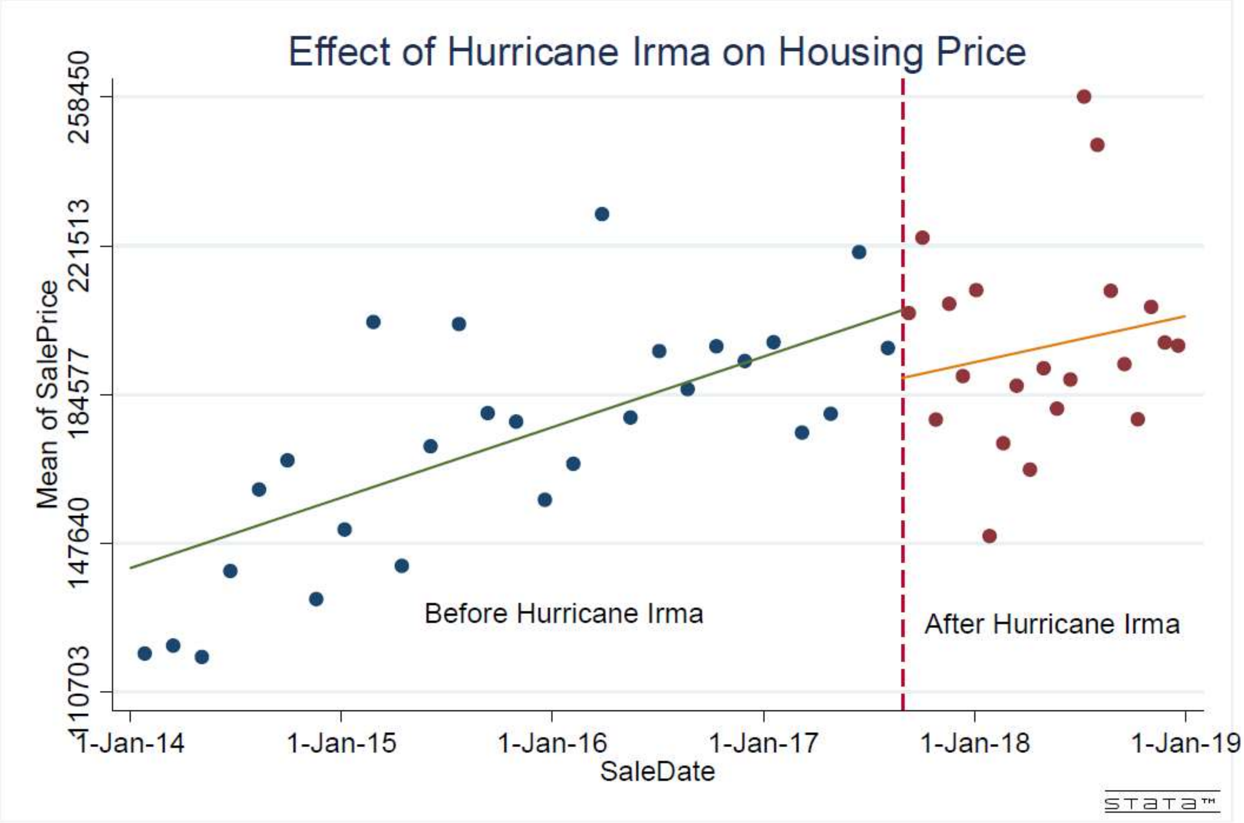
Note: dependent variable is the log of sales price. All models are estimated with time dummy variables. Robust standard errors are reported in parenthesis. *** significant at 1%, ** significant at 5%, * significant at 10%.

Table 8: Difference in differences estimates for the effect of new insurance law on different sinkhole locations.

Distance to nearest sinkhole location	Insurance	Sinkhole	Diff-in-diffs estimation	Quarter fixed effects	Number of observations
½ mile	0.05	-0.0003	-0.02 **	Yes	18,933
	(0.06)	(0.009)	(0.01)		
¾ mile	0.06	0.03 ***	-0.04 ***	Yes	18,933
	(0.06)	(0.008)	(0.01)		
1 mile	0.06	0.02 ***	-0.032 ***	Yes	18,933
	(0.07)	(0.008)	(0.01)		
2 miles	0.90	0.007	0.03 ***	Yes	18,933
	(0.07)	(0.01)	(0.01)		

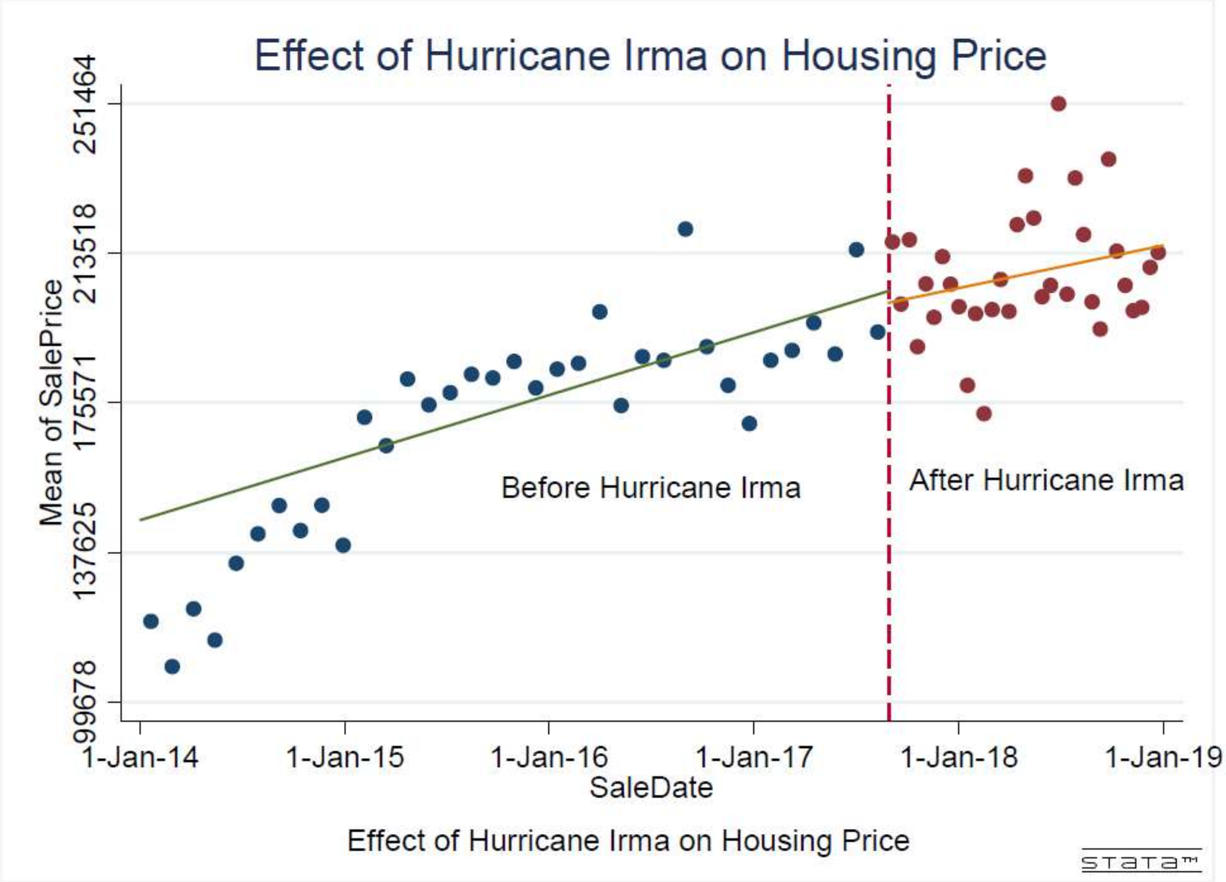
Note: dependent variable is the log of sales price. All models are estimated with time dummy variables. Robust standard errors are reported in parenthesis. *** significant at 1%, ** significant at 5%, * significant at 10%. All models include control variables for housing characteristics and quarter dummies.

Figure 6: Effect of Irma on houses within 0.25 mile of a sinkhole



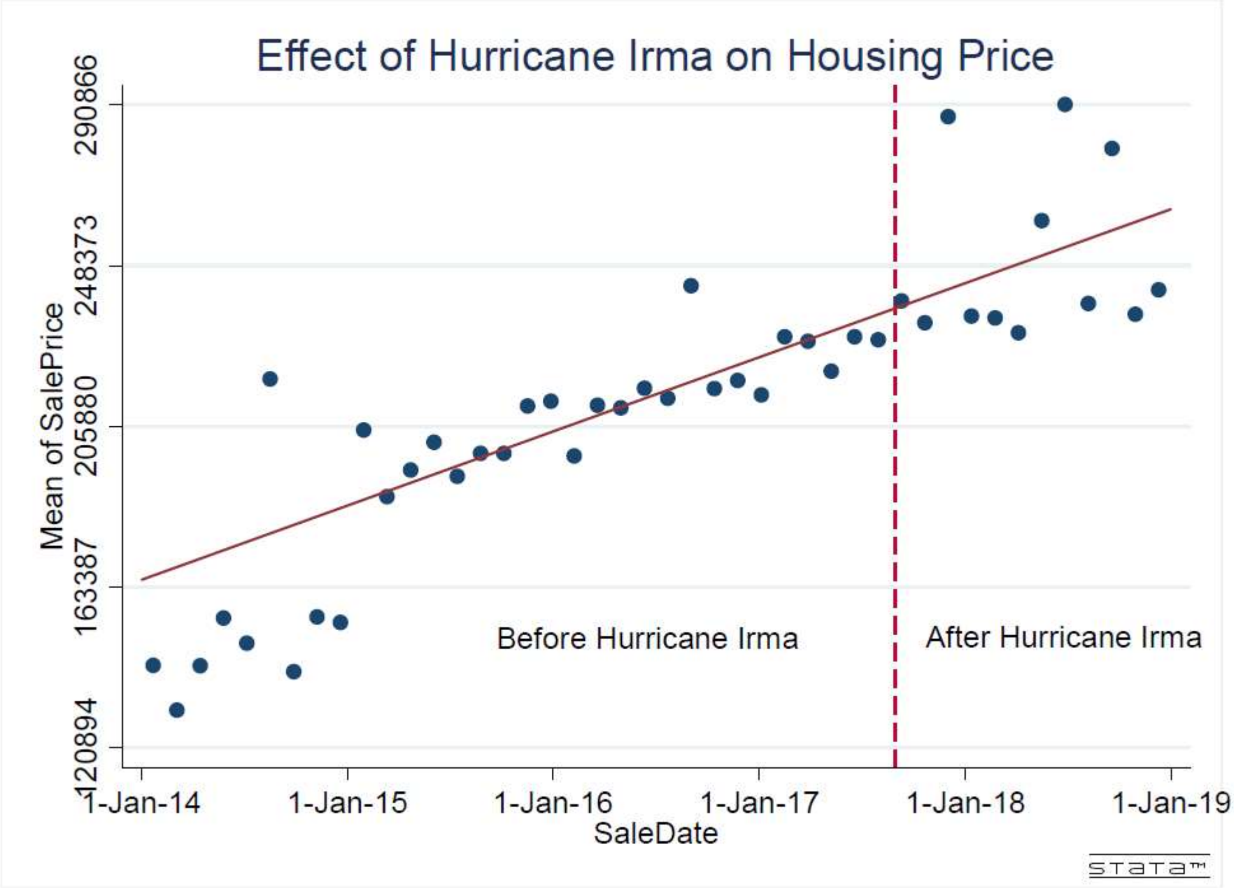
Note: This figure depicts the treatment effect of Hurricane Irma on the prices of the properties that are located within 0.25 mile of a sinkhole and compares the treatment effect with the same property prices before Hurricane Irma.

Figure 7: Effect of Irma on houses within 0.50 mile of a sinkhole



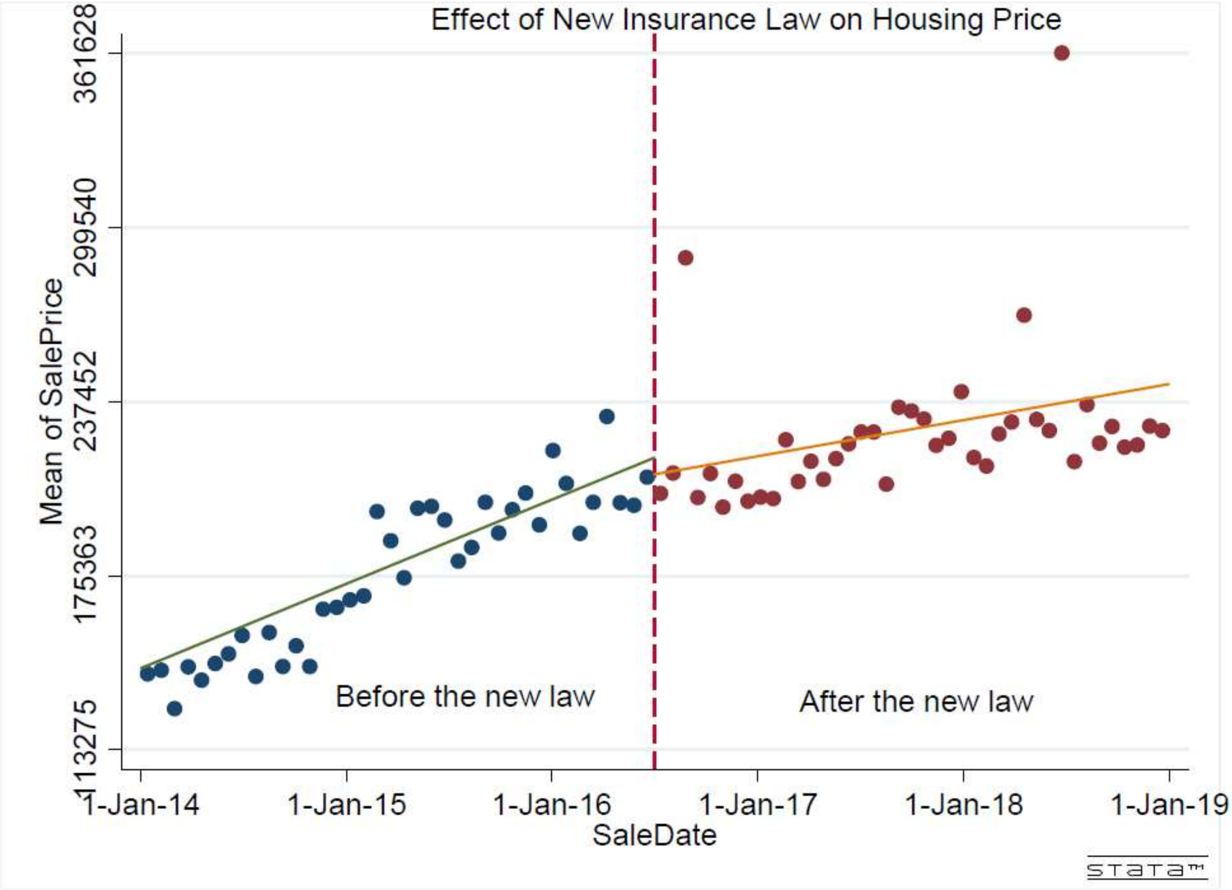
Note: This figure depicts the treatment effect of Hurricane Irma on the prices of the properties that are located within 0.50 mile of a sinkhole and compares the treatment effect with the same property prices before Hurricane Irma.

Figure 8: Effect of Irma on houses within 2 miles of a sinkhole



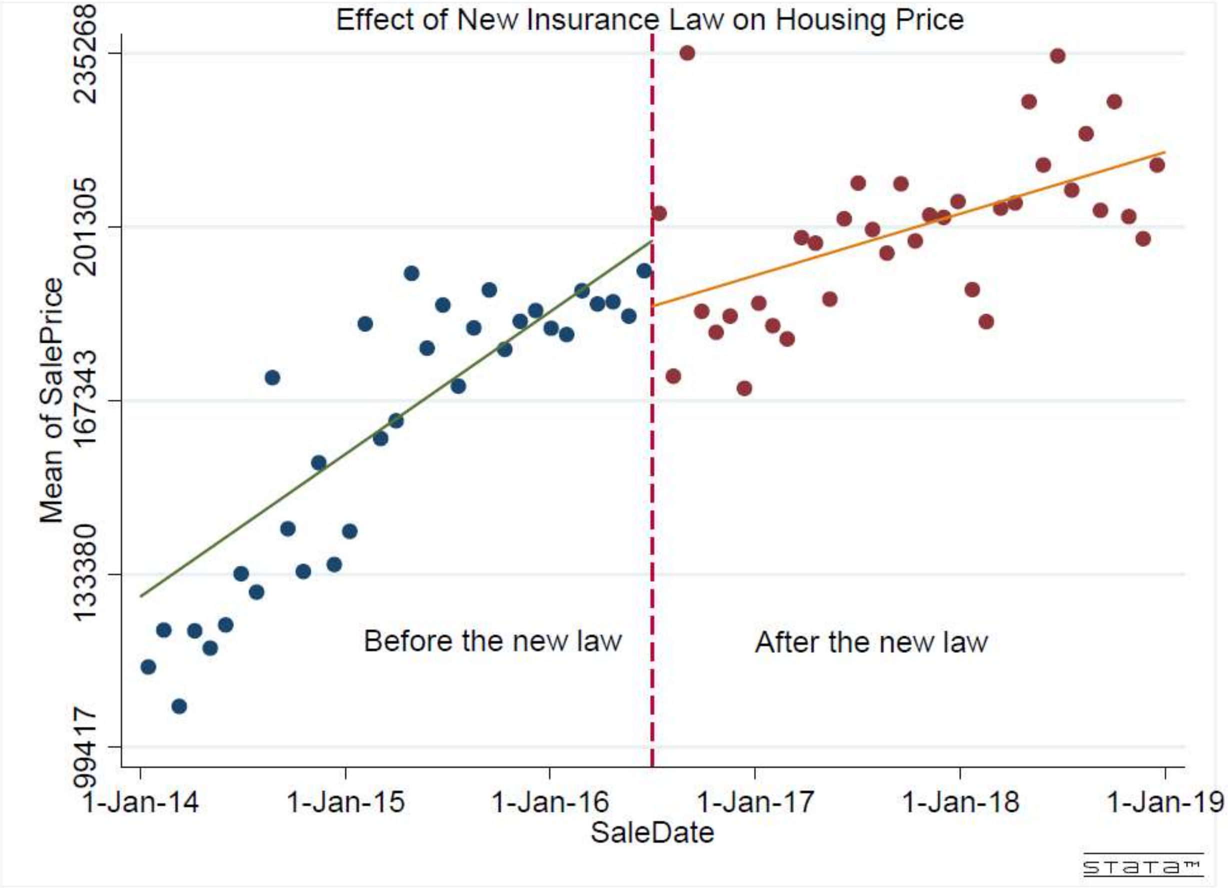
Note: This figure depicts the treatment effect of Hurricane Irma on the prices of the properties that are located within 2 miles of a sinkhole and compares the treatment effect with the same property prices before Hurricane Irma.

Figure 9: Effect of new insurance law on houses within 0.25 mile of a sinkhole



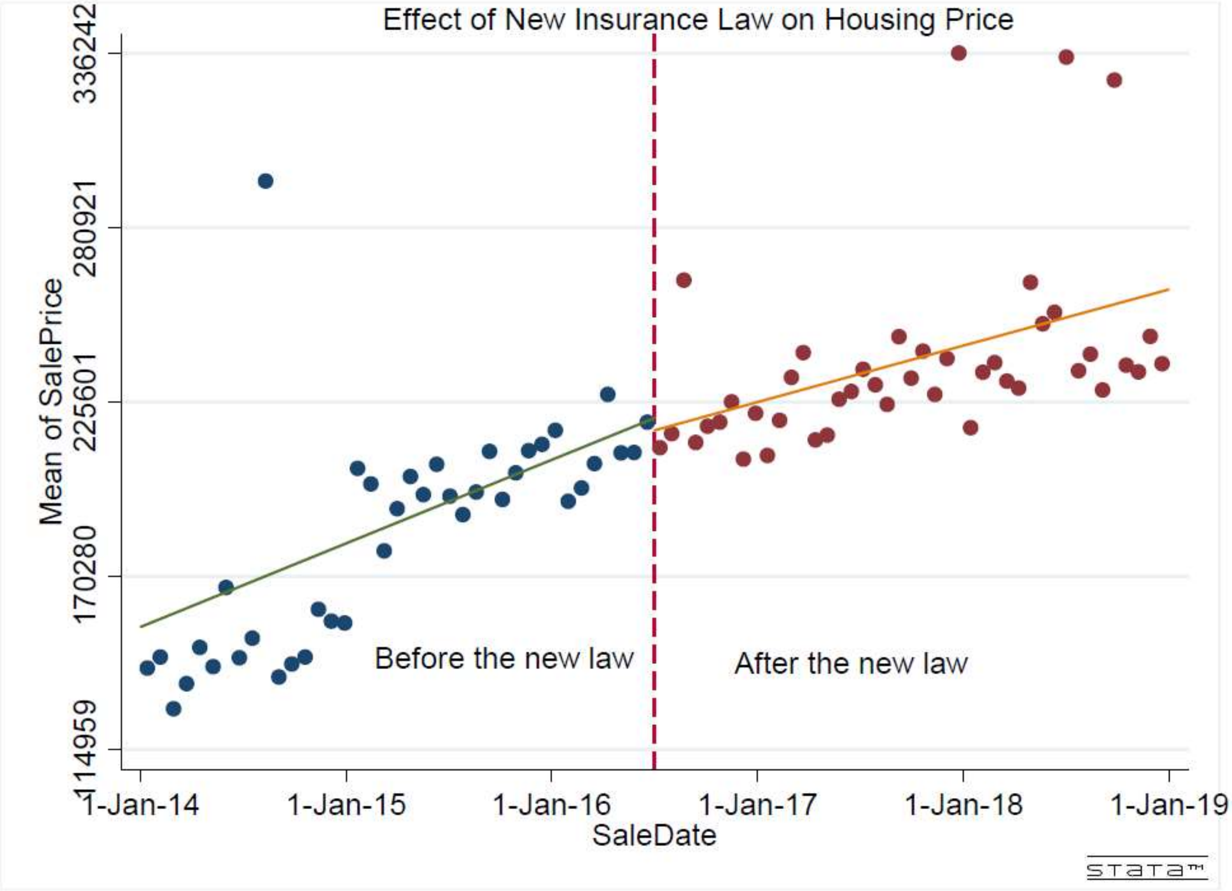
Note: This figure depicts the treatment effect of the new insurance law on the prices of the properties that are located within 0.25 mile of a sinkhole and compares the treatment effect with the same property prices before the new law was in effect.

Figure 10: Effect of new insurance law on houses within 0.50 mile of a sinkhole



Note: This figure depicts the treatment effect of the new insurance law on the prices of the properties that are located within 0.50 mile of a sinkhole and compares the treatment effect with the same property prices before the new law was in effect.

Figure 11: Effect of new insurance law on houses within 2 miles of a sinkhole



Note: This figure depicts the treatment effect of the new insurance law on the prices of the properties that are located within 2 miles of a sinkhole and compares the treatment effect with the same property prices before the new law was in effect.

Table 9: Robustness test with placebo regressions

	Coefficients	Std. error
DID14	-0.07	(0.04)
DID15	-0.003	(0.019)
DID16	-0.03 *	(0.02)
DID17	-0.03 *	(0.014)
DID18	0.025	(0.021)
Treatment	0.08	(0.04)
Constant	0.025	(0.06)
R^2	0.41	
N	31,901	

Note: dependent variable is the log of sales price. All models are estimated with time dummy variables. Robust standard errors are reported in parenthesis. *** significant at 1%, ** significant at 5%, * significant at 10%.