RIJKSUNIVERSITEIT GRONINGEN

Faculty of Spatial Sciences

Thesis MSc Real Estate Studies

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# The impact of flood risk on residential real estate property prices
# A case study on how flood risk in flood-endangered Kingston-upon-Hull affects real estate property prices

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June 30, 2022

*Keywords: natural hazard, flood risk, hurricane, house prices, property prices, property discount*

**Abstract**

This research analyzes the impact of flood risk on property prices on the example of Kingston-upon-Hull in the UK. Due to global warming, natural hazards have become a threat across the world and Europe has been hit by multiples storms and flooding over recent years. Therefore, understanding the various impacts of these hazards gained importance in order to adjust prevention and urban planning of infrastructure and real estate. Based on a hedonic pricing model, I analyze the effect of two floods, in June 2007 and December 2013, on the sales price of real estate property. For my research model I use a sample of 115,157 real estate transactions from 2000-2021 in the Kingston-upon-Hull area. I find evidence that the December 2013 flood had a significant negative impact on real estate property prices (December 2013: -.168; $p < .001$), whereas there is no clear evidence on the consequences of the June 2007 flood. I contribute to literature by advancing insights on the impact of natural hazards on property prices, specifically investigating floods in isolation (vs. e.g., floods as part of a hurricane), adding to a body of literature characterized by conflicting empirical results.

*Master theses are preliminary materials to stimulate discussion and critical comment. The analysis and conclusions set forth are those of the author and do not indicate concurrence by the supervisor or research staff.*

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# 1. INTRODUCTION

## 1.1. Motivation

Several cities in Europe have experienced severe natural hazards, such as storms and floods, over recent years. For example, Germany has most recently experienced the destructive power of flooding due to strong rainfalls in the Eifel area (Bundeszentrale für politische Bildung, 2021), while London has also experienced two severe flash floods in just two weeks in July 2021 (Greater London Authority, 2022). In general, flooding has become a more regular event, increasingly prominent in people's minds as well. For example, in the winter of 2013/14, the UK experienced strong storms and rainfalls, consequently leading to extreme flooding – including the highest recorded tides in the Humber and Thames (Thorne, 2014). To name a few, the UK has experienced the flood caused by storm Franklin in February 2022 (Brown, Topham and Campbell, 2022), the storm Bella flood in 2020 (Bunyan, 2020), and the Hull floods in 2007 (Convery, Carroll and Balogh, 2015). This is not surprising given the UK's geographical location: surrounded by the sea, and crossed by numerous rivers, the country is threatened by floods stemming from river, coastal, and surface water (Thorne, 2014). For the UK, flooding is the most dangerous natural disaster, with ~5 million properties endangered. Floods affect the whole infrastructure of an affected region: ranging from electricity, roads, railways, gas ways, to real estate property (Fekete, 2019).

With the number of severe flood events increasing (Ceola, Laio and Montanari, 2014), research has increasingly highlighted the need to gain a better understanding of flood events to improve prevention and enable sustainable urban planning of buildings, streets, and community design (Pizarro, Blakely and Dee, 2006). While the government has become more aware of the importance of flood prevention, it would be interesting to know whether it has also become a relevant factor for the individual's decision-making. One factor that can be assessed regarding flooding is whether the risk of flooding affects the purchase decision or the purchasing price of real estate (Lamond, Proverbs and Hammond, 2010). Previous research has shown conflicting results: whilst Belanger and Bourdeau-Brien (2018) show that flood risk does significantly affect house prices in areas severely affected by floods, other studies seem to conclude that for other areas individuals do not learn from natural hazards and keep repeating their mistakes without any actions or preventions taken (Donahue and Tuohy, 2006). Therefore, this study aims to find out whether flood risk affects house prices in an area of high flood risks – in the city of Kingston-upon-Hull.

## 1.2 Academic relevance

The effect of natural hazards on real estate property value has received increasing scholarly attention, considering the impact of natural hazard risk on real estate value from multiple perspectives. First, investigating the effect of natural hazard risk on residential property values from a consumer perspective can improve understanding of consumer behavior under uncertainty (Gharbia *et al.*, 2016).

Second, investigating real estate value in areas endangered by natural hazards helps governments to understand how to optimally protect and prepare for natural hazards based on the risk exposure (Gharbia *et al.*, 2016). Third, insurance companies use natural hazard risk assessments to determine a fair price for premiums they charge (Harrison, Smersh and Arthur L. Schwartz, 2001).

Scholars have investigated the effect of natural hazards on real estate property and their key findings can be summarized in three stylized facts (Bin and Landry, 2013). First, real estate property generally sell with a discount if located within a natural hazard risk zone (Troy and Romm, 2004). Second, directly following a catastrophic events, price discounts can be observed (Bin and Polasky, 2004; Hallstrom and Smith, 2005; Carbone, Hallstrom and Smith, 2006). Third, price discounts on real estate property after a flood event diminish over time. Whilst the first and second finding are in line with expectations, the fact that price discounts decrease over time (i.e., the longer the timely distance to a flood event in an area) is peculiar (Zhang, 2016) and raises suspicion that people either forget or underestimate the cost of natural hazards if not directly observing the effects (Atreya, Ferreira and Kriesel, 2013).

Among natural hazards, floods are the most commonly occurring natural disaster globally (Zhang, 2016). The effect of flood risk on house prices has hence been researched extensively, especially house price discounts and respective flood insurance premiums (Harrison, Smersh and Arthur L. Schwartz, 2001; Bin and Polasky, 2004; Atreya, Ferreira and Kriesel, 2013; Bin and Landry, 2013; Zhang, 2016). This is not surprising given that the cost of flood damage has increased over recent years due both to a higher rate of occurrence (Wetherald and Manabe, 2002) and higher property value at risk due to floods, since people have increasingly moved into flood-endangered areas (Freeman, Herriges and Kling, 2003; Kunreuther and Michel-Kerjan, 2007). It is therefore of high interest to understand whether real estate property located in flood-endangered areas are traded at a discount (Daniel, Florax and Rietveld, 2009) and how this discount varies over time, the longer the timely distance from the flood event. While some scholars agree that flood risk leads to a price discount (Bin and Landry, 2013), other scholars find that properties located in a flood zone sell with a premium due to their location (Atreya and Czajkowski, 2019). Since buyers in the US must be informed by mortgage lenders if their properties are located in a flood-risk zone (U.S. Department of Housing and Urban Development, 2009), the authors anticipate a constant risk discount on house prices; however, empirical evidence shows that the risk discount is higher directly after a flood event, and diminishes over time (Bin and Landry, 2013).

### 1.3. Research problem statement

Extant research confirms that real estate property located in areas prone to natural hazard risk, such as flooding, is traded at a discount (Beltrán, Maddison and Elliott, 2019). However, most papers concentrate on areas in the US (Atreya, Ferreira and Kriesel, 2013; Cohen, Barr and Kim, 2021), while the effect might differ in the UK. Additionally, most researches determine the price effects either based on more general investigations of floods or other natural hazard risks without concentrating on specific events, but rather on the general risk perception (Kousky, 2010; Shr and Zipp, 2019). Furthermore, they focus on the direct impact of the flood risk by analyzing the direct price discount and only Bin and Landry (2013) consider longer term effects. Against this background, this study concentrates on a specific area in the UK with a specific flood background (Kingston-upon-Hull) and also investigates the effect of flood risk over a longer time period to be able to assess the short- and long-term influences, by looking at the impact in the first four years compared to the changing effect four years after the flood event, on property prices. The study focuses on the area of Kingston-upon-Hull, an area prone to floods since it is located at just 5m above sea level, which means that most parts of the city lie below the sea level during high tide (World Pumps, 2011). Therefore, Kingston-upon-Hull regularly experiences smaller and larger flood events, such as England's summer floods in 2007 (Wainwright, 2007) and floods through a tidal surge in 2013 (Weaver, Owen and Urquhart, 2013). Given the constant and known flood risk, the area of Kingston-upon-Hull is a particularly interesting subject to study for a number of reasons: first, flood risk is a constant threat and the population is well aware of this threat (Ramsden, 2021). The North Sea and major rivers surround Kingston-upon-Hull, therefore, government has put in place numerous measures to prevent flood damages, which have however not been successful (University of Hull, 2014; Environment Agency, 2018). Furthermore, in studies, which focus on areas that experience multiple natural hazards, such as hurricanes and floods, in parallel, the results may be influenced by other effects, e.g. where floods are caused by hurricanes compared to tidal or surface water floods because these effects might differ since the hurricane may cause more damage in addition with the strength of the winds. In contrast thereto, in regions like Kingston-upon-Hull, the floods are not caused by hurricanes, and thus, the impact of flood risk might differ, expecting a lower discount due to less damage. In addition, this study investigates two major floods with different origins during the time period of 2000 to 2021. The June 2007 flood was caused by surface water and spread across the whole city. As opposed to the June 2007 flood, the December 2013 flood was caused by a tidal surge, concentrating on the areas located directly at the river Humber. In combination, these factors constitute a critical gap in existing research. The central research question addresses this gap by investigating the effect of flood risk on house prices in an area under constant flood threat as well as after two major flood events with different origins in June 2007 and December 2013 over a ~20-year time period.

***Central research question****: What effect does flood risk have on the market value of residential real estate property in the area of Kingston-upon-Hull?*

To answer this research question, the topic is broken down into three sub questions, which will be answered individually in within this thesis.

***(Sub-)research question 1****: How does flood risk affect residential real estate property prices?*

The first sub-question will be answered via a comprehensive review of the existing literature and a theoretical framework.

***(Sub-)research question 2****: At what discount (premium) is residential property in flood-affected areas in Kingston-upon-Hull traded?*

***(Sub-)research question 3****: How does this discount (premium) change the longer the timely distance to the last flood event?*

In particular, this study uses hedonic pricing theory to explain the effect of natural hazards on real estate property prices to examine the research question 2 and 3. Thus, this study relies on house price data in the area of Kingston-upon-Hull including details on the property sold (e.g., property type, new built, estate type) from 2000-2021 (HM Land Registry, 2022) in combination with GIS flood records (Environment Agency UK, 2022). To estimate the effect of flood risk on house prices, this research uses a hedonic model following Smith (1985). Hedonic models are frequently used to estimate the effect of natural hazards on housing prices because they can account for changing attribute prices and reduce the effect of unusual observations on price estimates (Wallace and Meese, 1997). Figure 1 below shows the thesis' research model. The conceptual model visualizes the relationship between the independent and dependent variables. This research analyses the relationship between property prices and flood risk. Therefore, the key independent variables are the two flood events in June 2007 and December 2013 showing the impact on the dependent variable, the property price. For more precise results, an interaction variable is added for each flood, defined as Post-flood 2007 / 2013. Finally, the model is completed with the control variables: property characteristics, time, and spatial fixed effects.

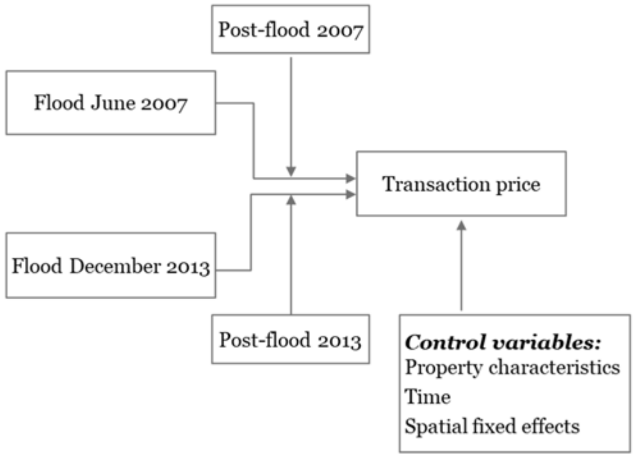



***Figure 1: Conceptual Model***

The remainder of this study is organized as follows. Chapter 2 presents the theoretical background for the effect of natural hazards on real estate property values, which is based on hedonic price theory (Rosen, 1974). Furthermore, it provides an overview of the current state of the literature. Chapter 3 explains the data and methodology used to investigate the previously identified research questions. Chapter 4 summarizes the results and discusses the implications in the context of existing literature. Chapter 5 concludes by explaining the thesis' contribution to research on real estate property value and provides an outlook for future research.

## 2. THEORY, LITERATURE REVIEW & HYPOTHESES

### 2.1 Theory

Hedonic pricing theory defines a price for a property as the consumer's willingness to pay for a "bundle of qualitative and quantitative housing characteristics" (Rosen, 1974; Daniel, Florax and Rietveld, 2009, p.4). The theory is based on the assumption that individuals value certain characteristics of real estate property, which can be features specific to the house or location factors in the neighborhood. Typical house-specific features are the number of rooms, size of house and/or whole property, building materials used etc. Typical neighborhood characteristics can be factors such as proximity to schools, crime rates, air pollution, or flood risk (Daniel, Florax and Rietveld, 2009). According to hedonic pricing theory, a property located within a flood zone will sell at a lower price compared to a property located outside of a flood zone, ceteris paribus. The price discount on the first property is considered to be the cost of flooding (Rajapaksa *et al.,* 2016). In sum, hedonic pricing theory derives the price of a property as a function of these house-specific features and neighborhood and location factors (Morgan, 2007). Hedonic pricing model has been extensively used in literature when investigating an impact on housing prices. Therefore, most articles in the literature review regarding the impact of natural hazards on property prices uses hedonic pricing theory.

### 2.2 Literature Review & Hypotheses

This literature review focuses on studies that determine the effect of natural hazards on real estate pricing. Considering that natural hazards occur regularly, unforeseen, and can destroy all belongings of people, it is only natural that real estate scholars investigate how these affects real estate property as well. In reviewing the literature on the effect of natural hazards on real estate pricing, I identify relevant academic articles published between 2000 and March 2022 focusing on the following search criteria. First, either title, abstract, or keywords must include at least one of the terms "natural hazard", "flood*", or "hurricane" and one of the terms "house prices", "housing prices", "house values", "property prices", "property values", or "property discount". Second, this study focuses on only those real estate journals considered as top-field journals ranked by the American Real Estate Society in 2020, which are listed in Table 1 in the appendix (American Real Estate Society, 2020). Based on these criteria, the initial search identifies >580 articles. By screening these articles through title and abstract, the number of relevant articles that investigate a natural hazard in combination with house prices can be reduced to 23.

Out of these 23 articles, 19 articles focus on the US, one focuses on Japan, two articles focus on New Zealand, and the last one on the Netherlands. Whilst the articles with focus on the US investigate a myriad of natural hazards, the Japan-focused article investigates radio-activity in the wake of the nuclear accident in Fukushima in 2009 to 2017 (Munro, 2018). The two articles in New Zealand focus on the decision-making process of individuals in form of housing transactions regarding the sea level rise and consequently the coastal erosion (Filippova *et al.*, 2020), while the other research studies the relationship between housing prices and liquefaction from 2005 to 2018 (Huang, 2021).

As can be seen in the geographical clustering of the articles identified, the type of natural hazards investigated is highly dependent on natural hazards that certain geographies have the highest exposure risk to, such as earthquakes in New Zealand (e.g. 2010/2011 Christchurch earthquake sequence (Huang, 2021)). Out of the 23 articles identified as relevant in the initial search, 13 focus on floods, three on sea level rise and coastal erosion (Below, Beracha and Skiba, 2015; Walsh *et al.*, 2019; Filippova *et al.*, 2020), two on earthquake-related risks (Koster and van Ommeren, 2015; Huang, 2021), two on the impact of hurricane Sandy (Ortega and Taşpınar, 2018; Cohen, Barr and Kim, 2021), and one each on wildfire (Donovan, Champ and Butry, 2007), radiation levels following a nuclear accident (Munro, 2018), and noise pollution (Cohen and Coughlin, 2008).

The major focus of this literature review lies on the 15 articles related to floods, including the research about hurricane related floods. While there exist numerous studies investigating the effect of flood risk on house prices, closer investigation reveals only few studies investigate the effect of proximity to flood sources on individual house prices, including their location and time of sale. Out of the 14 studies identified, all of them focus on areas within the US. Seven studies focus on a specific event, whilst the remaining eight studies look at more generalized flood risk. Out of the seven event-focused studies, four studies investigate the effect of a Hurricane on house prices (Bin and Polasky, 2004; Bin and Landry, 2013; Ortega and Taşpınar, 2018; Cohen, Barr and Kim, 2021) and therefore potentially include house price effects triggered both by the Hurricane and the following flood. Since hurricanes form over the water, and most often strongly affect coastal areas (NASA Space Place, 2022), these four studies investigate the impact of flooding on property prices after a coastal flood. In the case of Hurricane Floyd, which Bin and Polasky (2004) and Bin and Landry (2013) both analyze in their papers, the resulting flood had both coastal and tidal dimensions, with the Tar River in North Carolina stepping over its shores. Specifically, Bin and Polasky (2004) investigate the impact of flood risk on property prices after Hurricane Floyd, considering the already existing price discount due to the location in a floodplain. The price discount in a flood plain amounts to an average of 5.7%, which doubles after the event of Hurricane Floyd. Bin and Landry (2013) investigate the impact on housing prices after the Hurricanes Fran and Floyd, resulting in a price discount of 5.7% after Hurricane Fran and 8.8% after Hurricane Floyd. The study also examines the development of the risk premium in the years after Hurricane Floyd, which ranges from -6% to -20.2% and diminishes over time. Also Cohen, Barr and Kim (2021) find similar results, investigating the impact of Hurricane Sandy on property prices, including the properties within a flood zone and the distance to the flood zone. The discount after the natural hazard event ranges from 6% to 7% for each mile between property distance and flood zone. Again, this price discount diminishes over time since the residents seem to forget the natural hazard event. The remaining three studies investigate the impact on property prices after the 1993 flood on the Missouri and Mississippi rivers (Kousky, 2010), after the 1994 flood of the century of the Flint River in Georgia (Atreya, Ferreira and Kriesel, 2013) and after the participation in the National Flood Insurance Program (Dehring, 2006). Kousky (2010) and Atreya, Ferreira and Kriesel (2013) both investigate the impact of tidal floods. Whilst Kousky focuses on the Missouri and Mississippi river, Atreya, Ferreira, and Kriesel focus on the Flint River, they both investigate property price development following a flood event and the general flood risk on property prices, for properties located in a 100-year and 500-year flood plain. (Kousky, 2010) finds significant evidence, that property prices located at the river sell at a discount of 6 to 8% after the flood event. Similarly, Atreya, Ferreira and Kriesel (2013) find a 9% discount for properties located in a 100-year flood plain, while there is no significant evidence for a discount in the 500-year flood plain. After the flood event, there was an additional 23% discount in the 100-year flood plain, and property prices also decreased on average by 23% in the 500-year flood plain, however these results are weakly significant. This discount diminishes over time, becoming insignificant seven to nine years after the flood event.

Out of the eight studies with a more generalized approach, one study investigates land prices rather than house prices (Hodge, 2021). Out of the remaining seven studies, two find significant differences in effect sizes between lower- and higher-priced houses (Zhang, 2016; Atreya and Czajkowski, 2019) with a larger effect on lower-priced vs. higher-priced homes. Turnbull, Zahirovic-Herbert and Mothorpe (2013) include the two dimensions of property prices and liquidity in their analysis and find significant capitalization effects for both. Two studies find that despite the flood risk, location to a coastline is also considered an amenity, that can overcome the negative impact of the flood risk, and in sum the two effects result in a price premium on these properties (Bin *et al.*, 2008; Atreya and Czajkowski, 2019). Bin et al. (2008) even succeed in isolating risk factors from coastal amenities. Without controlling for coastal amenities the impact of flood risk has a significant negative impact when located in a 500-year floodplain and shows insignificant results in a 100-year flood plain. In contrast, including the coastal amenity in the research, both flood plains have significant negative coefficients. Therefore, these studies found varying results on the effect of flood risk because these include multiple effects at the same time.

In addition to the aforementioned factors, changing perceptions of risk also seems to have a significant effect on house prices (Hennighausen and Suter, 2020). One factor identified that changes risk perception is the occurrence of a natural hazard event (Huang, 2021). As a result, stakeholders wish to compensate for the resulting flood risks. For examples, insurances wish to charge risk-based flood premiums; however, this meets resistance within the real estate market (Atreya and Czajkowski, 2019). As previous researches have already shown, the flood risk reduces property prices. The flood insurance premium adapts to the flood risk, typically expressed through the price discount. So, the greater the property discount due to the higher flood risk the greater becomes the flood insurance premium. However, this insurance premium does not cover the total price discount due to non-insurable costs of flooding like personal belongings (Bin and Landry, 2013). Thus, the presence of flood insurance can partly restore the perfect market equilibrium and thus, prices become more independent from the flood. Another way to prevent house owners to experience significant losses is preventive measures. These have the ability to protect properties against floods, but also preserve the value of land in a community (Walsh *et al.*, 2019). Walsh et al. (2019) indicate a positive impact of protective measures on property prices. It can be assumed that high awareness of floods might have a decreasing effect on property prices, whilst protective measures, which inhabitants are aware of, might have a positive effect on property prices.

As the review of the literature shows, the majority of articles focus on areas subject to high risks of natural hazards. Interestingly, only few articles investigate natural hazards in Europe, whereas the research focus lies on the US due to the high occurrences of hurricanes. This might change in the near future given the increasing number of natural hazard events European countries have experienced over recent years, e.g. the German/ Belgian Eifel flood in July 2021 (euronews, 2021). Especially the UK is exposed to high flood risks given its geography, being surrounded by the sea, as well as heavy rainfalls and tidal floods (Wilby, Beven and Reynard, 2008). Interestingly, tidal floods seem to have caused a higher price discount than coastal floods as investigated in previous studies (Beltrán, Maddison and Elliott, 2019). In fact, the price discount diminishes over time, and after six years, there is actually a price premium for properties affected by coastal floods. In contrast, properties affected by tidal floods sell at a price discount, which also decreases over time, but does not fully diminish in the long-term. The long-term price premium of coastal properties might be explained through the coastal amenities and the opportunity for homeowners to upgrade the properties (Beltrán, Maddison and Elliott, 2019).

Furthermore, there is scarce literature determining the isolated effect of flood risk and the occurrence of major flood events on house prices. The previously analyzed articles show a large range of price discounts, ranging from 4-12 % (Bin and Landry, 2013). Thus, investigating the effect of flood risk and the occurrence of flood events on house prices within the UK remains a highly relevant research area. Additionally, these researchers have focused on the direct impact on property prices after a flood event, however the medium-term price discount development, a few years after a flood event, has only received little attention yet. Specifically, this study sets out to investigate this relationship in Kingston-upon-Hull, a flood-endangered city in the UK (Coulthard and Frostick, 2010). Therefore, this study proposes:

*H1: Residential properties located within areas affected by recent floods (June 2007 and December 2013) in Kingston-upon-Hull sell at a discount compared to similar properties un-affected by these floods.*

*H2: Residential properties located within an area flooded during the most recent December 2013 flood sell at a higher discount directly after the flood events compared to similar properties four years later.*

## 3. DATA & METHODS

### 3.1 Context

The City of Kingston-upon-Hull is a city, located on the east cost of Northern England, in the Yorkshire and the Humber region. It lies upon the river Hull at its confluence with the Humber river, a large estuary entering shortly thereafter into the North Sea. In Figure 3 below, the exact location of Kingston-upon-Hull is presented in a map. The city has about 323.000 inhabitants across an area of 71,45 km². The city only lays 2-4 meters above sea level and is therefore, additionally to their location very prone to flooding (*Kingston upon Hull topographic map, elevation, relief*, no date). Due to their location close to the sea and directly located at the large tidal estuary, there is an increased flood risk. Besides, the city is surrounded by high land of the Yorkshire Wolds, pushing the water even more in the lower located city of Hull. The effects of global warming worsen the situation, since the weather changes increases the events of storms and the sea level rises.

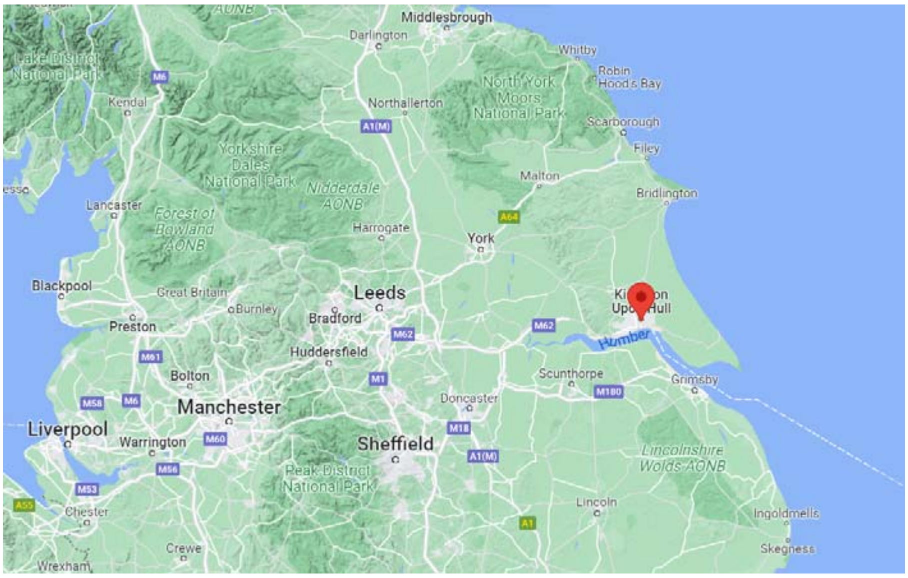



***Figure 2: The map shows the North of England with the marked location of Kingston-upon-Hull. The city is surrounded by the tidal river, the Humber, from the south side, as well as the North Sea from the east side of the city.***

Kingston-upon-Hull has experienced two major floods in June 2007 and December 2013 during the time period of 2000 to 2021. The flood in 2007 lasted from June 1st to July 25th and was caused by surface water, affecting the east cost of Great Britain as well as Northern Ireland. The heavy rainfalls lead to an overloaded drainage system, which then flooded the city of Hull. During the flood, 13 people were killed and the estimated property damage calculates to about 6.5 billion pounds across Great Britain (BBC News, 2008). The December 2013 flood hit the east coast of England and was caused by a tidal surge, created by strong winds followed by low pressure (Environment Agency, 2014).

Protecting a property against flood risk in the UK, the building or home insurance includes the coverage for major risk like floods. The insurance premium depends on the flood risk, meaning that a property with a higher flood risk, also charges a higher insurance premium. There has been an agreement, called Statement of Principles, which obligates insurance companies to maintain insurance offers for existing customers in a high flood risk area, but only if there is a plan reducing the flood risk in the next five years (Local Government Association, 2022). However, this agreement expired in 2013 and has been replaced by the Flood Re in April 2016 (Flood Re, 2022). The Flood Re, flood reinsurance, is an agreement between the government and insurance companies, protecting insurance companies against the cost of flooding. After a flood event, the insurance company can claim the costs to the Flood Re. This way the government can offer more affordable flood insurance to the population. But, the Flood reinsurance only covers properties built before 2009, to discourage real estate companies from constructing properties in high flood risk areas.

The flood records offer a precise geographical map outlining the floods in 2007 and 2013. With the GIS system, we can also create a layer of the transactions with the exact location and their x- and y-coordinates. This allows us to be exact with the statements, which transaction has been affected by the floods. It is important for the analysis to run the analysis with the exact positions in order to get representative results. A flood can reach up to a certain point and affect these properties, but the close neighboring properties are not affected. Consequently, these houses are not affected by the flood and are labeled accordingly.

Due to the cities high flood risk location, there has been ongoing research and education through the Living with Water partnership to invest in innovative engineering and infrastructure to increase the cities and population's resilience against floods (International Water Association, no date). This partnership is aiming to cooperate with the "public and private sector and including the communities to develop water sensitive urban regeneration", reducing vulnerability to flooding. Investing in new infrastructure and engineering ideas, the partnership is using global technology like adaptive green spaces, temporary lagoons, and eco-housing. Implementing one of these innovations is the construction of water resilient homes (International Water Association, no date). Thus, the case of Hull is a great example for other future cities getting into the same locational threat. It will help to understand the whole phenomenon on a deeper level and how to create flood resistant cities. In the context of this research, it has to be considered that these preventions might influence the results. On the one hand, these preventions, if successful, might reduce a negative price effect, or, if ineffective, may confirm the price discount. Either outcome, the city of Kingston-upon-Hull can be used as an example for other cities in the future, since some cities will be in the same locational situation as Hull, lying so close above sea level and therefore, being at higher risk for flooding. So, the effectiveness of these preventions, which may be reflected in the development of property prices, can be used as an example for other cities to make economical efficient decisions.

### 3.2 Data collection

The analysis relies on two datasets from different sources. The transaction prices of the City of Kingston-upon-Hull from 2000 to 2021 have been obtained from the HM Land Registry (HM Land Registry, 2022), which registers all transaction prices for the given location and time period. For the data about the flooded areas, I used the recorded flood outlines from the UK government website in form of a GIS layer (Environment Agency UK, 2022).

The transaction price data has a total of 118,025 observations in the City of Kingston-upon-Hull in the time period of 2000 to 2021. Following Morgan (2007), transaction prices below or above a threshold may represent outliers, hence any transactions outside a price range from 15,000 to 2,5 million pounds have been excluded. After excluding the potential outliers, the transaction dataset consists of 115,157 properties. The recorded flood outline map shows the recorded flood outlines of recent floods, recorded since 1969 (Environment Agency UK, 2022). This layer gives detailed information about the cause and time period of the floods. The recorded flood outline includes observations of three major flood events: the 1969 January and September flood, the June 2007 summer flood, and the December 2013 flood. After dropping the observations from the floods in 1969 because this study focuses on the time period of 2000 to 2021, there are 10,338 properties, which have been affected by the flood in 2007, and 1,451 properties affected by the December 2013 flood. As presented in Figure 3 below, which shows the map of Kingston-upon-Hull including the two flood outlines, these floods differ significantly in their origin. While the 2007 flood was caused by surface water due to an overwhelmed drainage system, the 2013 flood was caused by a tidal surge. Therefore, the June 2007 flood is spread across the whole city and there is no clear relationship between the flood-affected area and properties, whereas the December 2013 flood focuses on the area right at the tidal, the Humber, and “only” the properties close to the tidal are affected by the flood. In order to indicate, which properties are located within a flood affected area and which properties are located in a non-flooded area, I have to include the transaction dataset in GIS as well. Then, I can generate x and y coordinates for each transacted property. By intersecting the recorded flood outlines with the layer of transactions, which are both based on x and y coordinates, I created an additional layer showing which properties have been affected by the respective floods. By merging the datasets by the coordinates, I have exact determination whether a property was affected by either flood or is located in a non-flooded area.

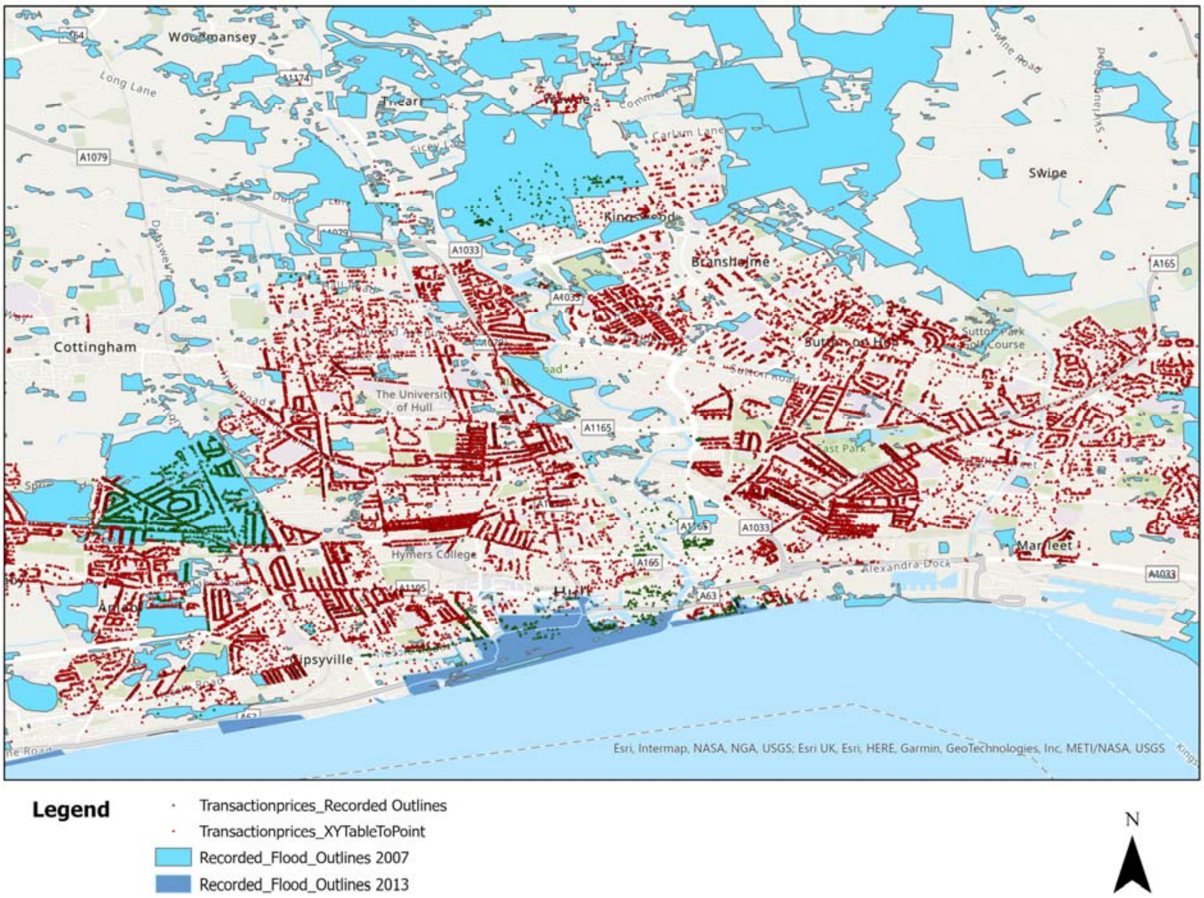



***Figure 3: The blue outlines are the areas affected by historic floods, separated by the flood in June 2007, presented in the lighter blue, and the December 2013 flood, which is shown in the darker blue. The green triangles represent the properties, which are affected by the floods, while the red triangles are the properties, which are not located in the flood zones.***

**3.3 Descriptive statistics/analysis**

As shown in the table 2, there are 115,157 total observations after merging the datasets. To compare the two different flood zones with itself as well as with the non-flood zone, I separate the data into three groups: flood zone 2007, flood zone 2013, and non-flood zone. The table 2 below shows that the flood zone in June 2007 affected a lot more properties in Hull than the December 2013 did. During the flood in 2007, 10,338 properties were located in the flood zone, compared to 1,451 properties in 2013. There are 103,368 properties located in the non-flood zone, meaning that these properties were neither affected by the flood in 2007 nor in 2013. For all observations, the transaction prices range from 15,000 pound to 2,5 million pounds, which stays constant across the three flood groups as well. The mean varies slightly across the groups, the flood 2007 has the highest mean of 122,250.4 pounds and the non-flood area has the lowest mean of 103,290.2 pounds. The following variables represent the control variables during the regression: new build, property type, and estate type. The variable for new build defines whether the property sold has been newly built. The number for new built properties is significantly higher in the flood zone area of 2007 than in the other ones. In the flood zone of 2007, there are 25.4% properties new built, while in the flood zone 2013 there are 2.3% and in the non-flood are 7.1% new built properties. A further control variable is the property type, separated by detached, semi-detached, flat/maisonettes, terraced, or other. In all three flood groups, the June 2007 flood affected properties, the December 2013 flood affected properties, and the non-affected properties, the property types are distributed somewhat evenly, with the terraced properties being the most present property type. Interestingly, the property types between the flood zone 2007 and the non-flood area behave very similar, while the flood zone in 2013 shows some differences. The similar pattern between the 2007 flood zone and the non-affected flood zone is expected because the 2007 flood is scattered throughout the city, while the 2013 flood focuses on the area right at the Humber. The flat and maisonettes are the most occurred property types in the December 2013 flood affected area, while the property type of terraced real estate occurs most often in the June 2007 affected flood area and the non-flood area. Similar behavior applies for the estate type, which describes whether the properties are sold as freehold or leasehold. In the UK, freehold describes the ownership of the building and the land, while leasehold is considered as leasing the property from the freeholder for a prespecified time period, which last usually around 90 to 120 years. In the flood zone 2007 and the non-flood area the estate for freehold is with 89.9% and 94.3% dominant, while in the flood zone 2013 the estate type for freehold and leasehold splits pretty evenly, the freehold being slightly higher with 52.7%. Accordingly, there is more leasehold in the flood zone of 2013, which again is expected by its coastal location, than in the flood zone 2007 and the non-flood area.

**Table 2: Descriptive Summary**

| Variables | Flood June 2007 | | | | | Flood Dec. 2013 | | | | | Non-Flood Area | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Observations | Mean | St. Dev. | Min | Max | Observations | Mean | St. Dev. | Min | Max | Observations | Mean | St. Dev. | Min | Max |
| Sales Price | 10,338 | 122,250.4 | 77,193.12 | 15,000.00 | 2,248,832.00 | 1,451 | 104,852.00 | 131,901.40 | 15,000.00 | 2,220,000.00 | 103,368 | 103,290.20 | 81,808.24 | 15,000 | 2,485,700 |
| New Build (1=Yes) | 10,338 | 0.254 | | 0 | 1 | 1,451 | 0.023 | | 0 | 1 | 103,368 | 0.071 | | 0 | 1 |
| Property Type | 10,338 | | | | | 1,451 | | | | | | | | | |
| *Detached* | 10,338 | 0.166 | | 0 | 1 | 1,451 | 0.083 | | 0 | 1 | 103,368 | 0.135 | | 0 | 1 |
| *Flat/ Maisonettes* | 10,338 | 0.041 | | 0 | 1 | 1,451 | 0.366 | | 0 | 1 | 103,368 | 0.049 | | 0 | 1 |
| *Other* | 10,338 | 0.005 | | 0 | 1 | 1,451 | 0.072 | | 0 | 1 | 103,368 | 0.012 | | 0 | 1 |
| *Semi-detached* | 10,338 | 0.248 | | 0 | 1 | 1,451 | 0.124 | | 0 | 1 | 103,368 | 0.291 | | 0 | 1 |
| *Terraced* | 10,338 | 0.539 | | 0 | 1 | 1,451 | 0.354 | | 0 | 1 | 103,368 | 0.513 | | 0 | 1 |
| Estate Type (1=Freeh.) | 10,338 | 0.899 | | 0 | 1 | 1,451 | 0.527 | | 0 | 1 | 103,368 | 0.943 | | 0 | 1 |
| Sales Year | 10,338 | 2011.571 | 6.333 | 2000 | 2021 | 1,451 | 2008.97 | 6,618 | 2000 | 2021 | 103,368 | 2009.368 | 6.477 | 2000 | 2021 |

*Note: The descriptive statistics shows the number of observations, the mean, the standard deviation, the minimum, and the maximum for each variable of property characteristics, separated by the flood affected area of the June 2007 flood, the December 2013 flood, and the non-flooded area.*

The graph in Figure 4, presented below, illustrates the median price development per year by each flood group. The graph shows that the price development of the properties, located in the June 2007 flood area and the non-affected flood area, behave quite similar. The mean price constantly increases over time with a small drop around 2008/2009, which might be explained by the financial crisis. However, the drop of the price development of the properties in the June 2007 flood affected area is a little bit bigger compared to the non-flooded properties, which might be a consequence of the flood event, but may also be a result of a stronger increase in previous years. In contrast thereto, comparing the price development to the December 2013 flood, the graph presents a lot more movement. There is a deeper drop during the 2008/2009 period, followed by ups and downs till 2016, when there is a sudden spike, which then decreases in 2017 till 2020 before the graph starts to increase again. A possible explanation for these strong movements in the price development might be a bias caused by the low number of observations for the December 2013 affected flood area. In total, there are 1,451 transactions covering real estate affected by the December 2013 flood during the time period from 2000 to 2021. Consequently, the price development does not show a steady mean, but more ups and downs and the spike in 2016, possibly caused by outliers, defined as high transaction prices during the year.

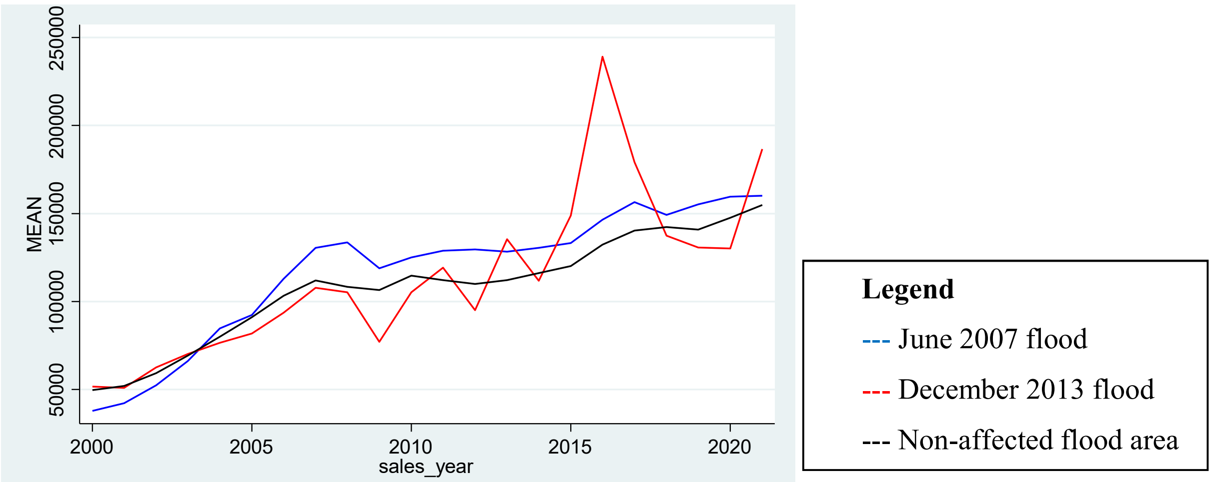



***Figure 4: The graph shows the mean price development for each year from 2000 to 2021 of the three flood groups: flood June 2007, flood December 2013, and non-affected flood area. The flood June 2007 is presented by the blue line, the flood December 2013 by the red line, and the non-flooded area by the black line.***

### 3.4 Methodology

This research aims to find the relationship between flood risk and property prices. Therefore, the model shows the impact of the independent variable, the flood in 2007 and the 2013 flood, on the dependent variable, the sales price. Since the distribution of the transaction prices is skewed, I take the natural logarithm of the transaction price, with that the distribution becomes normal. The natural logarithm of the dependent variable helps with the linearity between the dependent and independent variables and improves the results. I include control variables describing property characteristics like property type, estate type, and new build, time characteristics like sales month and sales year, and spatial fixed effects like street and zip code to reduce bias. The property type determines whether the property is a detached, semi-detached, terraced, flat/maisonettes, or other property. The estate type and new build variables are dummy variables, determining whether the property is freehold or leasehold, and whether the property is newly built. To determine the impact of flood risk on property prices, I used a hedonic price model to see the price change after a flood in a flood zone compared to the control area. Hedonic models are commonly used to find the relationship between house prices and external effects (Can, 1992). The equation of the base model is stated as followed:

$$\ln(P_{it}) = cons + \beta_1 Flood\ area\ 2007 + \beta_2 Flood\ area\ 2013 + \beta_3 NewBuild + \beta_4 Property\ Type + \beta_5 Estate\ Type + \beta_6 Sales\ Month + \beta_7 Sales\ Year + \beta_8 Street + \beta_9 Zip\ Code + \epsilon_{it} \quad (1)$$

where $P_{it}$ represents the sales price, $\beta$ is the coefficient for the independent variables, and $\epsilon_{it}$ the error term.

By using the Difference-in-Difference model, I run two sets of regressions, one regression for each flood separately, the first one investigating the flood in 2007, and in the second one investigating the flood in December 2013. The variable for sales year, sales month, and property type are factor variables, whereas the estate type, the flood in 2007 and the flood in 2013 are dummy variables. In specific, the Difference-in-Difference model, a variation of the hedonic pricing model, is used (Lee and Kang, 2006). This model is considered to be expressive because it includes the treatment effect and the time effect. It is usually often used in the medical research to determine the treatment effect by comparing the treatment group with the control group over a period of time. Explaining this model, consider two time periods and two groups. In the first period, no group is treated, while in the second period, one group, the treatment group is treated, whereas the other group is not treated, the control group. The model can then estimate the effect of the treatment comparing the treatment and control group before and after the treatment. So, in this study, the Difference in Difference model estimates the impact of the flood event, either June 2007 flood or December 2013 flood, by comparing the flood affected area with the non-flooded area before and after the flood event occurred.

**Table 3: Overview of Regression Models**

| Variable | Model 0 | Model 1 | Model 2 | Model 3 | Model 4 |
|---|---|---|---|---|---|
| Flood area | | X | X | X | X |
| Post | | X | X | X | X |
| Flood area x Post | | X | X | X | X |
| Property Characteristics | X | | X | X | X |
| Time Characteristics | X | | | X | X |
| Spatial fixed effects | X | | | | X |

*Note: The table shows which variables have been used in the different regression models. The X indicates whether the variables have been included.*

The table 3 above shows a summary of the different regression models when performing the Difference in Difference model. I start with the regression of my key variables of interest and the interaction term. In the following models I keep adding the control variables of property characteristics, which are the variables for new build, property type, and estate type, time characteristics, which differentiate between sales month and year, and spatial fixed effects, which control for street and zip code. By adding more control variables to each regression model, I can compare the results and use the best fitting model, which can be identified through the highest adjusted $R^2$. The Difference-in-Difference (DID) framework is used in order to test the differences between the property prices in the flood zone versus the control area before and after the flood in 2007. This method is used to compare the outcomes between a control area and the affected area before and after an event occurred (Gibbons and Machin, 2005). The aim of the DID-model is to calculate the intervention effect, which describes the difference between the property prices in the flood zone vs. outside the flood zone. To formulate a DID-model I include an interaction term with a new coefficient, which describes the intervention effect. I create an interaction term, defined as *Flood area x Post*, for the two floods in 2007 and 2013 separately by multiplying the *Flood area* variable, which determines the area affected by the flood, with the *Post* variable, determining the time after the flood occurred. The interaction terms for each flood, as well as the regression equation of the hedonic difference-in-difference model is stated as followed:

Interaction flood 2007:

$$Post\ Flood = all\ dates\ after\ flood\ (2007 - 2012) * dummy\ flood\ area\ Jun\ 2007 \qquad (2)$$

$$\begin{aligned} ln(P_{it}) = cons + \beta_1 Flood\ area\ 2007 + \beta_2 NewBuild + \beta_3 Property\ Type \\ + \beta_4 Estate\ Type + \beta_5 Sales\ Month + \beta_6 Sales\ Year + \beta_7 Street \\ + \beta_8 Zip\ Code + \beta_9 Post + \beta_{10} PostxTarget + \epsilon_{it} \end{aligned} \qquad (3)$$

Interaction Flood 2013:

$$Post\ Flood = all\ dates\ after\ flood\ (2013-2021) * dummy\ flood\ area\ Dec\ 2013 \tag{4}$$

$$\begin{aligned}\ln(P_{it}) = cons + \beta_1 Flood\ area\ 2013 + \beta_2 NewBuild + \beta_3 Property\ Type \\ + \beta_4 Estate\ Type + \beta_5 Sales\ Month + \beta_6 Sales\ Year + \beta_7 Street \\ + \beta_8 Zip\ Code + \beta_9 Post + \beta_{10} PostxTarget + \epsilon_{it}\end{aligned} \tag{5}$$

where the added interaction term *Flood area x Post* describes in case of the 2007 flood the dates after the summer flood in 2007 and before the floods in 2013. For the 2013 flood, the interaction term consists of all dates after the December 2013 flood, so including the years 2014 to 2021 and the dummy variable of the flood affected properties in 2013. The coefficient $\beta_9$ for the interaction term determines the intervention of the flood in 2007 on property prices located in the flood zones.

To test my second hypothesis, stating that *residential properties located within an area flooded during the December 2013 flood sell at a higher discount directly after the flood events vs. four years later,* I include another interaction term separating the dates after the 2013 flood into two groups. The first group are the dates directly after the December 2013 flood, defined with the sales year between 2013 and 2017, and the second group are the dates four years later, so 2018 to 2021. These two Post dummies are then multiplied with the Flood area variable, which is defined as the properties affected by the December 2013 flood. The difference-in-difference model including both interaction terms is presented as followed:

$$\begin{aligned}\ln(P_{it}) = cons + \beta_1 Flood\ area\ 2013 + \beta_2 Post13 + \beta_3 Flood\ area\ 2013\ x\ Post13 \\ + \beta_4 Post18 + \beta_5 Flood\ area\ 2013\ x\ Post18 + \beta_6 NewBuild \\ + \beta_7 Property\ Type + \beta_8 Estate\ Type + \beta_9 Sales\ Month \\ + \beta_{10} Sales\ Year + \beta_{11} Street + \beta_{12} Zip\ Code + \epsilon_{it}\end{aligned} \tag{6}$$

where two new interaction terms are included. The first interaction term includes all dates from 2013 – 2017 and is calculated by Flood area x Post13 = all dates after flood (2013-2017) * dummy flood area Dec. 2013. The second interaction term includes all dates from 2018 – 2021, and is defined as Flood area x Post18 = all dates 5 years after flood (2018-2021) * dummy flood area Dec. 2013.

Additionally, I perform a repeat sales analysis to be able to control for endogenous variables (Bailey, Muth and Nourse, 1963). Repeat Sales are property sales, which have been sold at least twice in the given time period, in this case from 2000 to 2021. This way I can observe price changes over time and especially after the flood events in June 2007 and December 2013. It allows a price analysis without control variables since the property characteristics are most likely staying constant over the time period, so that there should only be a change in property prices. Therefore, the bias of price differences between different properties due to their varying characteristics can be reduced. I run the regression models for each flood separately, including the Flood area variable, the dummy whether the property is located in a flood affected area, the Post variable, the dummy describing if the property is sold after the flood event, and the Interaction term, a dummy defining the properties located in a flood affected area and sold after the flood event. The repeat sales equation for the floods in June 2007 and December 2013 is determined as followed:

$$\Delta_{t,s} \ln(P_{i,t}) = cons + \beta_1 Flood\ area\ Jun. 2007 + \beta_2 Post + \beta_3\ Flood\ area\ x\ Post + \epsilon_{it} \quad (7)$$

$$\Delta_{t,s} \ln(P_{i,t}) = cons + \beta_1 Flood\ area\ Dec. 2013 + \beta_2 Post + \beta_3\ Flood\ area\ x\ Post + \epsilon_{it} \quad (8)$$

where $\Delta_{t,s}$ presents the change of the natural logarithm of the sales price comparing the difference in sales price of the same property sold at different times. The key independent variables are the flood June 2007 and flood December 2013, including the Post and interaction term for each flood.

Finally, I perform propensity score matching (PSM). PSM is a statistical method to estimate treatment effects and to help reducing selection bias (Caliendo and Kopeinig, 2005). This analysis is commonly used for research with a treatment group and a non-treatment group. In this case, the treatment group are the properties located in the flood zone and the non-treatment group are the properties outside the flood zone. The selection bias arises when trying to determine the property prices in the flood zone and outside the flood zone. By using the PSM, the properties outside the flood zone are matched with similar properties, based on their characteristics, located in the flood zone. The PSM is performed in two steps: first, I need to validate the assumptions and then, I can perform the propensity score matching. Starting with the first Step of the propensity score matching, I need to test the two assumptions. If these assumptions do not hold, I observe omitted variable bias. The first assumption is the selection of observables, meaning that the group receiving the treatment is determined entirely by observable characteristics. In this case this means that the properties affected by the flood events can be determined by the observable characteristics. I can make this assumption for the December 2013 flood since the flood was caused by a tidal surge, and consequently, the properties located at the riverside were affected by the flood. However, this assumption is more difficult to argue for the June 2007 flood. Considering the second assumption of common support, that the control and treatment group have similar observable characteristics in order to compare these two groups, I use a two-way plot, shown in Table 4 in the appendix. Before I create the plot, I need to generate the propensity scores. The plot shows the density of the propensity score depending on the propensity scores of the treatment group, the flood affected properties, and the control group, the non-affected properties. Both plots, June 2007 and December 2013, show common support because the graphs overlap a lot. A large amount of population overlaps, which indicates very good evidence for common support. Since I can make an argument for assumption 1 and there is good evidence for assumption 2, I can proceed with the propensity score matching. In Step 2, I can know perform the propensity score matching. The results are presented in 4.1 the results section.

*Sensitivity test*

To examine my dataset for robustness, I start by checking the data for multicollinearity using the three step process based on Kalnins (2018). First, I check for correlation between the variables, as seen in Table 5 in the appendix. Since I do not find correlations above the threshold of 0.3 between the variables, I can conclude that collinearity is unlikely to unduly bias my results. Additionally, I check collinearity using the VIF statistics (Aiken, West and Reno, 1991). The VIF statistics calculates a value for each variable starting at one and going up indefinitely. To interpret this value, the rule states that a value of one presents no correlation, a value between one and ten means a moderate correlation, and a value greater than ten indicates that there is a strong correlation between independent variables (Aiken, West and Reno, 1991). The VIF results, presented in Table 6 in the appendix, shows that the categorical variable property type and the dummy variable estate type have a moderate correlation, having VIF values around 2 and 3. To reduce multicollinearity a possible solution is to drop the variable, which is highly correlated with other variables. However, combining the results from the correlation matrix and the VIF statistics, I conclude that multicollinearity does not unduly threaten the validity of the results and therefore I keep all the variables in the model.

Additionally, I test the data for heterogeneity by performing the Chow-Test. The Chow-Test determines whether the data has any structural breaks by comparing the data when regressing together vs. separately (Nielsen and Whitby, 2015). In this case, I check for a structural break, analyzing the property types. Therefore, I test for a break in property types to determine whether the coefficients stay constant or differ across property types. Next, I can derive the hypotheses; the null hypothesis is defined as *The coefficients stay constant across the sample, whereas the alternative hypothesis is defined as The coefficients differ across the sample.* First, I separate the property types by generating a new variable and redefining each type, detached, semi-detached, flat/maisonettes, terraced, and other. After running a pooled regression, as well as for each property type, I can use the F-value formula to determine the F-value for the Chow-test. The results in table 7 in the appendix show that there is significant evidence at the 5% significance level that I can reject the null hypothesis. Therefore, the coefficients differ across the sample, meaning that the coefficients for the property types differ. This means that there is heterogeneity across property types and there is a difference in the impact of flood risk on property types.

# 4. RESULTS AND DISCUSSION

## 4.1 Results

*Baseline Results*

In this chapter, I summarize my main results on the relationship of flood risk on property prices. To determine the impact of flood risk, the analysis focuses on the specific flood events in June 2007 and December 2013, which were two major floods in the time period of 2000 to 2021 affecting the Kingston-upon-Hull area. I look first at the average reaction of the real estate market on the property prices after the flood event in 2007 and 2013 and then how prices develop yearly the first years after the 2013 flood event compared to the following years four years after.

To avoid biasing my results, I ran separate regressions for the June 2007 and December 2013 floods, so that there is no overlap between the two floods, reducing the influence from the June 2007 on the December 2013 flood on each other. The regression for the June 2007 flood includes transactions ranging from 2000 to 2013, while the regression for the flood event in December 2013 focuses on the sales years from 2013 to 2021. In building up the final model, I run five separate regressions, starting with the flood-related variables only. The second model includes an interaction dummy variable marking all transactions after the 2007 and 2013 floods respectively that are located within either of the flood-affected areas. This helps me to understand whether for the flood-affected properties, the price changes significantly from before vs. after a flood. I then successively add control variables including some property characteristics, time characteristics, including the sales month and year, and spatial fixed effects, including the street and the zip code, to improve the regression results.

The regression tables 8 and 9 below provide an overview of the coefficients for the regression equation, which describe the affect the independent variables have on explaining the variance of the dependent variable, i.e., transaction prices. Hence, the coefficients describe the relationship between property prices and the flood risk after controlling for other effects (property, time, spatial fixed effects). Since the distribution of transaction prices is skewed, I took the natural logarithm of the sales prices. To interpret the resulting regression coefficients, these need to be translated back to the “level” of sales prices. Following the interpretation of dummy variables by (Halvorsen and Palmquist, 1980) the impact of the coefficients on the sales prices can be calculated with

$$\%\Delta\ in\ sales\ price = \left(e^{coefficient} - 1\right) * 100 \tag{9}$$

Following this equation, I can answer the second research question, which is analyzing *at what discount (premium) is residential property in flood-affected areas in Kingston-upon-Hull traded?*

Firstly, adding (control) variables to the model increases the adjusted $R^2$, which means that the addition of the control variables improve the regression results. In contrast to the $R^2$ measure, the adjusted $R^2$ introduces a "penalty" for adding additional explanatory variables; hence, if the adjusted $R^2$ improves, this is an indication that the explanatory variables included have relevant explanatory power. Model 5 in table 8, with all variables included, shows the highest adjusted $R^2$ of .846, meaning that all variables included in the model together are able to explain 84.6% of the variance within the dependent variable, the sales price. The flood area variable, a dummy modeling whether a property is located in an area affected by the flood June 2007, shows a negative insignificant coefficient, meaning that being located in an area that was affected by the June 2007 flood leads to a decrease in property prices. This effect does not yet consider whether the property is sold before or after the flood event. The second variable I consider is the Post variable, i.e., the dummy whether a property has been sold before or after June 2007, the flood event. Again, this variable has a positive significant coefficient of .888 at the 1% significance level. This means that properties sold after June 2007 are sold at a premium compared to properties sold before June 2007 (independent of location). Lastly, we combine these two dummies to investigate whether properties located in an area affected by the June 2007 flood sell at a discount after the flood event vs. other properties. To do so, we use the interaction term *Flood area x Post*. This interaction variable does have a negative coefficient in line with my hypothesis; however, this coefficient is only significant in Model 1 to 3, and becomes insignificant when adding time characteristics and spatial fixed effects in Model 4 and 5. As a result, I do not find support for Hypothesis 1 for the June 2007 flood.

Looking at the December 2013 flood in table 9, I again find that Model 5 including all variables fits the data best since it has the highest adjusted $R^2$ of .846, meaning that the independent variables account for 84.6% of the variance of the dependent variable, the property prices. Again, the flood area variable, the dummy describing whether the property is located within a flood-affected area during the December 2013 flood, presents with a positive insignificant coefficient similar to the June 2007 flood. Properties sold after December 2013, described by the dummy Post, sold at a higher price than before, as reflected by a significant positive coefficient at the 1% significance level. Lastly, the interaction variable also exhibits a significant negative coefficient at the 1% significance level, stating that the flood event in 2013 decreases property prices in the flood affected area compared to the non-flooded area. In sum, properties affected by the 2013 flood sell at a $(e^{-.083} -1)*100 = -7.96\%$ discount after the flood event compared to properties sold in the non-flooded area after 2013.

**Table 8: Regression Results of the June 2007 flood**

| | Model 1 - variables of interest | | | Model 2 - + Interaction effect | | | Model 3 - + House Controls | | | Model 4 - + time controls | | | Model 5 - + spatial fixed effects | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Coefficients | | S.E. | Coefficients | | S.E. | Coefficients | | S.E. | Coefficients | | S.E. | Coefficients | | S.E. |
| ln sales price | | | | | | | | | | | | | | | |
| Flood June 2007 | .225 | *** | .006 | .234 | *** | .007 | .225 | *** | .006 | .098 | *** | .005 | -.005 | | .016 |
| Post | .180 | *** | .005 | .184 | *** | .005 | .219 | *** | .004 | .862 | *** | .010 | .888 | *** | .006 |
| Target x Post | | | | -.041 | ** | .016 | -.112 | *** | .013 | .007 | | .010 | -.010 | | .007 |
| *Controls* | | | | | | | | | | | | | | | |
| New Build | | | | | | | .163 | *** | .006 | .206 | *** | .005 | .135 | *** | .004 |
| Property Type (Base: Detached) | | | | | | | | | | | | | | | |
| Flat/ Maisonette | | | | | | | -.683 | *** | .014 | -.765 | *** | .011 | -.511 | *** | .009 |
| Other | | | | | | | .191 | *** | .015 | -.181 | *** | .012 | -.079 | *** | .010 |
| Semi-detached | | | | | | | -.442 | *** | .005 | -.461 | *** | .004 | -.284 | *** | .003 |
| Terraced | | | | | | | -.875 | *** | .005 | -.883 | *** | .004 | -.390 | *** | .004 |
| Estate Type (1=Freehold) | | | | | | | .153 | *** | .012 | .128 | *** | .009 | .290 | *** | .008 |
| Sales Month | | | | | | | No | | | Yes | *** (1) | | Yes | *** | |
| Sales Year | | | | | | | No | | | Yes | *** (2) | | Yes | *** (3) | |
| Street | | | | | | | No | | | No | | | Yes | *** | |
| Zip Code | | | | | | | No | | | No | | | Yes | (4) | |
| Constant | 11.304 | *** | .002 | 11.304 | *** | .002 | 11.750 | *** | .013 | 11.024 | *** | .120 | 10.520 | *** | .010 |
| *R2* | .024 | | | .024 | | | .305 | | | .579 | | | .854 | | |
| *Adj. R2* | .024 | | | .024 | | | .305 | | | .579 | | | .846 | | |
| *F-value* | 1398.680 | | | 934.800 | | | 5623.640 | | | 3960.960 | | | 5271.760 | | |

* p < .05; ** p < .01; *** p < .001
(1) significant, except February
(2) significant, except 2009 and 2011
(3) significant, except 2009
(4) partially significant; out of 5,816 zip codes, 2,561 are significant

*Note: The table shows the regression results of the June 2007 flood. The dependent variable is the natural logarithm of the sales price. Key independent variables are the Flood area and Post variable, as well as the Interaction variable, Flood area x Post.*

**Table 9: Regression Results of the December 2013 flood**

| | Model 1 - variables of interest | | | Model 2 - + Interaction effect | | | Model 3 - + House Controls | | | Model 4 - + time controls | | | Model 5 - + spatial fixed effects | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Coefficients | | S.E. | Coefficients | | S.E. | Coefficients | | S.E. | Coefficients | | S.E. | Coefficients | | S.E. |
| ln sales price | | | | | | | | | | | | | | | |
| Flood Dec 2013 | -.055 | *** | .016 | -.051 | ** | .019 | .060 | *** | .016 | .105 | *** | .014 | .033 | | .018 |
| Post | .489 | *** | .004 | .489 | *** | .004 | .443 | *** | .003 | 1.204 | *** | .009 | 1.220 | *** | .006 |
| Target x Post | | | | -.011 | | .033 | -.103 | *** | .028 | -.131 | *** | .023 | -.083 | *** | .015 |
| *Controls* | | | | | | | | | | | | | | | |
| New Build | | | | | | | .173 | *** | .005 | .227 | *** | .004 | .134 | *** | .004 |
| Property Type (Base: Detached) | | | | | | | | | | | | | | | |
| Flat/ Maisonette | | | | | | | -.741 | *** | .013 | -.790 | *** | .011 | -.511 | *** | .009 |
| Other | | | | | | | -.133 | *** | .014 | -.188 | *** | .012 | -.077 | *** | .010 |
| Semi-detached | | | | | | | -.442 | *** | .005 | -.461 | *** | .004 | -.284 | *** | .003 |
| Terraced | | | | | | | -.848 | *** | .005 | -.881 | *** | .004 | -.390 | *** | .004 |
| Estate Type (1=Freehold) | | | | | | | .086 | *** | .011 | .110 | *** | .009 | .291 | *** | .008 |
| Sales Month | | | | | | | | | | Yes | *** (1) | | Yes | *** | |
| Sales Year | | | | | | | | | | Yes | *** | | Yes | *** | |
| Street | | | | | | | | | | No | | | Yes | *** | |
| Zip Code | | | | | | | | | | No | | | Yes | (2) | |
| Constant | 11.180 | *** | .002 | 11.180 | *** | .002 | 11.702 | *** | .011 | 11.042 | *** | .012 | 10.518 | *** | .010 |
| *R2* | .139 | | | .139 | | | .390 | | | .578 | | | .854 | | |
| *Adj. R2* | .139 | | | .139 | | | .390 | | | .577 | | | .846 | | |
| *F-value* | 9318.160 | | | 6212.100 | | | 8185.450 | | | 3934.200 | | | 5273.770 | | |

* p < .05; ** p < .01; *** p < .001
(1) significant, except for February
(2) partially significant; out of 5,816 zip codes, 2,561 are significant

*Note: The table shows the regression results of the December 2013 flood. The dependent variable is the natural logarithm of the sales price. Key independent variables are the Flood area and Post variable, as well as the Interaction variable, Flood area x Post.*

To test the robustness of my results, I run a repeat sales analysis, included in Table 10 below. To identify properties that have been sold repeatedly, I check for properties sold with exactly the same address (i.e., including apartment unit). Overall, this results in a dataset of 46,777 transactions. The regression results for the repeat-sales analysis largely agree with the results shown before, yet the interaction term for the December 2013 flood remains only significant at the 10% level. Firstly, the results for the June 2007 flood show a significant negative Flood area variable, while the Post and Interaction variable have significant positive coefficients. This means that the properties affected by the flood are sold at a discount compared to the properties located in the non-affected flood area. However, the Post variable and the interaction term have positive significant coefficients, meaning that the properties affected by the flood in June 2007 and sold after 2007 are sold with a 5.02% premium. Looking at the December 2013 flood, the regression shows a significant negative Flood area and Post variable, but the interaction term has no significance. Thus, there is no significant evidence for the relationship between property prices and the December 2013 flood.

**Table 10: Regression results of the repeat sales analysis for the June 2007 and December 2013 flood**

| | **Model 1 - Repeat Sales Analysis 2007** | | |
|---|---|---|---|
| | Coefficients | | S.E. |
| Flood area June 2007 | -.109 | *** | .007 |
| Post | .044 | *** | .005 |
| Flood area x Post | .049 | ** | .018 |
| | | | |
| Constant | .312 | *** | 0.002 |
| *R2* | .007 | | |
| *Adj. R2* | .007 | | |
| *F-value* | 114.950 | | |

* p < .05; ** p < .01; *** p < .001

| | **Model 1 - Repeat Sales Analysis 2013** | | |
|---|---|---|---|
| | Coefficients | | S.E. |
| Flood area Dec. 2013 | -.045 | * | .020 |
| Post | -.170 | *** | .004 |
| Flood area x Post | -.054 | | .032 |
| | | | |
| Constant | .402 | *** | 0.003 |
| *R2* | .043 | | |
| *Adj. R2* | .043 | | |
| *F-value* | 697.790 | | |

* p < .05; ** p < .01; *** p < .001

*Note: The table shows the regression results of the repeat sales analysis, separately for 2007 and 2013. It includes only the Flood area, Post, and the Interaction variable, because control variables are not needed for this regression.*

To test heterogeneity across the independent variable of property types, I performed a Chow-Test with the results to reject the null hypothesis, meaning that there is significant evidence for heterogeneity across property types. Therefore, I ran further regressions for each property type individually, as presented in Table 11 below. The heterogeneity is underlined by these results since the coefficients for the Flood area x Post 2007 and 2013 vary strongly. The impact of flood risk across the building types on property prices, in fact, range from positive to negative coefficients. However, the coefficients are mostly not significant. Only the property type for semi-detached houses show a significant coefficient for both floods. The results here indicate a positive impact on property prices after the June 2007 flood, while the December 2013 flood has a negative impact on property prices after the flood event. After repeating the regressions for each flood separately, the results show similar outcomes. The interaction term for the property type for semi-detached properties is the only one showing significant results, while the coefficient for the June 2007 is positive and for the December 2013 flood negative. This is partly in line with my previous findings, which resulted no significant impact on property prices after the June 2007 flood and a negative significant impact after the December 2013 flood. However, since the property types other than semi-detached houses show insignificant coefficients for both floods, I have to assume that there is no significant difference on the impact of flood risk on property price across property types before and after a flood event.

**Table 11: Heterogeneity test for property type**

| | Pooled | | Detached | | Terraced | | Flat / Maisonettes | | Semi-detached | |
|---|---|---|---|---|---|---|---|---|---|---|
| Flood June 2007 | | | | | | | | | | |
| *Flood area 2007* | .089 | *** | .126 | *** | .175 | *** | .024 | | -.052 | *** |
| | (.006) | | (.012) | | (.007) | | (.030) | | (.009) | |
| *Post 2007* | .115 | *** | -.019 | | .129 | *** | .083 | *** | .010 | |
| | (.006) | | (.013) | | (.007) | | (.023) | | (.008) | |
| *Flood area x Post 2007* | .005 | | -.012 | | -.051 | ** | -.114 | * | .094 | *** |
| | (.013) | | (.023) | | (.015) | | (.054) | | (.018) | |
| Flood Dec 2013 | | | | | | | | | | |
| *Flood area 2013* | .174 | *** | 0.257 | *** | -.023 | | .205 | *** | .121 | *** |
| | (.017) | | (.041) | | (.022) | | (.027) | | (.034) | |
| *Post 2013* | -.286 | *** | -.475 | *** | -.333 | *** | -.478 | *** | -.424 | *** |
| | (.010) | | (.021) | | (.012) | | (.042) | | (.014) | |
| *Flood area x Post 2013* | -.125 | *** | .078 | | -.003 | | .013 | | -.177 | * |
| | (.028) | | (.078) | | (.043) | | (.047) | | (.059) | |
| *Controls* | | | | | | | | | | |
| Property Characteristics | Yes | *** | Yes | *** | Yes | *** | Yes | | Yes | *** |
| Time Characteristics | Yes | *** | Yes | *** | Yes | *** | Yes | *** | Yes | *** |
| Spatial fixed effects | Yes | *** | Yes | *** | Yes | *** | Yes | *** | Yes | *** |
| Constant | -123.529 | *** | -138.230 | *** | -132.665 | *** | -91.840 | *** | -130.854 | *** |
| | (1.408) | | (2.842) | | (1.662) | | (5.934) | | (1.917) | |
| *R2* | .3645 | | .464 | | .424 | | .218 | | .447 | |
| *Adj. R2* | .3644 | | .464 | | .424 | | .216 | | .446 | |
| *F-value* | 5485.31 | | 1127.010 | | 3618.270 | | 140.220 | | 2197.960 | |

* p < .05; ** p < .01; *** p < .001

*Note: This table presents the regression results for each property type individually. The dependent variable is the ln(sales price). Property characteristics include new build and estate type, time characteristics are sales month and sales year, and spatial fixed effects control for street and zip code.*

**Heterogeneity test for property type for the June 2007 flood**

| | Pooled | | Detached | | Terraced | | Flat / Maisonettes | | Semi-detached | |
|---|---|---|---|---|---|---|---|---|---|---|
| Flood June 2007 | | | | | | | | | | |
| *Flood area 2007* | 0.081 | *** | .111 | *** | .167 | *** | -.049 | | -.054 | *** |
| | (0.006) | | (0.012) | | (0.007) | | (0.030) | | (0.009) | |
| *Post 2007* | 0.233 | *** | .196 | *** | .261 | *** | .271 | *** | .195 | *** |
| | (0.004) | | (0.009) | | (0.005) | | (0.015) | | (0.005) | |
| *Flood area x Post 2007* | 0.020 | | .017 | | -.027 | | -.067 | | .098 | *** |
| | (0.013) | | (0.024) | | (0.015) | | (0.054) | | (0.018) | |
| *Controls* | | | | | | | | | | |
| Property Characteristics | Yes | *** | Yes | *** | Yes | *** | Yes | | Yes | *** |
| Time Characteristics | Yes | *** | Yes | *** | Yes | *** | Yes | *** | Yes | *** |
| Spatial fixed effects | Yes | *** | Yes | *** | Yes | *** | Yes | *** | Yes | *** |
| Constant | -86.233 | *** | -77.709 | *** | -89.093 | *** | -27.940 | *** | -76.497 | *** |
| | (0.465) | | (0.965) | | (0.556) | | (2.042) | | (0.636) | |
| *R2* | 0.360 | | .444 | | .416 | | .191 | | .431 | |
| *Adj. R2* | 0.360 | | .444 | | .416 | | .190 | | .431 | |
| *F-value* | 7158.41 | | 1388.19 | | 4677.39 | | 158.60 | | 2752.50 | |
| *Observations* | 114,781 | | 15,627 | | 59,060 | | 6,057 | | 32,693 | |

* p < .05; ** p < .01; *** p < .001

*Note: This table presents the regression results for each property type individually for the June 2007 flood. The dependent variable is the ln(sales price). Property characteristics include new build and estate type, time characteristics are sales month and sales year, and spatial fixed effects control for street and zip code.*

**Heterogeneity test for property type for the December 2013 flood**

| | Pooled | | Detached | | Terraced | | Flat / Maisonettes | | Semi-detached | |
|---|---|---|---|---|---|---|---|---|---|---|
| Flood Dec 2013 | | | | | | | | | | |
| *Flood area 2013* | 0.163 | *** | 0.245 | *** | -0.048 | * | 0.206 | *** | 0.121 | *** |
| | (0.017) | | (0.041) | | (0.022) | | (0.027) | | (0.034) | |
| *Post 2013* | -0.444 | *** | -.455 | *** | -.500 | *** | -.581 | *** | -.448 | *** |
| | (0.007) | | (0.013) | | (0.008) | | (0.027) | | (0.009) | |
| *Flood area x Post 2013* | -0.131 | *** | .064 | | -.006 | | .010 | | -.174 | ** |
| | (0.028) | | (0.078) | | (0.044) | | (0.047) | | (0.059) | |
| *Controls* | | | | | | | | | | |
| Property Characteristics | Yes | *** | Yes | *** | Yes | | Yes | * | Yes | *** |
| Time Characteristics | Yes | *** | Yes | *** | Yes | *** | Yes | *** | Yes | *** |
| Spatial fixed effects | Yes | *** | Yes | *** | Yes | *** | Yes | *** | Yes | *** |
| Constant | -144.545 | *** | -138.565 | *** | -155.648 | *** | -105.253 | *** | -133.572 | *** |
| | (0.998) | | (1.963) | | (1.200) | | (4.244) | | (1.326) | |
| *R2* | 0.361 | | 0.459 | | 0.413 | | 0.216 | | 0.446 | |
| *Adj. R2* | 0.361 | | 0.459 | | 0.413 | | 0.215 | | 0.446 | |
| *F-value* | 7190.12 | | 1474.31 | | 4614.76 | | 184.77 | | 2921.53 | |
| *Observations* | 114,781 | | 15,627 | | 59,060 | | 6,057 | | 32,693 | |

* p < .05; ** p < .01; *** p < .001

*Note: This table presents the regression results for each property type individually for the December 2013 flood. The dependent variable is the ln(sales price). Property characteristics include new build and estate type, time characteristics are sales month and sales year, and spatial fixed effects control for street and zip code.*

The results for the sensitivity analysis of the propensity score matching, presented in Table 12 in the appendix, have showed different results. The impact for both floods resulted in a positive impact on property prices. Specifically, the coefficient estimate for the impact of the flood June 2007 on the natural logarithm of the sales price is 11.57, and for the December 2013 flood the average treatment effect on the treated is 11.29. Interpreting these results, the properties located in the flood-affected area after the flood events are in average 11.57 of the ln(sales price) higher after the June 2007 flood and by 11.29 higher after the December 2013 flood. When performing the propensity score matching, I need to check my data for two assumptions. The first one is stating that the group, who receives the treatment can be explained by observable characteristics, and the second assumption controls whether the control group and the treatment group have similar observable characteristics. While the second assumption holds, there is no clear evidence that assumption one holds, and therefore, I acknowledge that the estimates might be biased and thus, I do not rely on these results.

As an additional robustness test, I ran the regression for the December 2013 flood without the June 2007 flood affected property transactions to exclude any delayed flood effects from 2007. The regression results for the December 2013, excluding the June 2007 flood affected properties, are presented in Table 13 in the appendix. The resulting changes on coefficients or significance levels are only minor, therefore, I have decided to continue with the full dataset.

*Difference-in-Difference Results*

To assess the second hypothesis, I investigate transactions that occurred during two time periods after the flood, i.e., the change in property prices when the properties are sold directly after the flood vs. 4 years after the flood event. I only look at the price development after the December 2013 flood because the time period between the 2007 and 2013 flood is too short to find significant results for the price development the further the timely distance from the flood event without getting biased results by the 2013 flood. Analyzing the price development, I created two new interaction variables, the product of the Flood area, Flood December 2013, and the sales years from 2013 to 2017 for the first interaction variable and the sales years from 2018 to 2021 for the second interaction variable. I also include the interaction variable for the June 2007 flood as a control variable to check whether the June 2007 flood still has an impact on property prices and therefore, influencing the results for the comparison of the immediate impact compared to the impact 5 years after the flood event.

First, I am investigating the development of the impact of flood risk on property prices after 1, 2, 3, and 4 years before comparing the immediate impact in the first 4 years compared to the following years 4 years after the flood event. The model includes the full regression model 5 of table 9, including the variables for Flood area 2013, Post, and Flood area x Post, as well as the control variables for property characteristics, time effects, and spatial fixed effects. The results are presented below in Table 14, only including the coefficients for the interaction term Flood area 2013 x Post, since this variable is the most expressive variable when looking at the impact of flood risk on property prices. The results show that there is a significant negative impact on property prices in the years 2014 to 2016. In 2017, the coefficient is negative, however it is not significant anymore. Furthermore, I can observe that the price discount is the highest in the first year after the flood event, with a coefficient of -.0074, meaning that in 2014 on average the properties located in the December 2013 flood affected area sold at a discount of $(e^{-0.074} - 1)*100 = -7.13\%$. The price discount then decreases in the following years.

**Table 14: Model results with different cut off years**

| | Flood area 2013 x Post | | |
|---|---|---|---|
| | Coefficients | | S.E. |
| Full Model - until 2014 | -0.074 | * | 0.031 |
| Full Model - until 2015 | -0.071 | *** | 0.005 |
| Full Model - until 2016 | -0.056 | * | 0.022 |
| Full Model - until 2017 | -0.035 | | .019 |

* $p < .05$; ** $p < .01$; *** $p < .001$

*Note: This table shows the regression results from running the complete Model 5 from Table 9, so including the Variable for Flood area 2013, Post, the Interaction Term Flood area 2013 x Post, as well as all control variables property characteristics, time effects, and spatial fixed effects. The table only includes the coefficients for the Interaction Term Flood area 2013 x Post, while looking at the impact of flood risk on property prices after 1, 2, 3, and 4 years after the flood event.*

Then, I compare the impact of flood risk in the first four years vs. the following years four years after the flood event in December 2013. As shown in Table 15 below, both interaction variables show a price discount, providing evidence against the proposition that people forget a flood event. Specifically, the Flood area variable (i.e., location within the area affected by the 2013 flood) stays consistent with the previous regression results and has a positive significant coefficient. I hypothesized a higher price discount directly after the flood, which diminishes over time. Surprisingly, however, the results show a price discount, which increases over time. The average price discount changes from $(e^{-0.064} - 1)*100 = -6.2\%$ in the time period from 2013 to 2017 to $(e^{-0.261} - 1)*100= -22.97\%$ in the time period from 2018 to 2021. A possible explanation for these results might be another external impact in the time period of 2018 to 2021, which pushes property prices down. An example would be the change in the population's behavior regarding flood risk. Although the government has invested a lot of time and money into flood prevention, these measurements might not have had the intended success after the flood in 2013. Possibly, the population has become more aware of the threat of flooding. Due to climate change and rising sea levels, natural hazards have become more present across the world. As the public discussion on climate change and the events of natural hazards have intensified, people may have taken action by preferring properties further away from the river Humber, a flood prone area. However, another explanation for the increasing discount might be a bias due to the fact that there had been a significantly lower number of transactions observed in the December 2013 flood area (i.e. in average only 66 transactions per year). As presented in Figure 4, showing the median price development for each flood group across the time period from 2000 to 2021, the graph for the December 2013 flood illustrates a lot of ups and downs, while the price development for the June 2007 and the non-flooded group shows a more constant development without any major upward or downward movements. Especially in 2016, the mean price for the December 2013 flood spikes and drops thereafter. These strong movements in the price development might be explained by the low number of observations for the December 2013 flood. Thus, outliers have a greater impact on the mean price and as seen in 2016 the mean price spikes. Although, possible outliers are excluded, the transaction prices range from 15,000 to 2.5 million pounds, with a mean transaction price of 104,852 pounds across the time period. Potentially transactions of exponentially expensive properties have caused this spike in 2016, especially with the low numbers of observations per year, it increases the mean price substantially. This might explain the unexpected results that the price discount increases with timely distance from the flood event, the spike in 2016 biased the regression result and consequently, the price discount for the 2013-2017 period appears to be lower, and the discount appears to increase with timely distance from the flood event.

**Table 15: Regression Results of timely effects**

| | **Model - Price effects 0-5 years vs. after 5 years** | | |
|---|---|---|---|
| | Coefficients | | S.E. |
| Flood area | .140 | *** | .014 |
| Time Dec 2013 - 2017 | | | |
| Post 2013 | -.490 | *** | .006 |
| Flood area x Post 2013 | -.066 | * | .031 |
| Time Dec 2018 - 2021 | | | |
| Post 2018 | -.708 | *** | .008 |
| Flood area x Post 2018 | -.263 | *** | .030 |
| *Controls* | | | |
| Flood area x Post 2007 | .066 | *** | .009 |
| Property Characteristics | Yes | *** | |
| Time Characteristics | Yes | *** | |
| Spatial fixed effects | Yes | *** | |
| Constant | -162.464 | *** | 0.946 |
| *R2* | .556 | | |
| *Adj. R2* | .556 | | |
| *F-value* | 8970.950 | | |

* p < .05; ** p < .01; *** p < .001

*Note: Regression Results including interaction terms comparing direct impact of flood risk on property prices vs. effect after 5 years*

The results of the regression analysis are generally in line with the literature, which has shown a negative relationship of property prices and flood risk. The flood event in June 2007 have shown inconclusive results, whereas the December 2013 flood has shown significant results, stating that properties after the flood event in 2013 are sold at a discount. Although the interaction term of the June 2007 flood shows a negative impact on property prices, it is not statistically significant on the 5% significance level and therefore, no significant impact on property prices can be derived from these results. However, although the December 2013 flood shows a significant positive impact for the Flood area variable, the Post and Interaction variable both have a significant negative coefficient, meaning that the flood event in December 2013 had a negative impact on property prices. The positive relationship of the Flood area variable (i.e. the location only, independent of the timing before / after the flood) can be explained by the location of the properties, which is close to the Humber River, so these properties might benefit from a good view or are somehow located in a preferable area, which increases sales prices. The important difference between the flood event in 2007 and 2013 is that the flood in 2007 was caused by surface water, while in 2013 there was a tidal flood. In 2007 the drainage system was overloaded due to heavy rainfalls and caused the flood. Therefore, as seen in the map in Figure 2 above, the floods in 2007 are spread across the whole city, while the 2013 flood is focused on the areas right at the tidal river. Hence, the fact that the 2007 flood occurred in an area not specifically connected to flooding in people's minds (i.e., not closely located to a water source) might explain why the flood event does not result in a significant price discount.

Consequently, for the first hypothesis that *Residential properties located within areas affected by recent floods (June 2007 and December 2013) in Kingston-upon-Hull sell at a discount vs. Properties un-affected by recent floods (June 2007 and December 2013)* I do not find support for the June 2007 flood, whilst I find support for the hypothesis for the December 2013 flood. Regarding the second hypothesis, the regression results have shown that the properties affected by the December 2013 flood actually sell in the first four years after the flood event at a lower average discount compared to the properties sold four years later. Therefore, I do not find support for the hypothesis that *Residential properties located within an area flooded during the December 2013 flood sell at a higher discount directly after the flood events vs. four years later.*

**4.2 Discussion**

With this study, I contribute to literature in two major ways. First, I find that the risk of flood events can, but does not always, have an effect on house prices, confirming that natural hazard risks lead to a certain discount on residential property value (Belanger and Bourdeau-Brien, 2018). Second, similarly to previous studies, I find evidence against the economic theory of perfect markets (Donahue and Tuohy, 2006). Although residential property in Kingston-upon-Hull trades at a discount shortly after the December 2013 flood, there is no significant evidence that the properties sell at a discount after the June 2007 flood. Therefore, although in a perfect market, the risk premium should equal the expected loss from a flood and stay constant over time if the natural hazard risk stays constant, I find this is not the case.

The first contribution shows that the risk of a flood event generally has an effect on house prices in Kingston-upon-Hull. In line with previous studies, that find residential property is traded at a discount, this study confirms this effect. Returning to the central research question of this paper, *"What effect does flood risk have on the market value of residential real estate property in the area of Kingston-upon-Hull?"*, this study provides three avenues to answer the question.

First, regarding (sub-)research question 1, *"How does flood risk affect residential real estate property prices?"*, an extant literature review shows that generally, real estate property affected by a flood trades at a discount shortly after flood events (Troy and Romm, 2004). However, despite the constant risk of a flood (e.g., location in a 100-yr floodplain) affected real estate property, this price discount diminishes over time (Bin and Landry, 2013).

Regarding (sub-)research question 2, *"At what discount (premium) is residential property in flood-affected areas in Kingston-upon-Hull traded?"*, I have used a hedonic pricing model to investigate the effect of two floods in Kingston-upon-Hull, that took place in June 2007 and December 2013, on residential property value. The December 2013 flood had an imminent effect on prices, whilst the June 2007 flood did not show significant results regarding the impact on transaction prices. However, these results can be explained through the different origins of the floods. The June 2007 flood was caused by an overwhelmed drainage system and was therefore, spread across the whole city. Thus, there is no clear relationship between the flooded area and the properties affected by the flood. Possibly, the population perceives the June 2007 flood risk as a general flood risk across the city. In contrast, the December 2013 flood focuses right at the Humber since the flood was caused by a tidal surge. Consequently, there is a clear relationship between the flood and the properties affected and the population can clearly define high risk properties, which explains the price discount after the December 2013 flood.

Regarding the third sub-research question, *"How does this discount (premium) change the longer the timely distance to the last flood event?"*, i.e. whether the price discount decreases over time because people "forget the flood", I again find surprising results. Although I hypothesized that the price discount diminishes over time after a flood event, in fact after the December 2013 flood this discount increased comparing the immediate effect of the flood vs. four years later. Although comparing the first four years from 2014 to 2017 after the flood event, the largest price discount is in the first year after the flood event and decreases over the following years. But after analyzing the impact the first four years after the flood event vs. the following years after, the price discount actually becomes larger for the following years four years after the flood event. A possible explanation for this development is that the population becomes more aware of the increasing flood risk due to climate change and rising sea levels. Due to the cities location, which lies only 2 to 4 meters above sea level, and increasing flood events, the population might have realized the increasing flood risk, which motivates the population to avoid properties close to the Humber. Another explanation for this price development is that the results might be biased since there are only on average 61 transactions per years in the December 2013 flood affected area. Potentially due to transactions of exponentially expensive properties, the mean transaction price for 2016, as seen in Figure 4, increases significantly compared to the previous and following years. Thus, comparing the price discount from 2014 to 2017 to the price development of 2018 to 2021, it seems that the price discount has increased.

In sum, the answers to the three (sub-)research questions help us to provide an answer to the central research question *"What effect does flood risk have on the market value of residential real estate property in the area of Kingston-upon-Hull?"*. The hedonic pricing model in this study supports the hypothesis that flood risk results in a discount on real estate property prices shortly after a flood. However, I only find support for this hypothesis for the December 2013 flood. Surprisingly, this effect actually increases over time. These results are only partially supported by previous findings in literature. However, it cannot be excluded that these results are influenced by other effects like higher flood awareness or by biased results due to a too low number of observed transactions. Based on my results, the amount of the risk premium changes over time, despite the fact that the flood risk remains constant. Specifically, people seem to become more aware of the risk of flood events and the resulting damages over time, and therefore the risk premium increases. Specifically, property prices actually decline further over time for the December 2013 flood, as seen in the regression results. The difference between previous research and my research of Kingston-upon-Hull might be the factor of the location. The city of Hull has suffered from numerous floods due to their risk prone location directly at the Humber and the east cost of England. The city lays 2-4 meters above sea level and most parts of the city below sea level during high tide. Although the government is investing in flood prevention, the population might have realized the increasing threat of flooding due to climate change and rising sea levels.

# 5. CONCLUSION

## 5.1 Main Findings

This thesis examines the relationship between flood risk and property prices for a case study in Kingston-upon-Hull, UK. Flood risks and other natural hazards have become a bigger threat across the world due to climate change, affecting the whole infrastructure of electricity supply, roads, railways, and real estate. It is therefore important to understand the impact of flood risk on the real estate market in order to guarantee information transparency of the real estate market, adjust efficient insurance premiums, and implement efficient preventions. Existing literature has shown conflicting results regarding the relationship between flood risk and property prices, with some articles stating that properties sell at a discount in a flood zone and also affirming that the population does not show any behavior change regarding property transactions after a flood event. The central research question is: *what effect does flood risk have on the market value of residential real estate property in the area of Kingston-upon-Hull?*

To answer the first main research question, I first reviewed existing literature extensively and in the following step, I analyzed the impact of two major floods on property prices in Kingston-upon-Hull. The results of previous research have shown that the risk of natural hazards leads to a discount on transaction prices for affected property. However, there is a lack in literature determining the long-term relationship between flood risk and property prices. Therefore, this research contributes to answer the question to what extent the properties are sold at a discount (premium) and how this behavior changes over time.

I used a difference-in-difference regression model to analyze the impact of the flood events in June 2007 and December 2013 on property prices, as well as the direct impact of flood risk compared with four years after the flood event. Firstly, the regressions results show contrary results for the flood events. While there is no significant result on the impact of the June 2007 flood on property prices, properties affected by the December 2013 flood sell at a discount after the flood event. A possible explanation for this phenomenon is that the flood types differ. In June 2007 the flood was caused by an overwhelmed drainage system, which led to a flooding across the whole city. Therefore, there is no direct relationship between the flood and location of the flood zones. However, the December 2013 flood was caused by a tidal surge affecting only the properties located close by the tidal river. Thus, there is a direct relationship between the flood and the affected flood area. So, for the population this means that if they aim to avoid the flood risk, they will move away from the flood area close to the tidal river after the December 2013 flood. By contrast, predicting a flood-prone area based on the June 2007 flood is very difficult, because the affected area was so large and comparably far away from water sources. Consequently, it is difficult to actively avoid the resulting flood area or assign a specific discount.

Comparing the price discount development in the first years after the flood event vs. the following years showed results contrary to my hypothesis. I hypothesized based on previous research that the discount after a flood event would diminish over time. However, the regression has resulted that the sale discount directly after the 2013 flood event compared with four years after has increased, meaning that the price discount becomes larger over time. These results are unexpected and therefore, I believe that there is an exogenous explanation for this result.

Finally, I tested the data for heterogeneity by performing the Chow-test. Specifically, I checked whether the impact of flood risk on property prices differ across property types. The results of the Chow-test conclude that I can reject the null hypothesis, meaning that there is heterogeneity across property types. After running the different regressions, most property types do not show significant coefficients and the property type for semi-detached houses is the only property type showing significant results for both floods. Therefore, I conclude that there is heterogeneity across property types, however the results are mostly not significant.

In conclusion, the results of this research have been surprising and partly contrary to my hypotheses. To answer the research question *What effect does flood risk have on the market value of residential real estate property in the area of Kingston-upon-Hull?*, I conclude that flood risk has an impact on the market value of residential property in Kingston-upon-Hull. The 2007 flood caused by surface water has no significant results on the impact on real estate prices, and the December 2013 flood caused by a tidal surge shows a negative impact on real estate prices. This price discount actually increases over time in Kingston-upon-Hull, which might be a biased result caused a too few observations or influenced by an external impact. Based on these partly conflicting results, it can help the government to introduce a policy regarding flood awareness to improve market transparency. Especially due to climate change, flood risk becomes a greater threat across the world. When the population gets educated about this risk, they will be able to act on it, which might lead to a better-priced market due to improved market transparency.

### 5.2 Limitations and Future Research

During the analysis, I identified several limitations, which should be considered for future research. Firstly, to improve model fit, more property characteristics should be included as control variables. In the initial dataset property characteristics like new build, property type, and estate type were included. However, additional control variables such as individual characteristics like property size, number of rooms, garden, basement, year of construction, and renovations. By adding these control variables, properties sold in the transactions might be described more accurately, thereby potentially improving the model fit (i.e., R2). In addition, the more of the dependent variable's variation is explained before adding the variable of interest (i.e. flood risk) and the better the overall model fit, the more accurate researchers might be able to distill the impact of the flood risk. Collecting these individual characteristics would be highly labor-intensive (e.g., via collecting data on the ground in real estate agent offices) and is therefore out of scope for this study.

Secondly, the two floods in 2007 and 2013 differ regarding their origin and the affected location. While the flood in June 2007 was caused by an overwhelmed drainage system after heavy rainfalls, the December 2013 flood was caused by a tidal surge due to wind. Therefore, the summer 2007 flood is spread across most parts of the city and the 2013 flood focuses on the areas located right at the tidal river. There is no clear relationship between the location and the flooding during the 2007 flood, compared to the 2013 flood, where the tidal surge only affects the areas close to the river. So, future research may investigate whether there are significant differences between different types of floods (i.e. tidal surge vs. surface water). It is important to separate the types of floods because they give different results, as seen in my research. When a flood affects the whole city, the question is if this changes prices significantly, since alternatives are limited. But for a flood limited to a small area within Hull, the population has sufficient alternatives, and the behavior might be different. Future research should aim to generally investigate coastal, surface, and tidal floods differently.

A further limitation in this research is the lack of determining the damage in the flood zones. In this study I just define properties either located in the flood affected area or in the non-affected flood area. However, including the extent of damage of the floods could improve the outcome. It would be valuable to separate properties, which have actually been damaged by the flood and which properties are identified as located in the flood affected area but have not been damaged. Even more precise information about the extent of the damage for each property would give more accurate outcomes.

Lastly, the research focuses on the time period of 2000 to 2021, investigating two major flood events in June 2007 and December 2013. However, with the financial crisis shocking housing markets around the world in 2008, this might have been an additional idiosyncratic shock affecting house prices with an overlap to the two floods. This might introduce a bias to the results.

## REFERENCES


Aiken, L.S., West, S.G. and Reno, R.R. (1991) *Multiple Regression: Testing and Interpreting Interactions*. SAGE.

American Real Estate Society (ed.) (2020) 'ARES Real Estate Journal List'. Available at: https://cdn.ymaws.com/www.aresnet.org/resource/resmgr/files/ARES_Journal_List_Draft_Feb_.pdf (Accessed: 8 April 2022).

Atreya, A. and Czajkowski, J. (2019) 'Graduated Flood Risks and Property Prices in Galveston County', *Real Estate Economics*, 47(3), pp. 807–844. doi:10.1111/1540-6229.12163.

Atreya, A., Ferreira, S. and Kriesel, W. (2013) 'Forgetting the Flood? An Analysis of the Flood Risk Discount over Time', *Land Economics*, 89(4), pp. 577–596. doi:10.3368/le.89.4.577.

Bailey, M.J., Muth, R.F. and Nourse, H.O. (1963) 'A Regression Method for Real Estate Price Index Construction', *Journal of the American Statistical Association*, 58(304), pp. 933–942. doi:10.1080/01621459.1963.10480679.

BBC News (2008) 'Key points: Pitt report on floods', 25 June. Available at: http://news.bbc.co.uk/2/hi/uk_news/7472813.stm (Accessed: 14 June 2022).

Belanger, P. and Bourdeau-Brien, M. (2018) 'The impact of flood risk on the price of residential properties: the case of England', *Housing Studies*, 33(6), pp. 876–901. doi:10.1080/02673037.2017.1408781.

Below, S., Beracha, E. and Skiba, H. (2015) 'Land Erosion and Coastal Home Values', *Journal of Real Estate Research*, 37(4), pp. 499–536. doi:10.1080/10835547.2015.12091427.

Beltrán, A., Maddison, D. and Elliott, R. (2019) 'The impact of flooding on property prices: A repeat-sales approach', *Journal of Environmental Economics and Management*, 95, pp. 62–86. doi:10.1016/j.jeem.2019.02.006.

Bin, O. *et al.* (2008) 'Viewscapes and Flood Hazard: Coastal Housing Market Response to Amenities and Risk', *Land Economics*, 84(3), pp. 434–448. doi:10.3368/le.84.3.434.

Bin, O. and Landry, C.E. (2013) 'Changes in implicit flood risk premiums: Empirical evidence from the housing market', *Journal of Environmental Economics and Management*, 65(3), pp. 361–376. doi:10.1016/j.jeem.2012.12.002.

Bin, O. and Polasky, S. (2004) 'Effects of Flood Hazards on Property Values: Evidence before and after Hurricane Floyd', *Land Economics*, 80(4), p. 490. doi:10.2307/3655805.

Brown, M., Topham, G. and Campbell, L. (2022) 'Storm Franklin: "danger to life" flood warnings in Shropshire and Worcestershire', *The Guardian*, 21 February. Available at: https://www.theguardian.com/uk-news/2022/feb/21/storm-frankin-hundreds-evacuated-and-travel-halted-uk (Accessed: 12 April 2022).

Bundeszentrale für politische Bildung (2021) *Jahrhunderthochwasser 2021 in Deutschland | bpb.de*. Available at: https://www.bpb.de/kurz-knapp/hintergrund-aktuell/337277/jahrhunderthochwasser-2021-in-deutschland/ (Accessed: 12 April 2022).

Bunyan, N. (2020) 'Storm Bella: high winds add to flooding chaos across UK', *The Guardian*, 27 December. Available at: https://www.theguardian.com/uk-news/2020/dec/27/storm-bella-high-winds-add-to-flooding-chaos-across-uk (Accessed: 12 April 2022).

Caliendo, M. and Kopeinig, S. (2005) 'Some Practical Guidance for the Implementation of Propensity Score Matching', p. 33.

Can, A. (1992) 'Specification and estimation of hedonic housing price models', *Regional Science and Urban Economics*, 22(3), pp. 453–474. doi:10.1016/0166-0462(92)90039-4.

Carbone, J.C., Hallstrom, D.G. and Smith, V.K. (2006) 'Can Natural Experiments Measure Behavioral Responses to Environmental Risks?', *Environmental & Resource Economics*, 33(3), pp. 273–297. doi:10.1007/s10640-005-3610-4.

Ceola, S., Laio, F. and Montanari, A. (2014) 'Satellite nighttime lights reveal increasing human exposure to floods worldwide', *Geophysical Research Letters*, 41(20), pp. 7184–7190. doi:10.1002/2014GL061859.

Cohen, J.P., Barr, J. and Kim, E. (2021) 'Storm surges, informational shocks, and the price of urban real estate: An application to the case of Hurricane Sandy', *Regional Science and Urban Economics*, 90, p. 103694. doi:10.1016/j.regsciurbeco.2021.103694.

Cohen, J.P. and Coughlin, C.C. (2008) 'SPATIAL HEDONIC MODELS OF AIRPORT NOISE, PROXIMITY, AND HOUSING PRICES*', *Journal of Regional Science*, 48(5), pp. 859–878. doi:10.1111/j.1467-9787.2008.00569.x.

Convery, I., Carroll, B. and Balogh, R. (2015) 'Flooding and schools: experiences in Hull in 2007', *Disasters*, 39(1), pp. 146–165. doi:10.1111/disa.12091.

Coulthard, T. j. and Frostick, L. e. (2010) 'The Hull floods of 2007: implications for the governance and management of urban drainage systems', *Journal of Flood Risk Management*, 3(3), pp. 223–231. doi:10.1111/j.1753-318X.2010.01072.x.

Daniel, V.E., Florax, R.J.G.M. and Rietveld, P. (2009) 'Flooding risk and housing values: An economic assessment of environmental hazard', *Ecological Economics*, 69(2), pp. 355–365. doi:10.1016/j.ecolecon.2009.08.018.

Dehring, C.A. (2006) 'Building Codes and Land Values in High Hazard Areas', *Land Economics*, 82(4), pp. 513–528. doi:10.3368/le.82.4.513.

Donahue, A.K. and Tuohy, R.V. (2006) 'Lessons We Don't Learn A Study of the Lessons of Disasters, Why We Repeat Them, and How We Can Learn Them'. Available at: https://calhoun.nps.edu/handle/10945/25094 (Accessed: 12 April 2022).

Donovan, G.H., Champ, P.A. and Butry, D.T. (2007) 'Wildfire Risk and Housing Prices: A Case Study from Colorado Springs', *Land Economics*, 83(2), pp. 217–233. doi:10.3368/le.83.2.217.

Environment Agency (2014) 'The Tidal Surge on the 5th of December and its Effects on the Humber'.

Environment Agency (2018) *Humber: Hull Frontage Flood Defence Improvements*. Available at: https://consult.environment-agency.gov.uk/yorkshire/humber-hull-frontages/ (Accessed: 20 March 2022).

Environment Agency UK (2022) *Historic Flood Map*. Available at: https://data.gov.uk/dataset/76292bec-7d8b-43e8-9c98-02734fd89c81/historic-flood-map (Accessed: 20 March 2022).

euronews (2021) 'More than 160 dead in Germany-Belgium floods as water recedes', *euronews*, 15 July. Available at: https://www.euronews.com/my-europe/2021/07/15/at-least-8-dead-in-heavy-rains-floods-in-germany-and-belgium (Accessed: 11 April 2022).

Fekete, A. (2019) 'Critical infrastructure and flood resilience: Cascading effects beyond water', *WIREs Water*, 6(5), p. e1370. doi:10.1002/wat2.1370.

Filippova, O. *et al.* (2020) 'Who Cares? Future Sea Level Rise and House Prices', *Land Economics*, 96(2), pp. 207–224. doi:10.3368/le.96.2.207.

Flood Re (2022) *Can Flood Re help me?*, *Flood Re*. Available at: https://www.floodre.co.uk/can-flood-re-help-me/ (Accessed: 1 August 2022).

Ford, G. (2022) *Storm Eunice Hull LIVE: Roads closed, flood warnings and 60mph winds*, *HullLive*. Available at: https://www.hulldailymail.co.uk/news/hull-east-yorkshire-news/storm-eunice-hull-live-flood-6679262 (Accessed: 20 March 2022).

Freeman, A.M., Herriges, J.A. and Kling, C.L. (2003) *The Measurement of Environmental and Resource Values: Theory and Methods*.

Gharbia, S.S. *et al.* (2016) 'Attitudes to systemic risk: The impact of flood risk on the housing market in Dublin', in *2016 18th Mediterranean Electrotechnical Conference (MELECON)*. *2016 18th Mediterranean Electrotechnical Conference (MELECON)*, Lemesos, Cyprus: IEEE, pp. 1–5. doi:10.1109/MELCON.2016.7495471.

Gibbons, S. and Machin, S. (2005) 'Valuing rail access using transport innovations', *Journal of Urban Economics*, 57(1), pp. 148–169. doi:10.1016/j.jue.2004.10.002.

Greater London Authority (2022) *Surface Water Flooding in London*, *London City Hall*. Available at: https://www.london.gov.uk//WHAT-WE-DO/environment/environment-publications/surface-water-flooding-london (Accessed: 27 June 2022).

Hallstrom, D.G. and Smith, V.K. (2005) 'Market responses to hurricanes', *Journal of Environmental Economics and Management*, 50(3), pp. 541–561. doi:10.1016/j.jeem.2005.05.002.

Halvorsen, R. and Palmquist, R. (1980) 'The Interpretation of Dummy Variables in Semilogarithmic Equations', *The American Economic Review*, 70(3), pp. 474–475.

Harrison, D.M., Smersh, G.T. and Arthur L. Schwartz, J. (2001) ‘Environmental Determinants of Housing Prices: The Impact of Flood Zone Status’, *Journal of Real Estate Research*, 21(1/2), pp. 3–20.

Hennighausen, H. and Suter, J.F. (2020) ‘Flood Risk Perception in the Housing Market and the Impact of a Major Flood Event’, *Land Economics*, 96(3), pp. 366–383. doi:10.3368/le.96.3.366.

HM Land Registry (2022) *HM Land Registry Open Data*. Available at: https://landregistry.data.gov.uk/app/ppd (Accessed: 12 April 2022).

Hodge, T.R. (2021) ‘Flooding and the Value of Agricultural Land’, *Land Economics*, 97(1), pp. 59–79. doi:10.3368/wple.97.1.061019-0075R1.

Huang, Y. (2021) ‘Salience of hazard disclosure and house prices: Evidence from Christchurch, New Zealand’, *Regional Science and Urban Economics*, 88, p. 103679. doi:10.1016/j.regsciurbeco.2021.103679.

International Water Association (no date) *Yorkshire Water*, *International Water Association*. Available at: https://iwa-network.org/yorkshire-water/ (Accessed: 31 May 2022).

Kalnins, A. (2018) ‘Multicollinearity: How common factors cause Type 1 errors in multivariate regression’, *Strategic Management Journal*, 39(8), pp. 2362–2385. doi:10.1002/smj.2783.

*Kingston upon Hull topographic map, elevation, relief* (no date) *topographic-map.com*. Available at: https://en-gb.topographic-map.com/maps/vh6f/Kingston-upon-Hull/ (Accessed: 22 June 2022).

Koster, H.R.A. and van Ommeren, J. (2015) ‘A shaky business: Natural gas extraction, earthquakes and house prices’, *European Economic Review*, 80, pp. 120–139. doi:10.1016/j.euroecorev.2015.08.011.

Kousky, C. (2010) ‘Learning from Extreme Events: Risk Perceptions after the Flood’, *Land Economics*, 86(3), pp. 395–422. doi:10.3368/le.86.3.395.

Kunreuther, H. and Michel-Kerjan, E. (2007) *Climate Change, Insurability of Large-scale Disasters and the Emerging Liability Challenge*. w12821. Cambridge, MA: National Bureau of Economic Research, p. w12821. doi:10.3386/w12821.

Lamond, J., Proverbs, D. and Hammond, F. (2010) ‘The Impact of Flooding on the Price of Residential Property: A Transactional Analysis of the UK Market’, *Housing Studies*, 25(3), pp. 335–356. doi:10.1080/02673031003711543.

Lee, M. and Kang, C. (2006) ‘Identification for difference in differences with cross-section and panel data’, *Economics Letters*, 92(2), pp. 270–276. doi:10.1016/j.econlet.2006.03.007.

Local Government Association (2022) *Flood risk and flood risk management | Local Government Association*. Available at: https://www.local.gov.uk/topics/severe-weather/flooding/flood-and-coastal-erosion-risk-management/flood-risk-and-flood-risk (Accessed: 1 August 2022).

Morgan, A. (2007) ‘The Impact of Hurricane Ivan on Expected Flood Losses, Perceived Flood Risk, and Property Values’, *Journal of Housing Research*, 16(1), pp. 47–60. doi:10.1080/10835547.2007.12091977.

Munro, A. (2018) ‘Economic valuation of a rise in ambient radiation risks: Hedonic pricing evidence from the accident in Fukushima’, *Journal of Regional Science*, 58(3), pp. 635–658. doi:10.1111/jors.12381.

NASA Space Place (2022) *How Do Hurricanes Form? | NASA Space Place – NASA Science*. Available at: https://spaceplace.nasa.gov/hurricanes/en/ (Accessed: 30 July 2022).

Nielsen, B. and Whitby, A. (2015) ‘A Joint Chow Test for Structural Instability’, *Econometrics*, 3(1), pp. 156–186. doi:10.3390/econometrics3010156.

Ortega, F. and Taşpınar, S. (2018) ‘Rising sea levels and sinking property values: Hurricane Sandy and New York’s housing market’, *Journal of Urban Economics*, 106, pp. 81–100. doi:10.1016/j.jue.2018.06.005.

Pizarro, R.E., Blakely, E. and Dee, J. (2006) ‘Urban Planning and Policy Faces Climate Change’, *Built Environment*, 32(4), pp. 400–412. doi:10.2148/benv.32.4.400.

Rajapaksa, D. *et al.* (2016) ‘Flood Risk Information, Actual Floods and Property Values: A Quasi-Experimental Analysis’, *Economic Record*, 92, pp. 52–67. doi:10.1111/1475-4932.12257.

Ramsden, D.S. (2021) ‘Living with Water Hull Household Flood Survey Autumn 2018’.

Rosen, S. (1974) ‘Hedonic Prices and Implicit Markets: Product Differentiation in Pure Competition’, *Journal of Political Economy*, 82(1), pp. 34–55. doi:10.1086/260169.

Shr, Y.-H. (Jimmy) and Zipp, K.Y. (2019) ‘The Aftermath of Flood Zone Remapping: The Asymmetric Impact of Flood Maps on Housing Prices’, *Land Economics*, 95(2), pp. 174–192. doi:10.3368/le.95.2.174.

Thorne, C. (2014) ‘Geographies of UK flooding in 2013/4’, *The Geographical Journal*, 180(4), pp. 297–309. doi:10.1111/geoj.12122.

Troy, A. and Romm, J. (2004) ‘Assessing the price effects of flood hazard disclosure under the California natural hazard disclosure law (AB 1195)’, *Journal of Environmental Planning and Management*, 47(1), pp. 137–162. doi:10.1080/0964056042000189844.

Turnbull, G.K., Zahirovic-Herbert, V. and Mothorpe, C. (2013) ‘Flooding and Liquidity on the Bayou: The Capitalization of Flood Risk into House Value and Ease-of-Sale’, *Real Estate Economics*, 41(1), pp. 103–129. doi:10.1111/j.1540-6229.2012.00338.x.

University of Hull (2014) *Assessing the Hull Floods of 2007: establishing future flood management and protection strategies for the UK and the region*. Available at: https://impact.ref.ac.uk/casestudies/CaseStudy.aspx?Id=43516 (Accessed: 20 March 2022).

U.S. Department of Housing and Urban Development (ed.) (2009) ‘Flood Zone Requirements and Responsibilities of FHA Mortgagees and Appraisers’. Available at: https://www.hud.gov/sites/documents/09-37.ml.doc (Accessed: 20 March 2022).

Wainwright, M. (2007) ‘Hull pleads for aid after floods leave one in five homes damaged’, *The Guardian*, 5 July. Available at: https://www.theguardian.com/uk/2007/jul/05/weather.world (Accessed: 20 March 2022).

Wallace, N. and Meese, R. (1997) ‘The Construction of Residential Housing Price Indices: A Comparison of Repeat-Sales, Hedonic-Regression, and Hybrid Approaches’. doi:10.1023/A:1007715917198.

Walsh, P. *et al.* (2019) ‘Adaptation, Sea Level Rise, and Property Prices in the Chesapeake Bay Watershed’, *Land Economics*, 95(1), pp. 19–34. doi:10.3368/le.95.1.19.

Weaver, M., Owen, P. and Urquhart, C. (2013) *UK flood warning: thousands evacuated from homes | UK news | The Guardian*, *The Guardian*. Available at: https://www.theguardian.com/uk-news/2013/dec/05/uk-weather-warning-east-coast-braced-for-floods-live-updates (Accessed: 20 March 2022).

Wetherald, R.T. and Manabe, S. (2002) ‘Simulation of hydrologic changes associated with global warming’, *Journal of Geophysical Research*, 107(D19), p. 4379. doi:10.1029/2001JD001195.

Wilby, R.L., Beven, K.J. and Reynard, N.S. (2008) ‘Climate change and fluvial flood risk in the UK: more of the same?’, *Hydrological Processes*, 22(14), pp. 2511–2523. doi:10.1002/hyp.6847.

World Pumps (2011) ‘Flood prevention refurbishment’, *World Pumps*, 2011(6), pp. 16–17. doi:10.1016/S0262-1762(11)70239-5.

Zhang, L. (2016) ‘Flood hazards impact on neighborhood house prices: A spatial quantile regression analysis’, *Regional Science and Urban Economics*, 60, pp. 12–19. doi:10.1016/j.regsciurbeco.2016.06.005.

## APPENDIX A: NOTATIONAL GLOSSARY

| **Empirical Model** | |
|---|---|
| Ln($P_{i,t}$) | Natural logarithm of the sales price |
| Cons | Constant to be estimated |
| $\beta_i$ | Parameters to be estimated |
| I | Transaction $i = 1, 2, \ldots, N$ |
| T | Time $t = 1, 2, \ldots, N$ |
| Flood2007 | Dummy variable, which equals 1 if property sold is located within the area affected by the flood 2007 |
| Post07 | Dummy variable, which equals 1 if property is sold after 2007 |
| Flood area x Post2007 | Dummy variable, which equals 1 if property sold is located within the area affected by the flood 2007 and sold after 2007 |
| Flood2013 | Dummy variable, which equals 1 if property sold is located within the area affected by the flood 2013 |
| Post13 | Dummy variable, which equals 1 if property is sold after 2013 |
| Flood area x Post13 | Dummy variable, which equals 1 if property sold is located within the area affected by the flood 2013 and sold after 2013 |
| Post18 | Dummy variable, which equals 1 if property is sold after 2018 |
| Flood area x Post18 | Dummy variable, which equals 1 if property sold is located within the area affected by the flood 2013 and sold after 2018 |
| New Build | Dummy variable, which equals 1 if property sold has been newly built |
| Property Type | Categorical variable, describing whether the property sold is detached, semi-detached, flat/maisonettes, terraced, or other |
| Estate Type | Dummy Variable, which equals 1 if property sold is freehold and equals 0 if property sold is leasehold |
| Sales Month | Categorical variable, describing the transaction month |
| Sales Year | Categorical variable, describing the transaction year |
| Street | Categorical variable, describing the street where the property sold is located |
| Zip Code | Categorical variable, describing the zip code where the property sold is located |

## APPENDIX B: FIGURES & TABLES

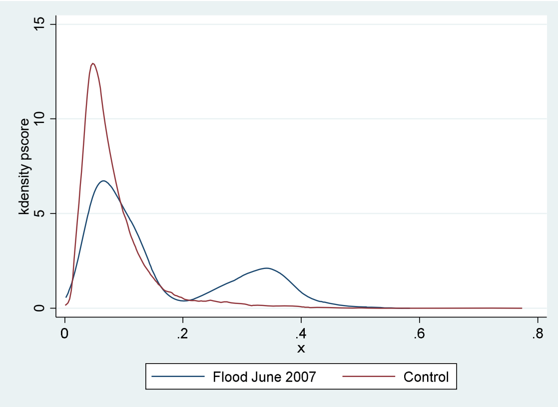
**Table 1: ARES Real Estate Journal List**

| **ARES Real Estate Journal List – January 2020** |
|---|
| Real Estate Economics |
| Journal of Urban Economics |
| Journal of Real Estate Finance & Economics |
| Land Economics |
| Journal of Real Estate Research |
| Journal of Regional Science |
| Regional Science and Urban Economics |
| Regional Studies |
| Journal of Housing Economics |
| Journal of Housing Research / Journal of Property Research |

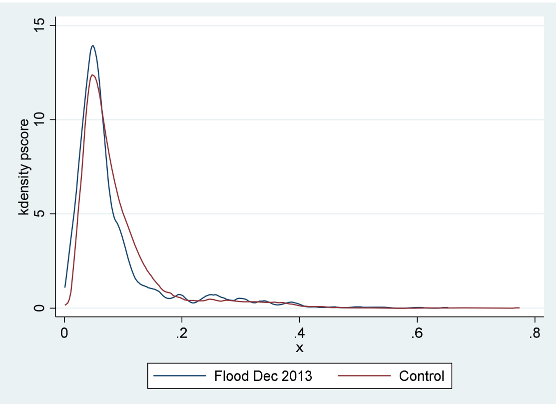
*Note: List of the 10 top ranked real estate journals by the American Real Estate society in 2020.*

**Table 4: Assumption of Common Support for Propensity Score Matching (PSM)**

**PSM Flood June 2007**




**PSM Flood December 2013**




*Note: The graphs show the results after checking the data for the assumption of common support, separated by June 2007 flood and December 2013 flood.*

**Table 5: Correlation Table of independent variables and control variables**

| | Flood 2007 | Flood 2013 | New Build | Property Type | Estate Type | Sales Month | Sales Year | Street | Zip code |
|---|---|---|---|---|---|---|---|---|---|
| Flood 2007 | 1 | | | | | | | | |
| Flood 2013 | -0.0355 | 1 | | | | | | | |
| New Build | 0.1867 | -0.0257 | 1 | | | | | | |
| Property Type | -0.0074 | -0.0558 | -0.24 | 1 | | | | | |
| Estate Type | -0.0428 | -0.1857 | -0.0736 | 0.2693 | 1 | | | | |
| Sales Month | 0.0164 | -0.0074 | 0.0205 | -0.0127 | 0.0012 | 1 | | | |
| Sales Year | 0.0973 | -0.0103 | -0.0013 | -0.0394 | -0.0169 | -0.0201 | 1 | | |
| Street | 0.0413 | -0.0063 | 0.0006 | -0.0055 | 0.0217 | -0.0017 | 0.0042 | 1 | |
| Zip code | 0.0775 | 0.0046 | 0.0138 | 0.19 | 0.0681 | -0.0019 | -0.0053 | -0.0023 | 1 |

*Note: This table shows the correlation table between all independent variables.*

**Table 6: VIF statistics**

| Variable | VIF | 1/VIF |
|---|---|---|
| Flood June 2007 | 1.07 | 0.932 |
| Flood December 2013 | 1.04 | 0.958 |
| New Build | 1.11 | 0.902 |
| Property Type | | |
| Flat/ Maisonette | 3.91 | 0.256 |
| Other | 1.11 | 0.897 |
| Semi-detached | 2.29 | 0.436 |
| Terraced | 2.53 | 0.395 |
| Estate Type | 3.57 | 0.280 |
| Sales month | 1 | 0.999 |
| Sales year | 1.03 | 0.966 |
| Street | 1 | 0.997 |
| Zip code | 1.05 | 0.951 |
| Mean VIF | 1.73 | |

*Note: The table shows the VIF statistics, presenting a VIF value for each variable.*

**Table 7: The Chow-Test**

$F(14, 114781) = 354.43$

F-value > $F_{critical}$-value = 1.67

*Note: The table shows the results of the Chow-Test.*

**Table 12: Results of Propensity Score Matching (PSM)**

**PSM Flood June 2007**

| Variable | Sample | Treated | Controls | Difference | S.E. | T-stat |
|---|---|---|---|---|---|---|
| Ln(Sales price) | Unmatched | 11.56894 | 11.3396719 | 0.229267824 | 0.006482174 | 35.37 |
| | ATT | 11.56894 | 11.4561912 | 0.11274847 | 0.010672405 | 10.56 |

**PSM Flood December 2013**

| Variable | Sample | Treated | Controls | Difference | S.E. | T-stat |
|---|---|---|---|---|---|---|
| Ln(Sales Price) | Unmatched | 11.288828 | 11.3612085 | -0.072380317 | 0.016706608 | 4.33 |
| | ATT | 11.288828 | 11.2609402 | 0.027888068 | 0.018078524 | 1.54 |

*Note: These table show the results of the propensity score matching, separated by the June 2007 and December 2013 floods. Each flood includes results about the treatment effect in the population and on the treated.*

**Table 13: Regression Results of December 2013 flood, excluding June 2007 affected properties**

| | **Model 1 - variables of interest** | | **Model 2 - + Interaction effect** | | **Model 3 - + House Controls** | | **Model 4 - + time controls** | | **Model 5 - + spatial fixed effects** | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Coefficients | S.E. | Coefficients | S.E. | Coefficients | S.E. | Coefficients | S.E. | Coefficients | S.E. |
| ln sales price | | | | | | | | | | |
| Flood Dec 2013 | -.041 *** | .016 | -.040 * | .019 | .067 *** | .017 | .116 *** | .014 | .036 | .019 |
| Post | .480 *** | .004 | .481 *** | .004 | .439 *** | .003 | 1.192 *** | .009 | 1.221 *** | .006 |
| Target x Post | | | -.003 | .033 | -.101 *** | .028 | -.129 *** | .024 | -.086 *** | .016 |
| | | | | | | | | | | |
| *Controls* | | | | | | | | | | |
| New Build | | | | | .116 *** | .006 | .211 *** | .005 | .147 *** | .004 |
| Property Type (Base: Detached) | | | | | | | | | | |
| Flat/ Maisonette | | | | | -.693 *** | .015 | -.730 *** | .013 | -.499 *** | .010 |
| Other | | | | | -.143 *** | .015 | -.200 *** | .012 | -.084 *** | .010 |
| Semi-detached | | | | | -.441 *** | .005 | -.462 *** | .004 | -.279 *** | .004 |
| Terraced | | | | | -.873 *** | .005 | -.911 *** | .004 | -.385 *** | .004 |
| Estate Type (1=Freehold) | | | | | .128 *** | .014 | .177 *** | .011 | .320 *** | .009 |
| Sales Month | | | | | | | Yes *** (1) | | Yes *** | |
| Sales Year | | | | | | | Yes *** | | Yes *** | |
| Street | | | | | | | No | | Yes *** | |
| Zip Code | | | | | | | No | | Yes (2) | |
| | | | | | | | | | | |
| Constant | 11.169 *** | .002 | 11.169 *** | .002 | 11.667 *** | .014 | 10.993 *** | .014 | 10.473 *** | .011 |
| *R2* | .131 | | .131 | | .382 | | .567 | | .851 | |
| *Adj. R2* | .131 | | .131 | | .382 | | .567 | | .843 | |
| *F-value* | 7894.860 | | 5263.190 | | 7207.230 | | 3427.240 | | 4757.900 | |

* p < .05; ** p < .01; *** p < .001
(1) significant, except for February
(2) partially significant; out of 5,499 zip codes, 2,403 are significant

*Note: Regression results of the December 2013 flood, excluding the properties affected by the June 2007 flood.*