How do households perceive flood-risk? The impact of flooding on the cost of accommodation in Dublin, Ireland

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Abstract: Climate change and human behaviour, such as building on floodplains, are increasing the incidence of floods in urban areas. This paper investigates the relationship between flood risk and residential accommodation costs, both sales and rental, using a detailed dataset of over 650,000 sale and rental listings in Dublin, Ireland over the period 2006-2015. These are combined with detailed data for the Dodder river on 1% flood risk and past flooding events. Research to date suggested that the lack of a persistent effect may have an impact on buyers' and sellers' risk perceptions by changing with the prevalence of hazard events and that homebuyers are unaware of flood risks and insurance requirements when bidding on properties. Using hedonic regression techniques, the presented work shows opposite results: flood events are found to have a negative impact, particularly on sale prices, while being at 1% risk has no effect once past flood events are controlled for. For past flood events, however, there is evidence to suggest that this impacts on property values, certainly in the areas affected and up to 200 meters away. Before the institutional flood risk maps were published, the assessment was based on existing Ordnance Survey maps which showed areas 'Liable to flooding' generated with land surveys carried out around the 1830. Set against these devices for raising awareness of flooding is the Irish constitution which regards property rights almost the same as human rights, which obvious impacts on the ability of planners to implement development/zoning plans. On the basis of this evidence, it is reasonable to conclude that households pay more attention to past flood events than to scientific assessments of flood risk, has important policy implications about communicating flood risk to consumers.

Keywords: Valuation, Environmental risk, Amenity valuation, GIS Spatial Analysis, Hedonic pricing, housing markets

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1. Introduction

The occurrence and consequences of floods is receiving increasing media coverage worldwide as a result of a higher incidence of these natural disasters. Sizeable human and material losses are associated with flooding disasters, making flooding an important question for economists and social scientists. Climate change is a result of the combined impacts of changing natural circumstances and human behavior, causing increases in the frequency and the magnitude of floods (Hirabayashi et al., 2013). Indeed, there is an increased chance of intense precipitation and flooding due to "greater water-holding capacity of a warmer atmosphere", and it is expected that "such events will continue to become more frequent" (IPCC, 2007): precipitation intensity is estimated to increase almost everywhere, but particularly at mid- and high latitudes where also the mean precipitation is anticipated to increase (Meehl et al., 2005), with a resulting impact on the risk of flash flooding and urban flooding.

This is also suggested by other studies specifically relevant to Ireland (Gharbia et al., 2016, Gharbia et al., 2018, Osman et al., 2013, Alexander et al., 2016). Agricultural interventions by farmers and local communities particularly in the rivers upstream areas can be one of the main causes of floods in many parts of Europe and other continents (Posthumus et al., 2008, Mustafa, 1998). This can happen by intentionally blocking or slowing surface runoff on farmlands. On the other hand, runoff from impermeable surfaces is considered to be one of the biggest contributors to flood risk, in addition to development activities in floodplains. While this is not the case in Dublin, Ireland's capital, this risk exists for other catchments in Ireland. Anthropogenic impacts on river flooding are clearly visible in changed river management practices (McNamara and Keeler, 2013). Construction in floodplains (Guarín et al., 2004), channel straightening and increased presence of impermeable surfaces such as transport infrastructure and residential areas are examples of urbanization that increases the risk of river floods in small catchment areas and small river networks (Berry et al., 2008, Bradford et al., 2012, Daniel et al., 2009, Kron, 2003).

This paper investigates behavioral responses to a natural hazard (flooding) by examining the cost of residential accommodation, both sale and rental. This type of research is important for at least two reasons. First, results can be used to develop cost effectiveness studies, which attempt to assess the economic merits of policies that change the likelihood or magnitude of an event (Zerger, 2002). Residential housing markets provide an avenue for estimating these values since the choice of where to live includes, at least implicitly, the choice of risk level.

Second, research on the role of natural hazards in urban housing markets is important also because the methodology provides a mechanism for testing consumer behavior under uncertainty. This was shown by Brookshire (Brookshire et al., 1985), who used house price differentials resulting from earthquake risk in Los Angeles and San Francisco to test predictions from the expected utility model. Bin et al (Bin and Polasky, 2004) used a hedonic property price function to estimate the effects of flood hazards on 8,000 single-family residential homes between 1992 and 2002 in Pitt County, North Carolina; this area experienced significant flooding from Hurricane Floyd in September 1999. The study found that a house located within a floodplain has a lower market value than an equivalent house located outside the floodplain. Furthermore, the price discount from locating within a floodplain was significantly larger after Hurricane Floyd than before.

Bin et al (Bin and Landry, 2013) re-examined the findings for Pitt County, North Carolina, using multiple storm events within a difference-in-differences framework, and they compared flood zone price differentials for a more recent sample of property sales. Prior to Hurricane Fran in 1996, they detected no price differential for location within a flood zone but significant price discounts after major flooding events: 5.7% after Hurricane Fran and 8.8% after Hurricane Floyd. Results from a separate model that examined more recent data covering a period without significant storm-related flood impacts indicated a significant risk premium ranging between 6.0% and 20.2% for homes sold in the flood zone, but this effect diminished over time, essentially disappearing about 5 or 6 years after Hurricane Floyd. The lack of a persistent effect suggested that buyers' and sellers' risk perceptions may change with the prevalence of hazard events and that homebuyers are unaware of flood risks and insurance requirements when bidding on properties.

Bernknopf et al., 1990 explored the effects on investment, recreation, and risk perception after earthquake and volcano hazard notices were issued for the Mammoth Lakes, California area by the U.S. Geological Survey under the authority granted by the Disaster Relief Act of 1974. The hazard notices did not affect recreation visitation, but investment was affected with a perceived loss in the market value of homes; property owners' perceptions of risk were also altered. Hallstrom et al (Hallstrom and Smith, 2005) used one of the strongest hurricanes to hit the US, Andrew in 1992, to define a quasi-random experiment that permitted the estimation of the responses of housing values to information about new hurricanes. The test site for this work was Lee County, Florida which did not experience damage from Andrew but was close to the affected areas. The authors hypothesized that Andrew conveyed risk information to homeowners in the county. A difference-in-differences (DND) framework identified the effect of this information on property values in areas likely to experience significant storm damage. The DND findings indicated at least a 19 percent decline in property values.

Murdoch et al., 1993 examined the effect of the Loma Prieta earthquake on housing prices in the San Francisco Bay area. This relationship was examined while controlling for potential confounding variables, such as location-specific risk and the timing of the earthquake. The results indicated that the Loma Prieta earthquake caused an area-wide reduction in property values. In addition, it seemed that individuals considered other measures of earthquake risk in their housing purchases, yielding a measurable price gradient. Dale et al (Dale et al., 1999) examined the Dallas area housing market before, during, and after the closure and cleanup of a 50-year-old lead smelter west of downtown Dallas, using a pooled time series and cross-sectional data set of over 200,000 observations, covering all single-family homes sold through the Multiple Listing Service (MLS) 1979-1995. Consistent with the existing literature, property values around the smelter were lower before the cleanup. However, after the cleanup, the prices consistently rebounded across all neighborhood types, although the areas that were nearest and poorest did so more slowly.

Simmons et al (Simmons and Kruse, 2000) explored the value of windstorm mitigation in a Gulf Coast city. Data for the study contained detailed information on the inclusion of storm-blinds, a mitigation feature specific to hurricanes. Results indicated that homes with storm-blinds commanded a premium compared to homes without this feature. This result, however, was limited to homes located on the island portion of the community, indicating that agents differentiated the risk from one area to another. Simmons et al (Simmons et al., 2002) further explored the valuation of two measures of windstorm mitigation in a Gulf Coast city. The hypothesis of this study was that since the home owner was not able to reduce the probability that a hurricane or tropical storm would occur at the structure's location, any voluntary mitigation intended to protect the home was a form of self-insurance. Using a unique MLS data set with detailed information on several hurricane mitigation features, the authors constructed two models to test the influence of mitigation on resale price. The results of the hedonic study indicated that individuals place a positive value on a self-insurance type of mitigation.

The study here uses hedonic regression techniques, as is standard in the literature, to estimate the effects of flood hazards on residential property values and rental prices. Hedonic techniques use high-dimension data on housing, such as a dwelling's size, type or energy efficiency and its proximity to location-specific features such as transport facilities or schools, to estimate the value of each characteristic holding other measured characteristics constant. Specifically, this study utilizes data from 158,890 sales listings and 499,147 rental listings in Dublin, Ireland, between 2006 and 2015, as well as detailed spatial information on the Dodder river and its flooding characteristics, in particular the extent of past flood events and the 1% flood risk zone (Figure 1). Results show that a dwelling located within the zone of past flood events has both lower sale and rental values than an equivalent dwelling located outside. However, once other location characteristics are controlled for, including past flood events, there is no statistically significant relationship between sale prices and scientifically assessed flood risk (at a 1% or 1-in-100 years level), while if anything, rents increase in areas most at risk of flooding.

Figure 1: Nested maps detailing: (A) The Country of the pilot study; (B) the position of the pilot study within Ireland; (C) the study area within Dublin; (D) the spatial extent of the different annual exceedance probability (AEP) events in the study area

The analysis presented in this paper shows that obfuscating amenity effects and risk exposure associated with proximity to water causes systematic bias in the implicit price of flood risk, in line with what was found by (Daniel et al., 2009), (Shultz and Fridgen, 2001) and (Kousky, 2010). It is reasonable to assume that locational amenities are more important to a person who wants to buy a house, compared to a person who just wants to rent a house, and so this could result in the over-valuation of amenities during boom periods. Evidence in favor of this was seen in Ireland's recent property cycle (1995-2012), when easing credit conditions during the boom shifted out demand for lower-amenity dwellings, relative to higher-amenity dwellings (Lyons, 2013). Previous studies have evaluated the influence of flood risk in the housing market by comparing prices before and after a flood event. This study compares prices before a flood event and after, both immediately and for an extended period, in the aforementioned catchment areas, controlling for the effects of other amenities and disamenities.

Most importantly, this paper demonstrates the fact that people may have an understanding of flooding that is more adaptive (i.e. learning/extrapolating from the past) than rational (a scientific assessment of risk). This is new to the literature. As such, it is reasonable to conclude that, in the absence of other regulatory pressures, perceptions of flood risk are related to memory. This is likely to be reinforced by Ireland's home insurance market, where insurers ask homeowners whether their property or other properties in their area have suffered flood damage in the past, rather than asking whether the property is located within a flood risk zone as assessed scientifically.

2. Methods

2.1 Site Description

The case study presented in this paper is the Dodder Catchment. The River Dodder is one of the principal rivers in Dublin. It rises in the Dublin Mountains and flows through many residential areas of Dublin including the suburban areas of Tallaght and Rathfarnham and through the city areas of Donnybrook and Ballsbridge before discharging into the River Liffey estuary at Ringsend. The lower section of the river is tidal up to Ballsbridge. The River Dodder has a history of flooding and is known as a river which responds quickly to a rainstorm event (Bradford et al., 2012), mostly because of the steep gradient of the river in its upper section. In the last century, it has overflowed its banks on numerous occasions causing damage to adjacent properties. In 1986 when Hurricane Charlie hit Dublin, over 300 properties surrounding the Dodder catchment were flooded (De Bruijn and Brandsma, 2000). Another significant event occurred on the 1st of February 2002 when a very strong high tide occurred and over 600 properties were flooded on the lower Dodder downstream of Lansdowne Road Bridge (Javelle et al., 2002). These form the bulk of properties included in extent of historical flood events.

The same magnitude of flood occurred again on the 24th of October 2011 when a similar number of properties were flooded throughout the catchment. This flood event is not captured in the historical events used by the national Catchment Flood Risk Assessment and Management (CFRAM) programme commenced in Ireland in 2011, as the study predates it.

2.2 Methodology

Stated and revealed preference methods have been used in literature to assess flood risks, with both methods having advantages and disadvantages (Daniel et al., 2009, Keen et al., 2003). Stated preference methods are based on interviews to individuals about their willingness to pay for reduced flood risk exposure: the major disadvantage of this methods is that it is unclear if the actual behavior of the interviewed people corresponds to their actual potential behavior (List and Gallet, 2001). The revealed preference method deals with actual consumer behavior in markets: the disadvantage of this approach is its limit to assess willingness to pay (WTP) values in different (real-world) scenarios, and one cannot readily control the information shaping the risk perception of individuals (de Blaeij and van Vuuren, 2003, Florax et al., 2005).

The study presented in this paper uses the revealed preference approach by assuming that the presence of the flood risk is considered by the buyer when choosing the location of a house. As such, the other underlying assumption is that sale and rental costs reveal individual preferences regarding the acceptance of flood risk, among other services offered by housing: this is a reasonable assumption if appropriate controls for differences in the property and the location are included (Watts and Zimmerman, 1979). In this paper, such differences are set as neighborhood or location characteristics and assessed by controlling the variance between sale and rental costs of houses located inside and outside the flood risk zone. Observed prices and rents and the specific characteristics associated with house define a set of implicit or "hedonic" prices (Rosen, 1974).

A housing unit is considered as a differentiated market good representing a set of hedonic prices as a bundle of quantitative and qualitative characteristics: hedonic prices are defined as the implicit prices of attributes and are revealed to economic agents from observed prices of differentiated products and the specific amounts of characteristics associated with them (ibid.). In this research, the dependent variable is the listed price, either sale or rental (both in natural logs, and the rent converted into monthly terms, where necessary).

The key regressors of interest reflect flood risk, calculated relative to two geographically delineated areas. The first is the 1% risk zone, i.e. areas scientifically assessed to be at risk of flooding by the Dodder once every 100 years (Figure 1). The second measure is the zone of historical flooding events on the Dodder. Both to account for zero values (i.e. properties being inside these risk zones) and to escape restrictive functional forms on the impact on accommodation costs of distance from these zones, these flood-risk variables can take one of seven values. A value of zero means that the property is inside the flood risk zone (either 1% or historical events). Values of 1 to 5 denote 100 meter bands from 0-100m up to 400-500m from the risk zone, while a value of 6 denotes any distance of more than 500 meters from the flood risk zone.

The baseline empirical specification, Model (0), expresses the dwelling's accommodation cost, either sale price or monthly rent, as a function of flood risk and the following four vectors of control variables: when it was listed on the market (as a proxy of market conditions); its size (number of bedrooms and bathrooms); its type; and other attributes, such as whether it has a garden or, for rental properties, whether a washing machine or internet access is included. All these variables are included as sets of indicator (0/1) variables. This flexible functional form means that no strong assumptions are made about the impact of related but distinct property attributes, for example, the price effect of a fourth bedroom being the same as a fifth.

Such a model is likely to suffer severely from the problem of omitted variable bias, due to the presence of location-specific amenities within Dublin. Therefore, Model (1) includes distance from Dublin's Central Business District (measured in logs) and a fifth vector of control variables: location, as measured by the Census 'electoral division' (ED) in which the property is located. The dataset covers 334 Census EDs.

Measuring the impact of flood risk on the value of accommodation as a service or an asset is rendered problematic due to the collinearity of flood risk with distance to water-based amenities, such as rivers, lakes and the coast. Model (2) specifically includes these distances, in order to capture the potential amenity benefit of being close to these features, controlling for risk. Without these, the coefficient on flood-risk may suffer from an attenuation bias or even a wrong sign, depending on the strength of the two opposing effects. Including these factors means the model can distinguish between proximity to water amenities, including the Dodder river, and the risk of flooding by the Dodder.

While EDs will capture many location-specific amenities, there will be variation within Census tracts, as well as across them, in population and neighborhood characteristics that may affect the value of accommodation. Therefore, Model (3) – the full model – includes a range of Census features measured at the sub-tract level, the Census 'Small Area', which typically consists of between 100 and 200 households. Factors included in this specification include the local unemployment rate, the fraction with a university degree, the average size and age of dwellings in the neighborhood (the latter proxied by the fraction of dwellings dating from before 1914), the percent of local authority housing, and population density. Also included in Model (3) is the elevation of the dwelling and the slope of its site, as well as distance from the nearest primary and secondary school and from the nearest train or light rail station.

All of the models so far include the two measures of flood risk simultaneously. To check the robustness of the results, the full specification, Model (3), was run separately on the two measures of flood risk – being within the 1% zone and being within the flood event zone. These results are reported as Model (4).

Lastly, the occurrence of the major flooding of the Dodder in October 2011, close to the middle of our sample, and after the compilation of the flood event zone presents an opportunity to assess how a new flood event affects dwelling prices and rents in the vicinity. Model (5) includes the two sets of flood risk measures – 1% and events – on their own (capturing the average effect throughout the sample) and interacted with a categorical post-2011 flood variable (capturing how that effect was different after the flood compared to before).

3. Results

3.1 Sale prices

Results from the analysis for the sale prices carried out by Gharbia et al. (S. Gharbia et al., 2016) are presented in the Figure 2 and 3 below (more details in Table 1 in the Appendix). Model 0 does not include any location fixed effects or attributes. This suggests a number of implausible results, including a large premium (+10.7%) for a property being located within areas affected by historical flood events. This is likely due to a number of high-income areas being located near the Dodder, relative to the control group (100m-200m away). This result disappears once location controls are included (Model 1).

Once location fixed effects are included, there is a clear negative impact of being within the Dodder flood event zone – but no clear impact of being within the Dodder 1% risk zone. This is shown in Figures 6 and 7 below. Relative to properties 100-200 meters away from the zone of historical flood events, properties inside that zone had during the period covered roughly 3% lower prices, everything else being equal. There is some evidence of a mild river amenity specific to the Dodder also, as properties 100-200m away were on average more valuable than those further away.

However, for the 1% risk zone – and controlling for a full range of dwelling, location and neighborhood attributes (Model 3) as well as Dodder flood events – there is if anything a positive premium, although this is not statistically significant. Indeed, once location controls are included, there is no statistically significant difference between properties inside the 1% risk zone (p-value=0.346), properties 0-100m from the zone (p-value=0.958) and the control group (100-200m away). These properties all have statistically significant higher values on average than those properties at least 200m away, once sufficient controls for location and other natural amenities are included.

Economic theory would suggest that the lines in Figures 6 should slope upwards; i.e. the further away from flood risk the property is, the higher its value ceteris paribus. However, for the 1% risk zone, the slope is the opposite – prices are lower, the further the property is from flood risk. This includes specifications where flood events are controlled for and highlights that those purchasing properties appear to take limited account of scientifically assessed flood risk when buying a home.

For past flood events, however, there is evidence to suggest that this impacts on property values, certainly in the areas affected (p-value=0) and up to 200 meters away. In all four empirical specifications graphed in Figure 7, there is an upward-sloping curve from inside the zone to the band 100m-200m away. On the basis of this evidence, it is reasonable to conclude that past flooding events have a more significant impact on buyer behavior in the housing market than scientific assessments of risk.

Figure 2: Regression results for the 1% risk zone for the Sales Segment

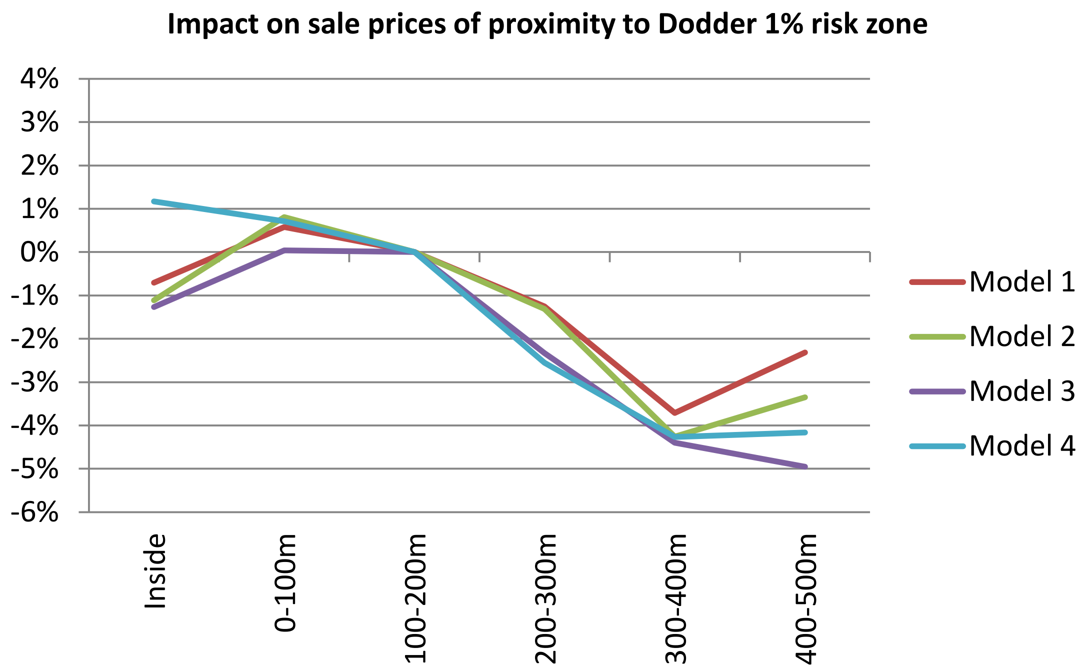
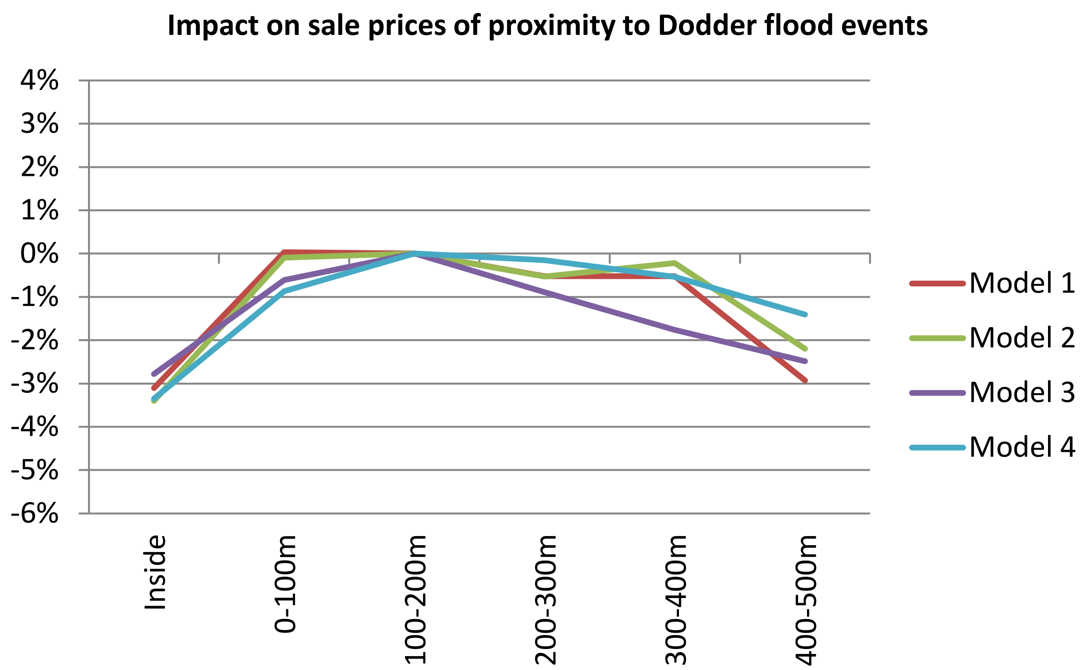


Figure 3: Regression results for the historical flood event zone for the Sales Segment



3.2 Rental prices

Results from the analysis on rental prices are presented in the Figure 4 and 5 below. As for sale prices, in Model 0, only basic controls were included and no location fixed effects were included. Again, this specification generates a number of implausible results, including a large premium (+9.2%) for a property being located within areas affected by historical flood events. As with sale prices, this is likely due to a number of high-income areas being located near the Dodder, relative to the control group (100m-200m away), which results in higher rental costs in these areas. This result disappears once location controls are included (Model 1).

Once location fixed effects are included, there is a clear negative impact of being within the Dodder flood event zone – but no clear impact of being within the Dodder 1% risk zone. This is shown in Figures 6 below. Relative to properties 100-200 meters away from the zone of historical flood events, properties inside that zone had during the period covered roughly 2% lower prices, everything else being equal. There is some evidence of a mild river amenity specific to the Dodder also, as properties 100-200m away were on average more valuable than those further away.

Once again, where the measure of flood risk is the 1% risk zone – and controlling for a full range of dwelling, location and neighborhood attributes (Model 3) as well as Dodder flood events – there is if anything a positive, if not statistically significant, relationship between flood risk and price. Once location controls are included, there is no statistically significant difference between properties inside the 1% risk zone (p=-value=0), properties 0-100m from the zone (p-value=0) and the control group (100-200m away). These properties all have statistically significant higher rental prices on average than those properties at least 200m away, once sufficient controls for location and other natural amenities are included.

The results are qualitatively similar to those for the sales segment. For scientifically assessed flood risk, if anything, there is a positive relationship between rental prices and proximity to locations most at risk of flooding, controlling for other factors. For past flood events, there is a negative relationship, although it should be noted that this effect is more muted than for sale prices: whereas being within the zone of past flood events entailed a price discount of 3.4% in the full model (Model 4), the rental discount was less than half the size (1.5%). This is consistent with the logic outlined in (Lyons, 2013), that limits to search efforts and match quality may drive renters to under-value amenities.

Figure 4: Regression results for the 1% risk zone for the Rental Segment

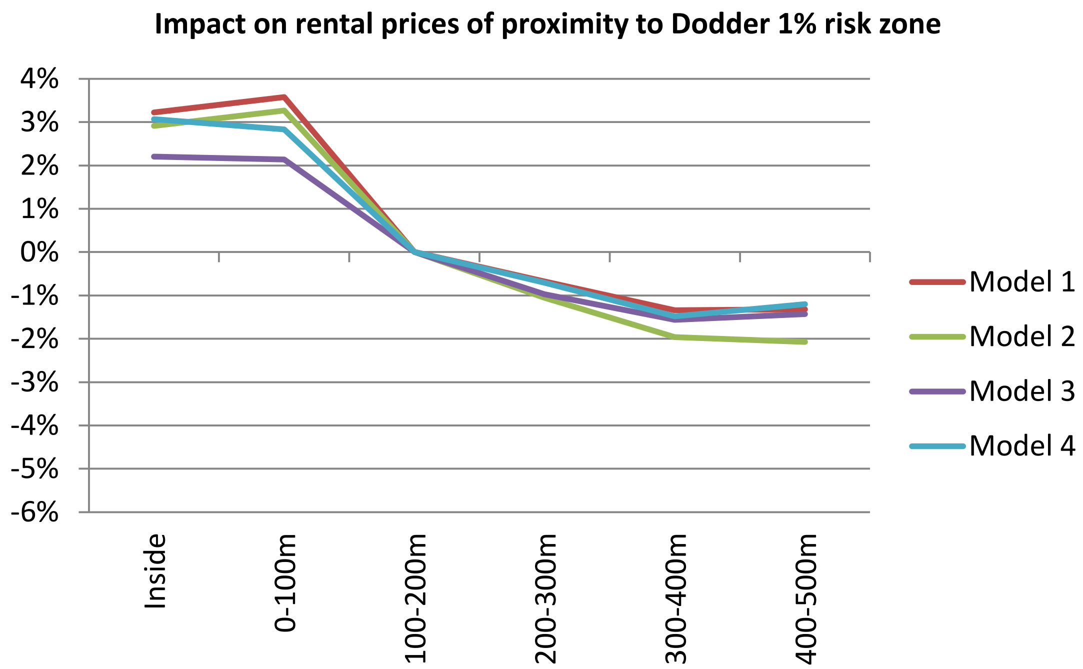


Figure 5: Regression results for the historical flood event zone for the Rental Segment

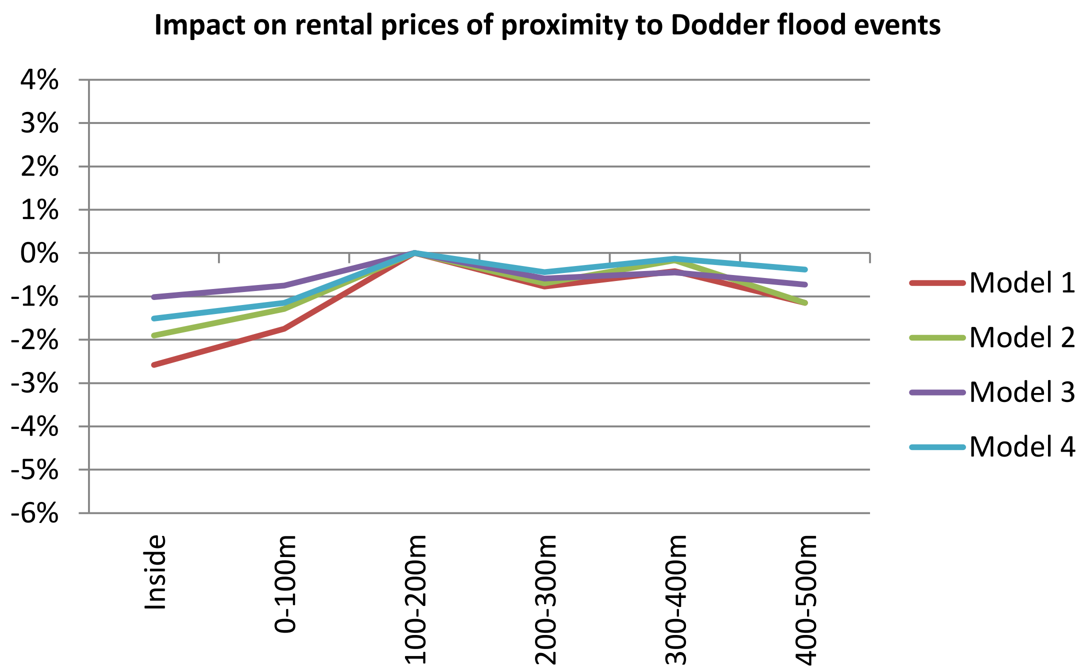
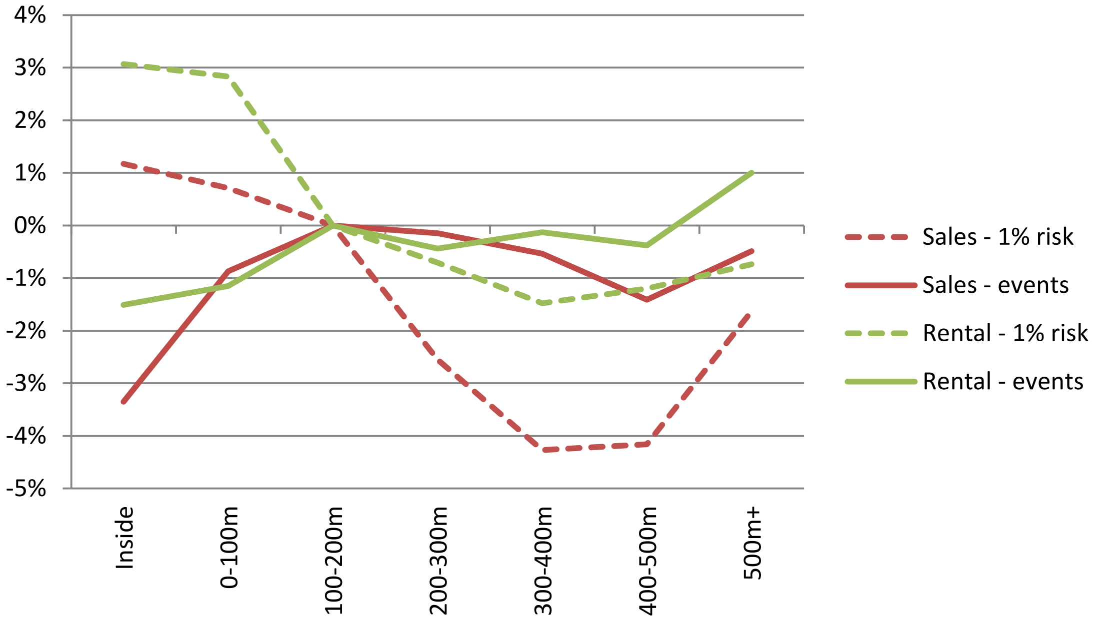


Figure 6: Impact on sale and rental prices of proximity to Dodder 1% risk zone and event zone



3.3 Exploiting the 2011 floods

As noted above, in October 2011, a severe flooding event took place in Dublin, with the Dodder badly affected and numerous homes flooded (Figure 7). As a result of this event, a series of interventions up-stream and down-stream of the flood event aimed at reducing the flood risk in the areas affected by the 2011 flood event of the Dodder were planned and deployed as part of the Dublin City Development Plan 2011-2017 and 2016-2022. Flood defenses incorporating 100-year river flow, plus 300mm freeboard have been constructed in several locations up-stream and down-stream of the affected areas on both sides of the river. The concrete wall in Lansdowne Lane has been increased in height to above the October 2011 flood levels as a temporary flood measure. The works to date would also reduce the risk of flooding due to overland flows downstream. No defenses have been taken into consideration in the flood zones except for the very large embankment in the Merrion Cricket Club. An increase of 20% on top of the estimated 100-year fluvial level is planned to be catered for by storage upstream of where the Tallaght Stream joins the Dodder, in order to account for sensitivity to climate change.

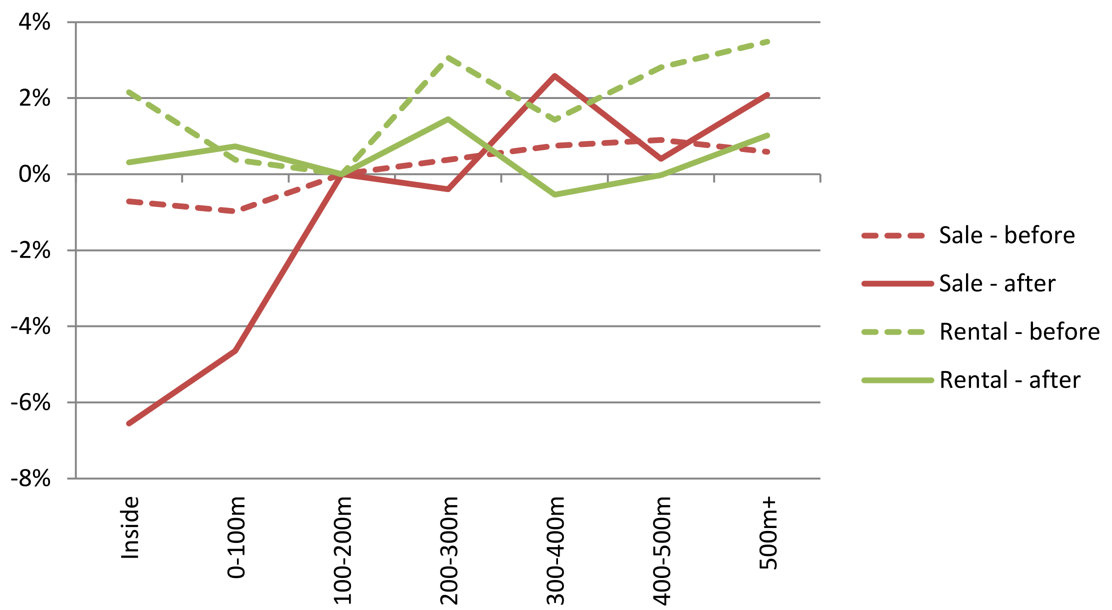
The richness of the dataset available for this analysis includes variation by flood-risk measure, by distance and by time, as described in the Methods

Section. Table 3 in the Appendix presents the results from Models (5) and (6), distinguishing between before and after the 2011 flood event, in addition to including the full set of controls in Model (4) above. Model (6) differs from Model (5) in the additional inclusion of controlling for the 1% risk zone and past flooding events, although this does not affect the estimated impact of the 2011 floods. These results are presented graphically in Figures 8-9. For rental properties, the 2011 flood appears to have had little impact on the relationship between flood risk and rents (Figure 9). Both sets of results are qualitatively similar for pre- and post-flood periods, with no statistically significant difference in rents for properties in the area flooded in 2011. Overall, the lack of a negative relationship between distance from flood risk and rental costs remained in the post-flood period.

However, for sale properties, the 2011 flood saw a dramatic change in the relationship between scientifically assessed risk and property values. As shown in Figure 5, the moderate downward slope for the period as a whole when split into pre- and post-flood periods reveals a strong downward slope prior to October 2011 and a strong upward slope after, out to 200m-300m from the risk zone. This upward slope for the post-2011 period is consistent with economic theory: holding other factors constant, greater risk of flooding is associated with lower property values. Controlling for 1% risk and previous flooding events, properties inside the area flooded in October 2011 had no statistically significant difference in price prior to this date, compared to properties 100m-200m away. However, after the 2011 floods, these properties listed at a discount of 6.6%.

Figure 7: Flooded areas (red) in flood event of 2011 and major rivers (blue) overlaid on Dublin's road network (grey)

Figure 8: Impact on sale and rental prices of proximity to Dodder flood event zone – before and after 2011 flood



4. Discussion

This study combines GIS techniques and hedonic price regression methods, to estimate and quantify the effects of a property being located within a flood risk and/or a flood event zone. Hedonic methods are frequently used to decompose the prices of goods with many attributes, such as homes or cars, into their constituent parts. In this study, hedonic regressions hold constant other factors affecting a dwelling's value – such as its type or size – and use variation in the measures of flood exposure discussed above to estimate their impact on prices, both sale and rental. Here, this procedure yields an estimate of the percentage impact on a sale and rental prices of being in a specific flood-risk zone, compared to not being in it. A study of the available literature suggested that the lack of a persistent effect may have an impact on buyers' and sellers' risk perceptions by changing with the prevalence of hazard events and that homebuyers are unaware of flood risks and insurance requirements when bidding on properties. Here, the distance from a set of amenities and the properties is also calculated using GIS. The amenities included in this procedure are: the Central Business Districts (CBDs), rivers, lakes, schools, green spaces, rail facilities and the coastline.

The CFRAM programme was implemented in Ireland so as to meet the requirements of the EU "Floods" Directive (2007/60/EC). This Directive was transposed into Irish law with the SI 122/2010, which set out the responsibilities of the OPW (Office of Public Works) and other public bodies in the implementation of the Directive, on consultation, and details the process for implementation of the measures set out in the flood risk management plans (CFRAM programme).

The CFRAM programme comprises of three phases: (i) the Preliminary Flood Risk Assessment (PFRA), completed in 2011; (ii) the CFRAM studies (flood maps), completed in 2014; (iii) the preparation of Flood Risk Management (to be completed at the time of the preparation of this article). The CFRAM flood hazard maps are used as part of this work to have a spatial estimate of the flood hazard; fluvial flood events are shown for 10%, 2% and 1% Annual Exceedance Probability (AEP). The AEP is estimated using computer models to predict how and where flooding is likely to occur and what receptors are likely to be affected by the flooding (Berry et al., 2008).

Finally, the dataset of listings of Irish dwellings for sale or rent used for this study comes from online property portal, Daft.ie. This dataset contains a list of 158,890 properties located in Dublin that were advertised online for sale, and 499,147 listed for rent, between January 2006 and April 2015. Daft.ie is Ireland's largest property portal website and their archives include all properties listed for sale online, including a small fraction not listed on the Daft.ie website. All the properties included in the used database are geolocated, which allows them to be connected to Census and other geographic information, and have information on property characteristics including the number of bedrooms, number of bathrooms and property type (detached, semi-detached, bungalow etc.).

Tables 2 and 3 in the Appendix show the number of sales and rental listings either within these at-risk zones or within 500 metres of them, for the entire period and for the periods before and after the October 2011 floods. In total, there are 10,292 sale listings and 31,033 rental listings within 500 metres of either flood-risk measure. This includes 575 sales listings within the 1% flood risk zone and a further 793 directly affected by past flood events. For rental listings, the figures are 1,674 and 2,531 respectively. In both sets of listings, there are significant numbers before the 2011 floods and after. This variation by location and time is at the heart of the identification strategy underpinning this research.

Using hedonic regression techniques, the regression analyses for the sales and rentals show that there is little evidence that being within the 1% risk zone has any impact on sale or rental prices of housing. Going from within the risk zone to ~150m away is associated a slight increase in prices (~1%) and this is not statistically significant, accounting for a full range of local characteristics. In general, the analysis demonstrates that the prices of the dwelling located within a floodplain are significantly affected by the distance from a set of amenities such as the CBDs, rivers, lakes, schools, green spaces, rail facilities and the coastline. However, being within the historical events zone does have a negative effect on prices, 3.4% and (strongly) statistically significant. Interestingly, it emerges that wrong conclusions could be potentially draw if flooding events are not controlled for: the relationship between prices and being within the 1% zone is indeed negative if flood events are not included in the analysis (although again not statistically significant). On the basis of this evidence, it is reasonable to conclude that past flooding events have a more significant impact on buyer behavior in the housing market than scientific assessments of risk.

This is explained by the fact that people may have an understanding of flooding that is more adaptive (i.e. learning/extrapolating from the past) than rational (a scientific assessment of risk). As such, this work also shows that, in the absence of other regulatory pressures, perception of flood risk is directly related to human memory.

Perceptions of flood risk in Ireland are shaped by only partial availability of information relating to both flood risk and past flood events. Throughout the period analysed here, some information on past flood events was available through the website floodmaps.ie, although not in an easily accessible format. Similarly, the myplan.ie website contained information on flood risk, although not at sufficient resolution to identify individual properties. That said, planning laws have increasingly required assessment of flooding potential for new building.

Finally, the work presented in this paper also demonstrates the effectiveness of using GIS for this type of analysis to solve the problem arising from the coincidence of positive and negative amenities related to proximity to the water and to account for the spatial organization of the data in terms of distance to the water front and elevation.

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Appendix

Table 1: Selected regression results for Sales and Rental Segment

	Sales				Rental			
	Coeff	SE	t-stat	p-value	Coeff	SE	t-stat	p-value
1 percent risk - within	0.0067	0.0146	0.46	0.645	0.0293	0.0062	4.72	0
1 percent risk - 0-100m	0.0039	0.0082	0.48	0.632	0.0278	0.0035	7.97	0
1 percent risk - 100-200m	0	.	.	.	0	.	.	.
1 percent risk - 200-300m	-0.0237	0.0083	-2.85	0.004	-0.0015	0.0041	-0.36	0.715
1 percent risk - 300-400m	-0.0393	0.0085	-4.63	0	-0.0096	0.004	-2.39	0.017
1 percent risk - 400-500m	-0.0385	0.0085	-4.56	0	-0.0065	0.0036	-1.82	0.068
1 percent risk - 500m+	-0.013	0.0072	-1.8	0.072	0.0015	0.0031	0.46	0.643
Historical events - within	-0.0281	0.0076	-3.69	0	-0.0148	0.0028	-5.36	0
Historical events - 0-100m	-0.0051	0.0049	-1.04	0.3	-0.0122	0.0017	-7.16	0
Historical events - 100-200m	0	.	.	.	0	.	.	.
Historical events - 200-300m	-0.0026	0.0052	-0.51	0.612	-0.0108	0.002	-5.54	0
Historical events - 300-400m	-0.008	0.0054	-1.5	0.134	-0.0061	0.0021	-2.92	0.004
Historical events - 400-500m	-0.0161	0.0054	-2.98	0.003	-0.0101	0.0022	-4.61	0
Historical events - 500m+	-0.0071	0.0049	-1.44	0.149	0.0012	0.0019	0.63	0.528
Before 2011 flood - within	-0.0072	0.0168	-0.43	0.67	0.0215	0.0052	4.15	0
Before 2011 flood - 0-100m	-0.0098	0.0077	-1.27	0.204	0.0038	0.0026	1.45	0.147
Before 2011 flood - 100-200m	0	.	.	.	0	.	.	.
Before 2011 flood - 200-300m	0.0038	0.0069	0.55	0.58	0.0306	0.0026	11.97	0
Before 2011 flood - 300-400m	0.0075	0.0073	1.02	0.308	0.0143	0.0027	5.26	0
Before 2011 flood - 400-500m	0.009	0.0073	1.23	0.218	0.0281	0.0028	9.96	0
Before 2011 flood - 500m+	0.0059	0.0061	0.97	0.33	0.0348	0.0022	15.68	0
After 2011 flood - within	-0.0656	0.0184	-3.56	0	0.0031	0.0058	0.53	0.595
After 2011 flood - 0-100m	-0.0465	0.0107	-4.34	0	0.0073	0.0037	1.97	0.048
After 2011 flood - 100-200m	0	.	.	.	0	.	.	.
After 2011 flood - 200-300m	-0.004	0.0102	-0.39	0.698	0.0145	0.0036	4.06	0
After 2011 flood - 300-400m	0.0258	0.0104	2.48	0.013	-0.0054	0.0038	-1.42	0.156
After 2011 flood - 400-500m	0.004	0.0105	0.38	0.702	-0.0003	0.0037	-0.07	0.946
After 2011 flood - 500m+	0.0209	0.0079	2.67	0.008	0.0102	0.003	3.42	0.001