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Assessing the economic benefits of flood defences: A repeat-sales approach

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Abstract

In this paper we identify the impact of the construction of flood defences on property prices using a difference-in-differences repeat-sales methodology. Our dataset contains information on over 12 million individual property transactions which is merged with GIS data identifying the spatial location and main characteristics of 1,666 flood defences built in England between 1995 and 2014. Results suggest that at the finer 6-digit postcode level the construction of flood defences raises urban house prices by 12.6 to 16.7%. However, for rural properties at the slightly coarser 5-digit postcode level the construction of defences *reduces* house prices by 0.8 to 5.0%. This suggests that in certain locations the disamenity impact of flood defences and the perceived threat of redirected flooding outweigh the benefits of reduced flood risk.

Keywords: Flood risk, flood defences, house prices, difference-in-differences, repeat-sales, hedonic price method

JEL Code: Q51, R21, D12

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1. Introduction

During the last 20 years, the UK has experienced a sequence of costly flood events. The Easter floods of 1998 broke records set by the Great Flood of 1947, causing damages of over £350m (Bye and Horner, 1998). This event was swiftly followed by further widespread flooding during the autumn of 2000 costing an estimated £1.0bn (EA, 2001) and by the summer floods of 2007, when over 55,000 properties were flooded causing around £3.2bn of damage (EA, 2010a). In 2012, flooding across the entire country cost an estimated £600m (Met Office and JBA, 2012; EA, 2013). During the winter of 2013-14 yet more flooding was visited upon the south of England causing damages of £1.3bn (Met Office, 2014; EA, 2016). Recently, storms Desmond and Eva once more brought severe flooding to the north of England during the winter of 2015-16 causing damage estimated to be worth £1.3bn (Met Office, 2016; ABI, 2016).

As elsewhere the construction of structural flood defences has in the UK been the traditional method of protecting low-lying communities against flooding (Ackers et al. 2009). The Environment Agency (EA) maintains records of all structural flood defences in England and Wales stretching as far back as 1739. The primary function of these structures is to contain / divert floodwaters and hence reduce the probability of flooding in the defended area.

Structural flood defences are however costly to construct and require ongoing maintenance. In the UK the 2010 Comprehensive Spending Review earmarked a total of £2.17 billion in central Government funding for the building and maintenance of new and existing flood defence assets representing an average expenditure of £542.5 million per year over the financial years 2011-12 to 2014-15 (Bennett and Hartwell-Naguib 2014).

There is now a substantial body of research on the economic valuation of flood risk including a number of studies for the UK. Some studies try to identify the economic value of the natural flood protection services of different ecosystems using various market and non-market valuation techniques e.g. King and Lester 1995, Leschine et al. 1997, Ming et al. 2007, Polyzos and Minetos 2007, Filatova et al. 2011 and Gibbons et al. 2014. Other studies focus on the macroeconomic impact of flooding e.g. Benson and Clay 2000, Pelling et al. 2002, Hallegatte et al. 2013, Ward et al. 2013, Winsemius et al. 2013 and Jongman et al. 2014. Yet more studies examine the prices of comparable properties located inside and outside of the 100 or 500-year floodplain e.g. Bin and Polasky 2004, Bin and Kruse 2006, Kousky 2010, Atreya et al. 2013, Bin and Landry 2013 and Atreya and Ferreira 2015. Finally, the determinants of households' adoption of private flood mitigation measures have also been explored e.g. Samarasinghe and Sharp 2010, Bubeck et al. 2012, Meyer et al. 2012, Dachary-Bernard et al. 2014, Bichard and Thurairajah 2014 and Osberghaus 2015.

However, despite the large amounts of public money spent every year on structural flood defences in the UK and elsewhere it appears that no efforts have hitherto been made to assess whether households actually benefit to the extent that was anticipated when these structures were planned.

In this study, we use a difference-in-differences (DID) repeat-sale hedonic price methodology to measure ex-post the resulting benefits to households in terms of capitalisation arising out of the construction of structural flood defences in England.[1] This analysis goes far beyond the usual scale of empirical studies by analysing the benefits of *all* structural flood defence projects undertaken in England during the period 1995-2014. The data that we analyse includes information on over 12 million property transactions and on 1,666 flood defences.

[1] Note that following Kuminoff and Pope (2014) and Kuminoff et al. (2010) with a DID design strictly-speaking what is measured is capitalisation rather than WTP.

To anticipate our main findings, we show that when measured at the finer 6-digit postcode level the construction of flood defences raises the price of urban properties by between 8.6 and 12.8%. By contrast, for rural properties at the slightly coarser 5-digit postcode area the evidence suggests flood defences *reduce* prices by between 1.3 and 4.0%. Our results also point to significant price falls for flats in newly defended areas. Possible disamenity impacts are not formally considered by the Department of the Environment Food and Rural Affairs (DEFRA) who bear ultimate responsibility for planning structural flood defences in England and the analysis of redirected flooding is perforce geographically limited. This could result in overinvestment in flood defences in some locations.

The remainder of the paper is organised as follows. Section 2 presents a literature review of the different methodologies used to quantify the benefits of flood risk reduction, with an emphasis on hedonic applications and a handful of ex-post assessments. Section 3 describes the theoretical model underpinning the analysis. Section 4 describes the identification strategy and section 5 describes the data and the econometric model. Section 6 presents the results and offers several tests of robustness. Estimates of the average effect of flood defences on the price of property in the same postcode are contained in section 7. Section 8 concludes.

2. Literature Review

Studies addressing the ex-ante economic benefits of constructing flood defences can be divided into two types: (1) averted future impacts (AFI) studies which use different flooding scenarios and depth / damage data to construct loss / probability curves (Oliveri and Santoro 2000, Brouwer and Van Ek 2004, Sheng et al. 2005, Blonn et al. 2010, Jongman et al. 2012) and (2) stated preference methods (SPM) exploring respondents' willingness to pay (WTP) for the construction of flood defences using hypothetical scenarios (Koutrakis et al. 2011, Brouwer et al. 2009, Zhai and Suzuki 2008, Phillips 2011, Veronesi et al. 2014).

The AFI method (Smith 1994, Merz et al. 2010) constitutes the current standard approach for assessing the economic benefits of flood alleviation schemes in the UK. The benefits of flood alleviation schemes are defined as the sum of averted future flood damages from a reduction in the frequency and / or the impact of flooding (Penning-Rowsell et al. 2014). In this approach flood damages are classified according to whether they are direct or indirect and tangible or intangible. Direct residential flood damages result from the physical contact of flood water with damageable property, whereas indirect flood losses refer to additional costs induced by adverse changes in prices. Intangible impacts refers to damage done to things that do not possess a market price e.g. loss of possessions of purely sentimental value.

The main inputs to the AFI are: (1) a hazard assessment detailing the probability of those future flood events which the project would eliminate and (2) a vulnerability assessment providing information on the damage that would have been caused by those floods e.g. an inventory of damageable goods along the costs of repair / replacement (Penning-Rowsell et al. 2014). As an example of this approach, Kousky and Walls (2014) calculate the benefits of floodplain conservation in St Louis County, Missouri. Specifically they use a hydrological and hydraulic model combined with depth-damage curves to calculate the avoided flood impacts associated with a counterfactual scenario involving development of the conserved area.

Although the AFI method is widely used for the economic assessment of flood defence projects it is nevertheless subject to some important shortcomings e.g. the extent that the household would indeed make the repairs or replacements suggested (Shabman and Stephenson 1996) and the fact that the estimates do not necessarily correspond to WTP. There is also concern that the predictive ability of these models is weak (Schröter *et al.* 2014). It also of course ignores impacts associated with the construction of the flood defences other than those resulting from a reduction in the probability of flooding e.g. disamenity impacts.

SPMs provide an alternative means of estimating economic benefits for flood alleviation schemes. Koutrakis et al. (2011) use contingent valuation (CV) to estimate the WTP for coastal defence systems in different regions of the Mediterranean area. Brouwer et al. (2009) use the same methodology to assess WTP for the construction of an embankment to protect the sub-district of Homna, Bangladesh against flooding. Zhai and Suzuki (2008) estimate the WTP of residents in the coastal area of Tianjin, China to reduce the risk of flooding. Veronesi et al. (2014) use choice experiments (CE) to assess the WTP of Swiss households to reduce the intangible impacts of wastewater flooding. Apart from these examples however, the use of SPM in the context of flood defences has been largely restricted to estimating the intangible components of AFI (see e.g. Merz et al. 2010; Penning-Rowsell et al. 2014).

Both the AFI and the SPM approach provide an *ex-ante* assessment of the benefits of constructing flood defences. However, despite the increasingly large amounts of money spent on the planning, construction and maintenance of flood defences, surprising little research exists providing an *ex-post* evaluation of the benefits delivered by such structures.[2]

Of those studies investigating the ex-post benefits of flood defences Damianos and Shabman (1976) use the hedonic price method (HPM) to assess capitalisation of the benefits of the construction of the Claytor Lake dam, Virginia, US. Results suggest that the price of lots sold after the construction of the dam was higher than those sold before. Thompson and Stoevener (1983) estimate capitalisation of the benefits of the Sutherlin Creek Watershed Project concluded in 1970, Oregon, US. Once again the authors use a before-and-after HPM approach

[2] The studies by Miyata and Abe (1994) and Dorfman, et al. (1996) are not considered in this description. Although the authors use HPMs to estimate the benefits of the construction of flood defences, their results are based on the simulation of the construction of a flood defence via changes in independent variables defining flood risk and therefore do not evaluate the ex-post benefits of the construction of a defence. See Beltran *et al*. (2018) for a summary on the disbenefits of floodplain location.

to identify any changes in the price differential of residential properties located inside and outside the floodplain.

A more recent study by Lee and Li (2009) uses the HPM to estimate capitalisation of the benefits of the construction of different designs of water detention basins. The authors focus on two communities in College Station, Texas, US. Two different detention pond designs are analysed: (1) a uni-use flood control detention basin (UDB) in Woodcreek solely for flood control and (2) a multi-use detention basin (MDB) in Edelweiss Estates incorporating sports, recreational and storm-water management benefits. For the UDB the authors conclude that those properties with a direct view of the UDB experience a significant price *reduction*. The results for the MDB by contrast, suggest that property values decrease for every additional 10m *away* from the basin. The authors argue that issues related to the construction of UDBs such as maintenance problems, safety issues, and visual disamenity, outweigh the flood risk reduction-benefits whereas for MDBs, the benefits of the multiple functions (mainly recreational in nature) result in relatively higher property prices.

These ex-post studies clearly suffer from significant shortcomings. All use appraised values rather than actual property prices and employed very small samples, ranging from 25 to 156 observations. Furthermore, although the studies by Damianos and Shabman (1976) and Thompson and Stoevener (1983) use a before-and-after approach the correct identification of the policy's effect on capitalisation requires successfully controlling for a large number of other factors impacting property prices.

Although not valuing the provision of flood defences to residential households Fell and Kousky (2015) examine whether levee protection is capitalised into the sale price of commercial property in Chesterfield, Missouri. They attempt to disentangle price effects from agglomeration effects in two ways: controlling for surrounding land cover and selectively choosing control properties. They find that properties protected by a 500-year levee are not discounted relative to those properties that are outside the floodplain. And although the sale prices of properties in levee protected areas tend to be higher than in floodplain areas not protected by a levee the difference in price is often statistically insignificant.

Lee and Li (2009) are not the only researchers to encounter negative impacts associated with the provision of flood protection. Phillips (2011) uses a CE to investigate the impact of coastal defences in Whitianga, New Zealand. He concludes that residents are willing to pay $20 NZD per year (in 2010 prices) to *remove* an existing floodwall due to its negative impacts on amenity values. Likewise, Penning-Rowsell and Fordham (1994) interview residents of riverside properties along the Lower Thames, UK and conclude that 34% of those interviewed were prepared to live with a 20% annual probability of flooding in exchange for the location being left *undisturbed* by any flood management engineering structures. This figure rises to 94% of residents being willing to live with a 0.5% annual probability of being flooded. Penning-Rowsell et al. (2014) argue that there is an important trade-off for households between flood protection and the preservation of amenity values. The results that we will go on to present appear to support this contestation.

3. The Hedonic Model for Flood Risk Valuation

Economic theory suggests residential housing markets provide a means of estimating the impacts of flood risk reduction. For example, the price of identical residential properties located within a floodplain should be lower than that of equivalent properties located outside the floodplain. Any observed price differential reveals the capitalisation of the economic benefits of a lower level of flood risk.

The hedonic price function (HPF) describes the price of a quality-differentiated commodity as a function of its multiple attributes. When an individual decides where to live this decision should include the level of flood risk and hence this can be regarded as an additional characteristic of a property. The theoretical model described below is based on the characterisation of the HPF by Rosen (1974) and its extension to flood risk by MacDonald et al. (1987), Carbone et al. (2006), Bin et al. (2008), Kousky (2010) and Bin and Landry (2013).

Let $\boldsymbol{S}$ represent a set of structural characteristics of residential property such as age, number of bathrooms and lot size; $\boldsymbol{N}$ the neighbourhood characteristics such as the crime rate, distance to the central business centre or to a major motorway, and $\boldsymbol{E}$ environmental characteristics such as the level of air pollution. Define $Z = \boldsymbol{S}, \boldsymbol{N}, \boldsymbol{E}$. Furthermore, let the subjective probability of flooding, i.e. the homeowner's subjective assessment of flood risk, be a function $p(i, r)$ of the set of information, i, the individual holds about flood risk in the location of the property and r which represents those site attributes related to flood risk, which could be locational characteristics such as proximity to water bodies or elevation. The HPF describing the price of a property, P, can be written as:

$$P = P\big(Z, r, p(i, r)\big) \tag{1}$$

Therefore, P is exogenous to individual buyers and sellers, but reflects subjective risk perception $p(i, r)$. Prices are assumed to be market clearing, given the stock of housing choices and its characteristics. The housing market is assumed to be in equilibrium, which requires households to optimise their residential choice based on the price of property in all alternative locations. It is assumed that homebuyers are able to adjust the different levels of each characteristic and no transaction costs are considered.

It is important to distinguish the subjective assessment of the probability of flooding, p, from the objective measure of flood risk, π. This distinction implies three things. First, perceived risk is not necessarily equal to objective risk. Second, changes in the objective risk are not necessarily perceived. Third, changes in perceived risk do not necessarily arise from changes in objective risk. In areas where flood risk disclosure is mandatory or public information about flood risk is available, the set of information, i, might nonetheless include the objective probability of flooding, π.

The model uses an expected utility framework that incorporates risk factors associated with a property. The household's decision is modelled using the following state dependent utility function:

$$EU = p(i,r) \cdot U^F[Z,r,Q] + \big(1 - p(i,r)\big) \cdot U^{NF}[Z,r,Q] \tag{2}$$

where $U^F(\cdot)$ is the utility of the homeowner in a state where a flood occurs and $U^{NF}(\cdot)$ is the utility of the homeowner when there is no flood. The budget constraint for the household is given by equation (3) where M is total income and Q is non-housing expenditure:

$$M = P\big(Z, r, p(i,r)\big) + Q \tag{3}$$

Maximizing expected utility (2), with respect to the subjective probability of flooding, p, subject to the homeowner's budget constraint, and dividing by the expected marginal utility of consumption yields:

$$\frac{\partial P}{\partial p} = \frac{U^F - U^{NF}}{p(i,r)\frac{\partial U^F}{\partial Q} + \big(1 - p(i,r)\big)\frac{\partial U^{NF}}{\partial Q}} \tag{4}$$

Equation (4) is the coefficient on the perceived risk variable estimated in the hedonic regression. It reveals that the marginal implicit price for flood risk is equal to the utility difference across states divided by the expected marginal utility of consumption.

3.1 The Role of Flood Defences

The main objective of constructing flood defences is to contain or divert floodwaters thereby reducing the objective probability of flooding (π) in the defended area (Ackers et al. 2009). Since the household chooses to live in a location which maximises expected utility subject to the budget constraint, a sales price differential might be expected to emerge in locations protected by flood defences. At the same time however, the construction of flood defences might result in a loss of amenity values (and redirect floodwaters elsewhere).

Formally, the protection of a property due to the presence of a flood defence can be considered an additional characteristic, d, of a property, and therefore can be included in the HPF. Note that although the main objective of flood defences is to reduce the objective probability of flooding (π), this change might, or might not, be fully perceived by the individuals. Therefore the level of flood protection, d, provided by the presence of the defence also enters as an argument in the households' subjective assessment of the probability of flooding, $p(i,r,d)$. Thus, equation (5) represents the HPF considering the presence of flood defences.

$$P = P\big(Z, r, d, p(i,r,d)\big) \tag{5}$$

Considering the HPF given in equation (5) and the expected utility to the homeowner in equation (2), the marginal bid for the construction of flood defences is now given by the following equation:

$$\frac{\partial P}{\partial d} = \frac{p\frac{\partial U^F}{\partial d} + (1-p)\frac{\partial U^{NF}}{\partial d}}{p(i,r,d)\frac{\partial U^F}{\partial Q} + \big(1-p(i,r,d)\big)\frac{\partial U^{NF}}{\partial Q}} + \frac{\frac{\partial p}{\partial d}\left(U^F - U^{NF}\right)}{p(i,r,d)\frac{\partial U^F}{\partial Q} + \big(1-p(i,r,d)\big)\frac{\partial U^{NF}}{\partial Q}} \tag{6}$$

Equation (6) is composed of two terms. The first term on the right represents the *direct* effect of the construction of flood defences on utility e.g. the loss of direct physical access to a water body or the visual disamenity caused by the structure itself. The second term consists of the price for a unit reduction in flood risk multiplied by the change in the subjective assessment of the probability of flooding due to the flood defence ($\partial p/\partial d$). Because the first term might be negative it can now no longer be simply assumed that the overall implicit price of flood defences is positive.

4. A Repeat-sales Model to Identify the Benefits of Flood Defences

Early applications of the HPM addressed the issue of floodplain location and its capitalisation using purely cross-sectional property price data. More recent applications of the HPM have by contrast, explored how new information about flood risk is capitalised into the price of properties located in the floodplain using a quasi-experimental design / difference-in-differences (DID) approach.

Note however, that whereas this approach pools property prices over time, the across-time price comparison does not correspond to sales of the same property and is therefore conditioned on values of the other covariates. A significant shortcoming of this approach therefore, is the sheer amount of information it requires; information on all the major structural and locational characteristics influencing the value of a property must be included (Palmquist 1982, 2005). An alternative approach that overcomes this weakness is the repeat-sales model.

Consider properties that have been sold multiple times over a given period. Between those occasions when a property is sold, whilst there may be changes in some of its characteristics e.g. the age of the property, in general many characteristics of the property remain the same. Therefore, by considering two sales of the same property it is possible to control for all the time-invariant characteristics thereby recovering more precise estimates for the effect of those characteristics that have changed. In this way, a repeat-sales specification allows us to evaluate the price effect of an environmental change which is not uniform across properties (Kousky 2010, Palmquist 1982, 2005).

Formally, consider the following additive representation of the HPF in equation (7):

$$lnP_{it} = \beta_0 + \sum_{j=1} \beta_j Z_{ij} + \phi p_i + \gamma r_i + \theta d_i + \alpha Defence_{it} + \psi(Defence_{it} \times d_i) + \varepsilon_{it} \qquad (7)$$

Where i denotes a specific property, t is time and j represents a specific structural, neighbourhood or environmental characteristics of property i. As before P represents the sale price of the property; Z is the set of structural, locational and environmental characteristics of the property; p is perceived flood risk; and r as a control for proximity to water-based amenity values. β_0, β_j, ϕ, and γ are coefficients.

Since we are interested in the effect of the construction of a flood defence, let d represent a dummy variable identifying properties located in areas that experienced the construction of a flood defence during the period of analysis and $Defence$, represent a dummy variable equal to unity for those sales occurring after the construction of the flood defence. The parameter θ represents the incremental impact on price of location within the vicinity of the flood defence whereas parameter α captures the time effect, i.e. the relative price difference for all properties sold after the construction of the flood defence. The parameter ψ represents the treatment response, i.e. the ex-post effect on property prices in thereby defended areas. Finally, ε_i is the property-specific error term to which the usual assumptions apply i.e. $\varepsilon_i \sim N(0, \sigma^2 I)$.

As the repeat-sales model requires at least two sales for each property, there are two sales in time periods, t and s. P_{it} denotes the price observed after the construction of the defence and P_{is} identifies the price prior to construction. Thus, for property i there is an earlier sale in year s for which the price is explained by an equation similar to (7) but where the variable $Defence$

takes the value of zero. Considering the difference in sales prices for the same home ($lnP_{it} - lnP_{is}$) yields equation (8).

$$(lnP_{it} - lnP_{is}) = (\beta_0 - \beta_0) + \sum_{j=1} \beta_j \left(Z_{ij} - Z_{ij}\right) + \phi(p_i - p_i) + \gamma(r_i - r_i) + \theta(d_i - d_i) \\ +\alpha(Defence_{it} - Defence_{is}) + \psi[(Defence_{it} \times d_i) - (Defence_{is} \times d_i)] + (\varepsilon_{it} - \varepsilon_{is}) \tag{8}$$

The one critical assumption for identification using the repeat-sales model is that all structural, locational, and neighbourhood characteristics (Z_i, p_i, r_i) of the property remain constant between the period of the two sales, t and s, as well as all the parameters of the HPF. Therefore, these terms drop out of equation (8) and time-invariant characteristics of the property are no longer a concern.[3] The resulting expression appears in equation (9).

$$\Delta ln(P_{its}) = \alpha Bracket_{its} + \psi(Bracket_{its} \times d_i) + \lambda_0 Year_t + \lambda_1 Year_s + \Delta\varepsilon_{its} \tag{9}$$

Notice that the term identifying properties that were sold after the construction of the flood defence, $Defence_i$, now translates into a dummy variable, $Bracket_{its}$, that identifies properties sold before and after the implementation of the project, i.e. sales that bracket the timing of the construction of the defence. Following Kousky (2010) and Phaneuf and Requate (2011), the variables $Year_t$ and $Year_s$ are also included to control for appreciation and age-effects.

Although the repeat-sales model sidesteps the need for data on those characteristics of properties that are assumed time-invariant there are nevertheless possible problems. Previous studies suggest that the use of repeat-sales models might induce a bias if properties with repeat sales are unrepresentative of the housing stock as a whole, e.g. buy-to-let properties (Lamond

[3] Notice that floodplains are defined as spatially delineated areas that would naturally be affected by flooding should a river or lake rises above its banks, or high tides and stormy seas cause flooding in coastal areas; therefore the construction of a flood defence does not change the floodplain designation status of a property, but the standard of protection for the benefited area.

et al. 2007; Steele and Goy, 1997). We minimise any potential bias by using a large dataset which includes all information on repeat sales at a national level in a sample that spans almost 20 years. For longer time periods, the probability of re-sale increases and therefore more information is included in the regression. Clapp et al. (1991) argue that in the long run there are no systematic differences between the repeat sales sample and the full sample, and Nagaraja et al. (2014) argue that as the time period increases, the efficiency of the repeat-sales method increases faster than that of the standard HPM.

5. Data and Econometric Model

Data on property prices is taken from the England and Wales Land Registry (EWLR). This dataset is publicly available and includes essential details on all residential properties in England and Wales that were sold for full market value and whose details were lodged with the EWLR. The data includes information on sale price, date of transaction (DD/MM/YYY), address and the most basic property characteristics.[4] It also includes information on whether a property is new or second-hand and whether it is sold on a freehold or leasehold basis.

The complete set of data from the EWLR consists of over 19 million observations for properties sold in England and Wales between January 1995 and the end of July 2014. Since details on structural flood defences are available only for England (see below), all observations corresponding to Wales are dropped.

Housing units with repeat-sales are identified by matching the exact address of the properties using four criteria: full postcode, street name, primary property number and secondary property

[4] Authors such as Case and Quigley (1991) and Shiller (1993) suggest the use of 'hybrid models' combining repeat sales data and the property characteristics included in standard hedonic analyses. Unfortunately, property characteristics are not available in our data.

number (e.g. for buildings divided into flats).[5]Whenever there is a match for all four variables, the transaction is regarded as a repeat-sale. Over 6 million observations for properties with only a single sale are dropped, as well as over 12,000 observations with a missing postcode.

The final dataset includes over 12 million transactions corresponding to 4.8 million properties in England. All sale prices are adjusted to July 2014 prices using the county-specific Property Price Index (PPI) available through the EWLR.[6] On average, a property in the sample was sold 2.5 times between January 1995 and July 2014, with a minimum of 2 and a maximum of 29 sales. Finally, the between-sales growth rate for the price of each property is calculated as the first difference of the logged price, as shown in equation (8). Thus, the final dataset we use for estimating the repeat-sales model consists of over 7 million observations representing the between-sales growth rate for approximately 4.8 million properties.

We acquired licensed GIS data from the National Flood and Coastal Defence Database (NFCDD) from the EA. These data contain information on the spatial location and main characteristics of all flood defences protecting against fluvial flooding in 100-year floodplains and tidal flooding in 200-year floodplains. These data also include important characteristics of the defences such as the standard of protection, the length, the crest level, and year of

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[5] The postcode system in the UK is an alphanumeric code comprising an 'outward' code and an 'inward' code. Consider the postcode LN8 2DN. The first two letters refer to the postcode area (of which there are 124 in the UK) and the number 8 refers to the postcode district (of which there are 3,111). Turning to the inward component, the number 2 refers to the postcode sector (of which there are 12,381). The final two letters respectively identify the 5 and 6-digit postcode areas. There were in 2014 approximately 1.75 million distinct 6-digit postcodes in the UK. In practice the full postcode (postcode unit level) of a property in the UK can range between 6 and 8 alphanumeric characters. Throughout this chapter we use the term '*6-digit postcode*' to refer to the full postcode of the property. Likewise, we use the term '*5-digit postcode*' meaning one character less than a full postcode, *i.e.* five to seven characters. In the UK the typical 6-digit postcode is shared by an average of 17 houses grouped together, and the typical 5-digit area contains approximately 442 properties.

[6] Local Government in England operates either under a one-tier system or a two-tier system. The property price indices we use are based on information on the geographical areas covered either by single-tier or upper-tier Local Government i.e. county councils and unitary authorities. The geographical boundaries of these areas are displayed in Figure 1. Henceforth we referred to these as "counties".

construction.[7,8] It also indicates the type of asset (e.g. floodwall or embankment), the type of flooding it protects against (fluvial or coastal) and a description of the structure and its condition.

The NFCDD identifies a total of 24,257 structural flood defences in England constructed between 1739 and 2014. Due to the design of the analysis and the fact that information on property prices is only available since 1995, the final dataset only includes information for flood defences that were built after this year. The final dataset therefore consists of a total of 1,666 flood defences built between 1996 and 2014, representing a defence length of 553 km. A summary of the data on flood defences is presented in Table 1. Figure 1 shows the location of the flood defences included in the analysis. Table A1 in the appendix provides a description of the general features of the different types of flood defences included in the dataset.

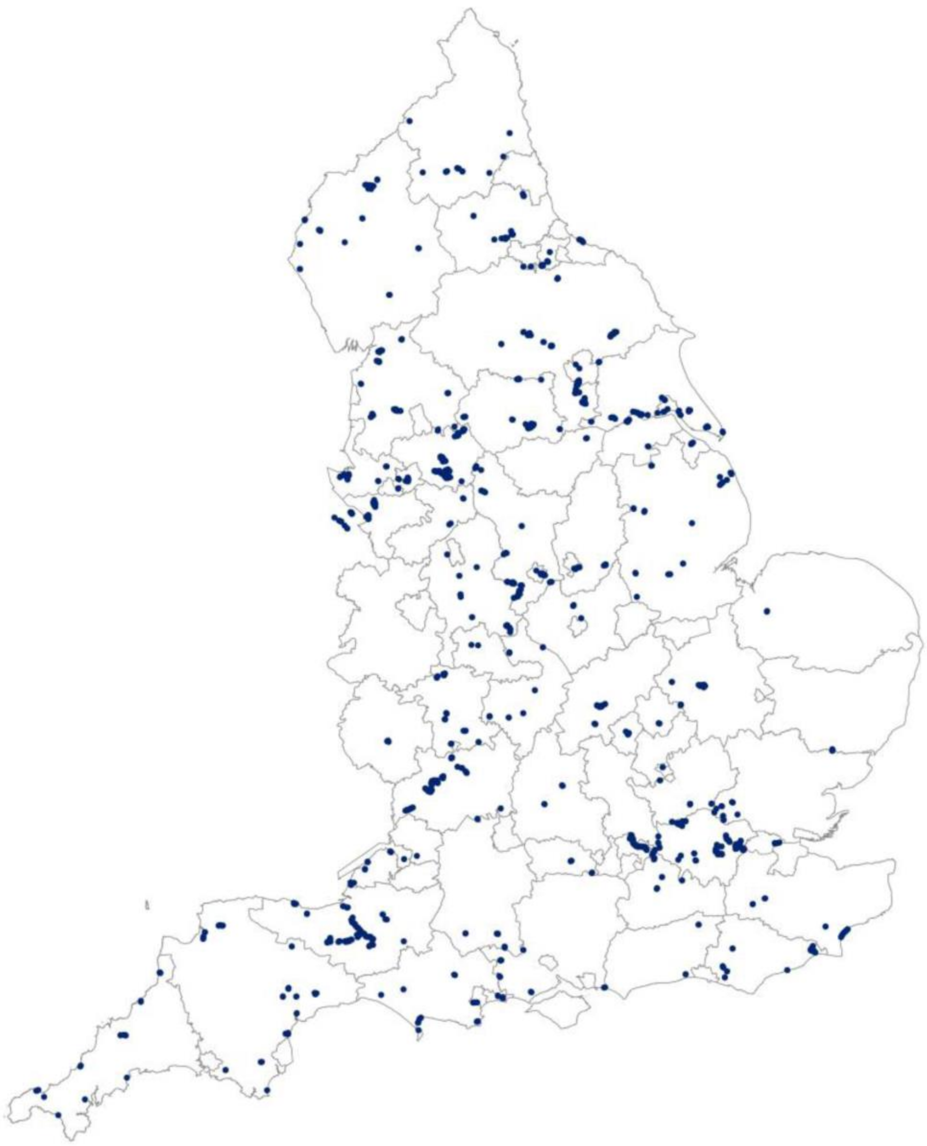
Table 1. Summary of flood defence structures constructed in England after 1995

Type of flood risk	Number of defences	Length (km)
Coastal	224	102
Fluvial	1,442	451
Total	**1,666**	**553**

Source: Based on data from the NFCDD.

[7] The standard of protection of a flood defences is the flood level (expressed as a return period) which a flood defence will withstand with a high degree of certainty (Kirby and Ash, 2000).
[8] The crest level of a flood defence is the height of the defence measured in meters above sea level (mAOD). The crest level of defence includes the height required to achieve the desired standard of protection, plus a suitable safety margin, a.k.a. freeboard, that allows for uncertainties (Ackers et al. 2009).

Figure 1. Structural flood defences constructed in England, 1996 - 2014



Source: Own elaboration based on data from the NFCDD. Note: the lines represent the boundaries of counties and unitary authorities.

Using GIS, the data on flood defences is then merged with postcode data from the Ordnance Survey to identify in which postcodes particular defences are located. In this way, it is possible to identify those properties exhibiting repeat-sales located within postcodes where flood defences had been built. Furthermore the data on the year of construction of the defence and the date of transaction of the property allow us to identify those properties with transactions that bracket the construction of a defence.

Note that we identify treated observations using the 6-digit postcode area where the defence is located. We regard such properties as ‘impacted’ rather than ‘benefited’ because we wish to account for the theoretical possibility that disamenity impacts arising from the construction of flood defences might outweigh the benefits from a reduction in flood risk. Note also that the 6-digit postcode area is not the same as the area that a particular flood defence is intended to protect. Obviously, the ideal would be to use hydrographic information produced during the planning phase in order to identify the geographical boundaries of the protected area. This information is however largely unavailable in the dataset that we utilise and more importantly fails to reflect the areas benefitted by the incremental expansion of existing flood defences. Accordingly, our strategy is to use the smallest possible postcode area to identify properties that are in the newly protected area.

For a number of flood defences we possess the geographical boundaries of the area that the flood defence was intended to benefit. Visual inspection confirms that the area protected by the flood defence contains the 6-digit postcode area whilst at the same time making it clear that distance bands around flood defences include properties not benefitting from the flood defence.[9] Thus, our identification strategy consists of examining repeat-sales of the same property within 6-digit postcode areas in which defences were constructed.[10] We later investigate impacts within somewhat larger 5-digit postcode areas. Figure A1 in the appendix exemplifies the spatial difference between 5-digit and 6-digit postcode areas.

Other GIS datasets include the Flood Map and Recorded Flood Outlines, again both available through the EA. The former shows the spatial delineation of the 100-year floodplain for fluvial

[9] We nonetheless see scope for further research using maps of the areas benefitting from improved flood defences.

[10] Merging the GIS data on flood defences with the GIS representation of the postcode units allow us to identify all the cases where flood defences are constructed across different postcodes to include them in the analysis.

flooding and the 200-year floodplain for tidal flooding in England and Wales. The latter consists of spatial polygons indicating the extent of known individual flood events from rivers and the sea, including details such as the start and end date of the event and the source of flooding.[11] Finally, GIS files for England classifying land as either rural or urban are taken from DEFRA.[12] By merging these files with the postcode data it was possible to identify all properties located inside a floodplain, properties which are located in a postcode which has been previously flooded (including the date and duration of the flood event) and whether properties were located in a rural or an urban area.[13]

The construction of the variable $Defence$ in our model is slightly more involved. We keep the comparison of price differentials for properties before-and-after the construction of a defence within the geographical borders of the county within which the defence has been constructed. Therefore the variable $Defence$ in our model is a county-property-time specific dummy that takes the value of unity for sales within county k that occur after the construction of a flood defence in that county. Therefore $(Defence_{ikt} \times d_{it})$ is a dummy variable signalling those sales that occur after the construction of a flood defence, within 6-digit postcode areas where flood defences were constructed.

Note that the repeat-sales specification in equation (9) does not take account of any other factors that might differentially affect the housing market prospects of newly protected properties, such as the characteristics of the property and those of the flood defence structure. Nevertheless, there are important reasons to believe that both might play a role in determining the precise extent to which the benefits of flood defence structures are capitalised into property

[11] In locations which have been flooded more than once, the file overlaps individual polygons for each flood event.
[12] Following Defra's 2011 Rural-Urban classification of land (see DEFRA 2013), a rural area comprises all physical settlements with a population of less than 10,000 people. This mainly includes small towns, villages, hamlets and isolated dwellings.
[13] Note that the Environment Agency has a public website that provides flood risk for any postcode. It is customary in property transactions to provide this information. Standard pre-contract enquiries will also include a question as to whether a property has previously been flooded.

prices. Meldrum (2016) for example tests for the effect of floodplain designation on property prices in Boulder County in Colorado in the US, with special attention to two different types of structures: houses and condominiums. It is plausible to assume that properties such as detached, semi-detached and terraced houses are more exposed to flooding than properties built mainly above ground level such as condominiums. Accordingly, the benefits of constructing flood defences might be perceived differently by those who live in flats (excluding obviously ground floor and basement flats). And even when dealing only with properties built at ground level characteristics e.g. the existence of communal walls associated with each type of construction might result in differences in the capitalisation of flood defences.

Likewise differences in the location of the property e.g. whether it is located in a rural or urban area and whether it is near to the coast might influence the extent to which the benefits of constructing flood defence schemes are capitalised into property prices. This might occur because of differences in the degree of damage caused by seawater, or differences in the extent to which people living in rural areas experience disamenity impacts associated with the construction of defences. We also allow for possible differences related to the price of properties.

Even when analysing the same type of flood defence structure, differences in its dimensions might also influence the extent to which flood protection benefits are capitalised into property prices e.g. flood defence structures offering a higher standard of protection. Differences in the length of defences might also result in differential impacts e.g. more extensive loss of physical access to water bodies used for recreational purposes.

As noted the sample includes different types of flood defence structures that have been constructed in England during the period of analysis: floodwalls, embankments, bridge abutments, high ground, floodgates and demountable flood defences. All possess different design and visual characteristics which might influence the benefits obtained from their construction. A particularly important distinction is between permanent and demountable defences. Flood defences can also sometimes also be part of a more inclusive structure serving multiple purposes. In what follows we also therefore allow for the possibility that the type of flood defence influences the benefits capitalised into property prices.

Finally, based on the work of Tobin and Newton (1986) we hypothesise that the extent to which flood defence structures are capitalised into property prices might depend on the prior history of flooding. People estimate the probability of an event by the ease with which such events can be brought to mind. Therefore, we expect to find a greater capitalisation of flood defences in locations with a recent history of severe flooding.

To control for all these differences, we incorporate four sets of variables into the repeat-sales specification in equation (9). The first set includes a categorical variable identifying the price quartile of the property, three dummy variables controlling for different types of properties (detached, semi-detached, terraced and flats) and dummy variables to control for freehold versus leasehold, rural versus urban and fluvial versus coastal flooding. These are all interacted with the group assignment variable, d, identifying the 'treated' observations. The second set of variables includes two continuous variables controlling for the standard of protection (the return period) and the length of the defence also interacted with the group assignment variable. The third set of variables includes five dummy variables to control for the six different types of flood defences included in the analysis (floodwalls, embankments, bridge abutments, high grounds, floodgates and demountable flood defences). Finally, the fourth set of variables includes two that are used as a proxy for the perception of flood risk. The first variable represents the number of months since the previous flood with respect to the second sale of the property, *i.e.* after the construction of the defence, and the second represents the duration, measured as the number of days, of that flood. Equation (10) below shows the final specification of the repeat-sales model used to identify the capitalisation of flood defences on property prices.

$$\Delta ln(P_{its}) = \alpha_1 Bracket_{ikts} + \alpha_2(Bracket_{ikts} \times house\_type_i) + \psi_1(Bracket_{ikts} \times d_i) \quad (10)$$
$$+\psi_2(Bracket_{ikts} \times d_i \times house\_type_i) + \psi_3(Bracket_{ikts} \times d_i \times defence\_design_i)$$
$$+\psi_4(Bracket_{ikts} \times d_i \times defence\_type_i) + \psi_5(Bracket_{ikts} \times d_i \times flood\_perception_i)$$
$$+\lambda_0 Year_{is} + \lambda_1 Year_{it} + \Delta\varepsilon_{ikts}$$

Notice that equation (10) also includes as the second term on the RHS a set of variables controlling for property type *without* the interaction with the group assignment variable, d, identifying the 'treated' observations. The purpose of including the property-type variable without the interaction with the group variable, d, is to allow for different rates of property price inflation across different types of properties. Basically, it serves to isolate the treatment effect from a property-specific time-trend. The coefficient ψ_1 can be interpreted as the incremental price paid by buyers of detached houses in urban areas to acquire the protection provided by a floodwall. The differential effect for other types of properties is given by the coefficient ψ_2 in equation (10), and this is measured over and above ψ_1. Finally, the sets of variables categorised as defence design, defence type and flood perception, represent characteristics that modify the treatment effect and are therefore only included in equation (10) with an interaction with the group assignment variable, d. The differentiated price impacts of these characteristics are given by the coefficients $\hat{\psi}_3$, $\hat{\psi}_4$, $\hat{\psi}_5$ in equation (10), and are measured over and above $\hat{\psi}_1$.

Table 2 describes the variables included in the model together with the usual summary statistics. The sample includes over 7 million properties with at least one repeat-sale, out of which 1,824 properties, represent treated observations, i.e. properties whose sales bracket the construction of a flood defence and which are located within the same 6-digit postcode area. The sample of treated observations is similar in terms of composition to the population of all properties sold.

Table 2. Summary statistics

	Variable	Description	No. Obs.	Mean	S.D.	Min.	Max.
	Price	Property sale price adjusted to July 2014 GBP	12,012,455	234,130	259,475	4,742	44,200,000
	Δln(Price)	Property-specific firs-difference of the logged real price	7,222,401	0.078	0.252	-6.28	4.17
	Bracket (B)	Dummy variable = 1 if the two sales bracket the construction of a defence in a county where a defence was constructed		0.192	0.394	0	1
	Lyear (s)	Year of the first sale		2001	3.90	1995	2014
	Year (t)	Year of the second sale		2006	4.46	1995	2014
Bracket sample [1]							
(A) *Type of property (see note 2)*	B*sdetached	Dummy variable = 1 if the sale corresponds to a semi-detached property	1,390,457	0.295	0.456	0	1
	B*terraced	Dummy variable = 1 if the sale corresponds to a terraced property		0.320	0.466	0	1
	B*flat	Dummy variable = 1 if the sale corresponds to a flat		0.135	0.343	0	1
	B*free	Dummy variable = 1 if the sale corresponds to a property acquired on a freehold contract		0.823	0.381	0	1
	B*rural	Dummy variable = 1 if the sale corresponds to a property located in a rural area		0.209	0.406	0	1
	B*coastal	Dummy variable = 1 if the sale corresponds to a property exposed to coastal flood risk		0.234	0.423	0	1
	B*quartile	Categorical variable which takes the value 1 to 4 to identify the quartile price of the property (lowest to highest price)		2.527	1.116	1	4
Bracket-defence sample [3]							
	B*Defence (D)	Dummy variable =1 if the sales bracket the construction of a defence and the property is located within the 6-digit postcode area where a flood defence was constructed	1,390,457	0.001	0.036	0	1
(B) *Type of property (see note 2)*	B*D*sdetached		1,824	0.218	0.413	0	1
	B*D*terraced			0.326	0.469	0	1
	B*D*flat			0.179	0.383	0	1
	B*D*free			0.743	0.437	0	1
	B*D*rural			0.334	0.472	0	1
	B*D*coastal			0.270	0.444	0	1
	B*D*quartile			2.391	1.083	1	4
Defence design	B*D*sop	Standard of protection (sop) of the defence. Return period in number of years	1,824	109	143	0	1,000
	B*D*length	Length of the defence in meters		291	419	0.54	4,013
Type of defence (see note 4)	B*D*embankment	Dummy variable = 1 if the property is benefited by the construction of an embankment	1,824	0.472	0.499	0	1
	B*D*bridgeabt	Dummy variable = 1 if the property is benefited by the construction of a bridge abutment		0 [5]	0	0	0
	B*D*highground	Dummy variable = 1 if the property is benefited by the construction of a high ground		0.081	0.272	0	1
	B*D*demount	Dummy variable = 1 if the property is benefited by the construction of a demountable defence		0.009	0.093	0	1
	B*D*floodgate	Dummy variable = 1 if the property is benefited by the construction of a floodgate		0.010	0.101	0	1
Flood_ perception	B*D*months	Number of months since the last flood, to the time of the second sale (*t*), in the impacted area	1,824	121	184	0	1,633
	B*D*duration	Duration of the last flood in number of days		58	126	0	364

Notes:
[1] The summary statistics under this title correspond to the 19% of the sample with repeat sales that bracket the construction of a flood defence in a county where a defence was constructed.
[2] Omitted categories are dummy variables for detached property, urban location and fluvial flood risk.
[3] The summary statistics under this title correspond to the 1% of the sample with repeat sales that bracket the construction of flood defence and are located within the 6-digit postcode area where the defence is constructed.
[4] The omitted category is a dummy variable for floodwall.
[5] The 6-digit postcode treatment area does not contain properties with repeat sales before and after the construction of a bridge abutment.

6. Results

6.1. Treatment group: 6-digit postcode area

Table 3 contains the results for the DID repeat-sales regression model as specified in equation (10) with the treatment group defined as every 6-digit postcode area in which a flood defence is located. Whereas the results in column (1) use the full sample, one possible criticism of our identification strategy is that it relies on a quasi-experimental design where the assignment of the treatment is not completely random. More specifically, flood defences are constructed only in floodplains and it could be argued that the housing in such locations possesses special characteristics. Comparing the price increase of properties impacted by the construction of defences with the price increase of all other properties in the same county might therefore be misleading.

To address this issue and also to test the robustness of our findings column (2) contains the results of regressions where the control group is restricted to those properties located inside the floodplain. In this way we compare the price increases of properties impacted by the construction of a flood defence with those of properties exposed to a similar risk (by virtue of also being in the floodplain) but where the level of flood risk remains unchanged. Although the results turn out similar, the ones reported in column (2) constitute our preferred specification.

All specifications include county-level fixed-effects to control for between-county heterogeneity. Heteroscedasticity-robust standard errors (Huber 1967, White 1980) appear in parentheses.

The first group of variables in Table 3 are intended merely to control for differences in price trends across different types of properties. The coefficient on the variable $Bracket$ measures the average price change for all detached properties (the omitted category) sold before and after the construction of a flood defence. The remaining coefficients measure the price change differential for properties with different characteristics, over and above that of detached properties. In general these variables are highly significant; regardless of the construction of a flood defence, different types of properties enjoyed notably different price increases during the period of analysis. For example, the benchmark property (a detached house in an urban area) enjoyed a relative price increase of 14.7% compared to the all-property price index.[14]

In column (1) the first coefficient of substantive interest (*B*Defence*) corresponds to the effect of the construction of a floodwall on a detached property, situated in an urban area that is threatened by fluvial flooding. The remaining coefficients represent the capitalisation of flood defences *over and above* that experienced by detached properties protected by floodwalls in urban areas threatened by fluvial flooding. As explained also included are those controls that *modify* the capitalisation of the impacts of flood defences. These include variables that control for the price-quartile in which the property finds itself, the design characteristics of the flood defences and factors responsible for differences in flood risk perception.

[14] As noted by Halvorsen and Palmquist (1980) the coefficient on a dummy variable cannot strictly be interpreted as indicating a percentage change. Using the formula $e^{\gamma} - 1$ taken from that paper the coefficient 0.147 translates into a 15.8% change. Hereafter we ignore this adjustment due to the small size of the coefficients.

Table 3. Repeat-sales model: The effect of flood defences on property prices
(*Area impacted: 6-digit postcode*) [1]

	Variables	(1) All	(2) Flood Plain
	Bracket sample		
	Bracket (B)	0.147***	0.185***
		(0.00153)	(0.00424)
(A) *Type of property (see note 2)*	B*sdetached	-0.0109***	-0.0286***
		(0.000639)	(0.00167)
	B*terraced	-0.0299***	-0.0488***
		(0.000673)	(0.00173)
	B*flat	-0.0313***	-0.0647***
		(0.00142)	(0.00392)
	B*free	0.0510***	0.0419***
		(0.00126)	(0.00355)
	B*rural	0.0241***	0.0444***
		(0.000564)	(0.00133)
	B*coastal	0.0172***	0.0189***
		(0.000442)	(0.00104)
	B*quartile	-0.0633***	-0.0702***
		(0.000276)	(0.000704)
	Bracket-defence sample		
	B*Defence (D)	**0.195*** **	**0.172*** **
		(0.0409)	**(0.0419)**
(B) *Type of property (see note 2)*	B*D*sdetached	-0.0293	-0.0100
		(0.0211)	(0.0217)
	B*D*terraced	-0.0662***	-0.0472**
		(0.0231)	(0.0237)
	B*D*flat	-0.198***	-0.170***
		(0.0337)	(0.0340)
	B*D*free	-0.0226	-0.0205
		(0.0273)	(0.0279)
	B*D*rural	-0.0141	-0.0423***
		(0.0152)	(0.0155)
	B*D*coastal	0.0144	0.0119
		(0.0163)	(0.0166)
	B*D*quartile	-0.0356***	-0.0303***
		(0.0101)	(0.0103)
Defence design	B*D*sop	8.39e-05	7.93e-05
		(6.91e-05)	(6.92e-05)
	B*D*length	-2.03e-05	-1.76e-05
		(2.45e-05)	(2.46e-05)
	B*D*(sop*length)	7.00e-09	1.99e-08
		(2.28e-07)	(2.29e-07)
Type of defence (see note 3)	B*D*embankment	-0.00786	-0.00370
		(0.0156)	(0.0159)
	B*D*bridgeabt	-	-
	B*D*highground	-0.0288	-0.0274
		(0.0258)	(0.0269)
	B*D*demount	0.0246	0.0299
		(0.0487)	(0.0485)
	B*D*floodgate	0.0366	0.0382
		(0.0742)	(0.0743)
Flood perception	B*D*months(sqrt) [4]	-0.00282***	-0.00310***
		(0.000947)	(0.000962)
	B*D*duration	0.000234**	0.000215*
		(0.000111)	(0.000112)
	B*D*months(sqrt)[4]*duration	3.79e-06	5.49e-06
		(8.37e-06)	(8.44e-06)

(Continued)

Table 3.Continued

Lyear (s)	-0.000426***	-9.99e-05
	(2.98e-05)	(7.68e-05)
Year (t)	0.000478***	0.000132*
	(2.97e-05)	(7.66e-05)
Observations	7,217,966	1,135,690
Treated Obs.	1,824	1,794
County FE	YES	YES
R-squared	0.112	0.111

Notes: Robust standard errors in parentheses. *, ** and *** means rejection of the null hypothesis at the 10%, 5% and 1% significance level.

[1] Properties impacted by the construction of a flood defence are identified using the 6-digit postcode area where the defence was constructed.

[2] Omitted categories are dummy variables for detached property, urban location and fluvial flood risk.

[3] The omitted category is a dummy variable for floodwall.

[4] Square root of the number of months since the previous flood with respect to the second sale.

Column (1) indicates that for the case of detached houses in urban areas the construction of flood walls increases prices by 19.5% before accounting for those factors that modify the impact of the construction of flood defences. This seems to be the same for semi-detached properties. For terraced properties the capitalisation is somewhat smaller of around 12.5%. For the case of flats, however, following an examination of the sizes of the coefficients, it appears that there are no significant benefits from the construction of flood defences. Results in column (2) where the control group is confined to those properties located in the floodplain are similar except for rural areas where in column (2) the benefits from flood defences are around 4% smaller.

From the coefficient on B*D*quartile it appears that the benefits of flood defences are capitalised mainly in the prices of properties in the lowest price quartile. This is plausible because the value of more expensive properties frequently derives not from the value of the structure itself but rather because of the value of the land upon which it is built. Only the structure is damaged through flooding.[15]

Examination of the defence design variables shows that the standard of protection is statistically insignificant; even in the immediate vicinity of the flood defence, the area most

[15] All properties include land but sometimes this land is held leasehold rather than freehold.

likely to experience a benefit in terms of a reduction in the risk of flooding, there is no evidence that defences offering a higher standard of protection results in greater price increases. The coefficient estimates only hint at possibility that an increase in the standard of protection might increase property prices i.e. the coefficients on *B*D*sop* and *B*D*(sop*length)* are both positive but insignificant. Likewise, there is little evidence that the type of defence has a significant impact on prices.

Finally, contained among the flood perception variables there is evidence to suggest that the benefits of flood defences are greater when there is a more recent history of flooding. Benefits are also greater when the most recent episode of flooding was severe. Both of these are as expected.

We now consider a number of changes to gauge the plausibility of the underlying assumptions. One of these is that in the repeat sales model the only characteristic of properties that possibly changes between sales is the construction of a flood defence. This assumption is tested in Table 4 where, instead of making use of all repeat sales that bracket the construction of a flood defence, we use only those properties that are sold no more than 5 years prior to the construction of the flood defence and sold again no more than 5 years after the construction of the flood defence. The results contained in column (1) of Table 4 based on the narrower time-window are very similar to those contained in column (1) of Table 3. More specifically, the coefficient indicating the impact of the construction of the flood defence on the benchmark property is still positive and statistically significant at the 1% level of confidence. There also continues to be strong evidence that the impact on flats is much less than that on other types of property, and that the impact is more pronounced for properties in the lowest price quartile. None of these coefficients moreover, appears dramatically different to what they were previously.

We also investigate the consequences of the assumption of a unified market for across different property types and locations (Michaels and Smith, 1990). We start by distinguishing between flats and houses (defined as all types of property excluding flats). Analysing only houses the results are once more very similar to those obtained in column (1) of Table 3 where we combine all different property types. More specifically, there is still a strong, positive impact from the construction of a flood defence, and property in the lowest price quantile benefits more in terms of capitalisation. For flats by contrast, we observe that the construction of a flood defence on the benchmark property – now considered to be an urban flat – is small and not statistically significant. This is precisely the same result as in column (1) of Table 3 where the dummy variable B*D*flat is negatively signed and approximately equal in terms of magnitude to the coefficient on B*Defence. In other words, there continues to be no observed benefit in terms of capitalisation to owners of flats arising out of the construction of flood defences. The final two columns of Table 4 present results for urban and rural properties. For the case of urban properties once more we observe a positive and statistically significant coefficient on the variable B*Defence as well as a negative coefficient on the variable B*D*flat. There is however now some slight evidence that a higher standard of protection increases property prices (B*D*sop is significant from zero at 5%) although this is not actually statistically different from the corresponding coefficient obtained in column (1) of Table 3. For rural properties the coefficient on the variable B*Defence is expectedly signed and of a similar magnitude although now no longer statistically different from zero; something readily ascribable to the fact that there are far fewer treated observations in this regression.

We also investigated the consequences of running separate regressions for each of the 9 NUTS1 regions comprising England. These results are available from the authors upon request. Dividing the observations in this manner obviously results in some regressions having a relatively small number of treated observations. For this reason the variable B*Defence is statistically significant only at the 10% in 3 out of 9 regions and not statistically significant in the others. However, the coefficient values are similar and when pooled together the null hypothesis of parameter homogeneity cannot be rejected (p=0.871). Furthermore pooling the coefficients together points to a combined best estimate of 0.164 which is statistically significant at the 1% level of confidence but not statistically different from the corresponding estimate of 0.195 in column (1) in Table 3.

Table 4. Repeat-sales model: Additional results
(*Area impacted: 6-digit postcode*) [1]

	Variables	(1) Reduced Time Window	(2) House	(3) Flat	(4) Urban	(5) Rural
	Bracket sample					
(A) *Type of property (see note 2)*	Bracket (B)	0.147***	0.145***	0.163***	0.123***	0.269***
		(0.00153)	(0.00161)	(0.00162)	(0.00161)	(0.00482)
	B*sdetached	-0.0109***	-0.0163***		0.00209***	-0.0591***
		(0.000638)	(0.000652)		(0.000713)	(0.00141)
	B*terraced	-0.0299***	-0.0365***		-0.0129***	-0.102***
		(0.000673)	(0.000694)		(0.000740)	(0.00160)
	B*flat	-0.0316***	-	-	-0.0186***	-0.111***
		(0.00142)			(0.00151)	(0.00465)
	B*free	0.0510***	0.0595***	0.0418***	0.0462***	0.0939***
		(0.00126)	(0.00132)	(0.00472)	(0.00133)	(0.00414)
	B*rural	0.0241***	0.0306***	-0.0186***		
		(0.000564)	(0.000583)	(0.00218)		
	B*coastal	0.0173***	0.0162***	0.00251***	0.0124***	0.0224***
		(0.000442)	(0.000507)	(0.000890)	(0.000479)	(0.00114)
	B*quartile	-0.0633***	-0.0703***	-0.0535***	-0.0551***	-0.107***
		(0.000276)	(0.000314)	(0.000584)	(0.000292)	(0.000770)
	Bracket-defence sample					
	B*Defence (D)	0.265***	0.200***	0.00854	0.137***	0.0748
		(0.104)	(0.0442)	(0.0488)	(0.0509)	(0.1042)
(B) *Type of property (see note 2)*	B*D*sdetached	-0.0526	-0.0391	-	-0.00132	-0.0298
		(0.0407)	(0.0255)		(0.0277)	(0.0311)
	B*D*terraced	-0.0749	-0.0742***	-	-0.0301	-0.0520
		(0.0455)	(0.0239)		(0.0307)	(0.0434)
	B*D*flat	-0.235***	-	-	-0.167***	-0.00650
		(0.0746)			(0.0374)	(0.0737)
	B*D*free	-0.0302	-0.0298	0.0666	-0.0410	0.0562
		(0.0207)	(0.0286)	(0.0760)	(0.0284)	(0.0443)
	B*D*rural	0.0105	-0.00528	-0.0409	-	-
		(0.0291)	(0.0161)	(0.0441)		
	B*D*coastal	0.00540	0.00435	-0.0533*	0.0232	-0.0224
		(0.0352)	(0.0183)	(0.0317)	(0.0204)	(0.0245)
	B*D*quartile	-0.0570***	-0.0398***	-0.0118*	-0.0185	-0.0456***
		(0.0237)	(0.0113)	(0.0068)	(0.0127)	(0.0170)
Defence_ desig	B*D*sop	-7.42e-05	0.000240	2.92e-05	0.000229**	-0.000102
		(6.33e-05)	(0.000157)	(8.43e-05)	(0.000110)	(7.82e-05)
	B*D*length	-4.57e-05	-1.18e-05	2.31e-05	-7.71e-06	-1.86e-05
		(4.79e-05)	(2.77e-05)	(6.39e-05)	(3.88e-05)	(3.71e-05)
	B*D*(sop*length)	4.71e-07	-1.74e-07	-4.13e-07	2.68e-08	-3.13e-07
		(4.05e-07)	(2.58e-07)	(1.06e-06)	(3.95e-07)	(3.42e-07)
Type of defence (see note 3)	B*D*embankment	-0.0419	0.0140	-0.0400**	-0.00560	-0.0143
		(0.0311)	(0.0172)	(0.0152)	(0.0194)	(0.0274)
	B*D*bridgeabt	-	-	-	-	-
	B*D*highground	-0.0874	0.00242	-0.0572	-0.0350	-0.0411
		(0.0616)	(0.0253)	(0.0495)	(0.0248)	(0.0661)
	B*D*demount	-0.0228	0.0473	-0.0350	-	-0.0319
		(0.0815)	(0.0484)	(0.0219)		(0.0491)
	B*D*floodgate	-	0.0547	-	-0.104	0.0836
			(0.0749)		(0.100)	(0.0919)
Flood_ perception	B*D*months(sqrt) [4]	-0.00362***	-0.00253**	-0.00295**	-0.00379***	-0.00323*
		(0.00123)	(0.00103)	(0.00138)	(0.00113)	(0.00171)
	B*D*duration	0.000510***	0.000210*	-9.27e-05	8.47e-05	0.000700***
		(0.000188)	(0.000115)	(0.000217)	(0.000127)	(0.000233)
	B*D*months(sqrt)[4]*duration	-1.32e-05	4.24e-06	1.09e-05	8.19e-06	-3.40e-05
		(1.59e-05)	(1.01e-05)	(1.57e-05)	(9.33e-06)	(2.14e-05)

(Continued)

Table 4.Continued

Lyear (s)	-0.000425***	-0.00174***	-0.00681***	-0.000231***	-0.00189***
	(2.98e-05)	(3.25e-05)	(7.18e-05)	(3.26e-05)	(7.45e-05)
Year (t)	0.000477***	0.00180***	0.00676***	0.000284***	0.00195***
	(2.97e-05)	(3.24e-05)	(7.17e-05)	(3.25e-05)	(7.43e-05)
Observations	7,222,401	5,802,937	1,419,464	5,925,246	1,201,622
Treated Obs.	487	1,498	326	1,215	609
COUNTY FE	YES	YES	YES	YES	YES
R-squared	0.112	0.138	0.042	0.113	0.129

Notes: Robust standard errors in parentheses. *, ** and *** means rejection of the null hypothesis at the 10%, 5% and 1% significance level.
[1] Properties impacted by the construction of a flood defence are identified using the 6-digit postcode area where the defence was constructed.
[2] Omitted categories are dummy variables for detached property, urban location and fluvial flood risk.
[3] The omitted category is a dummy variable for floodwall.
[4] Square root of the number of months since the previous flood with respect to the second sale.

6.2. Treatment group: 5-digit postcode area

The consequences of flood defences, in terms of the reduced risk of flooding and the disamenity impacts, are likely to find expression at different geographical distances. Quite plausibly, flood-relief benefits might be experienced by those in the immediate vicinity of the flood defence construction, whereas disamenity impacts might occur over a somewhat wider area. As previously noted these disamenity impacts are likely to include visual intrusion as well as impacts associated with restricted access to water bodies.[16] There may also be adverse ecosystem impacts arising out of the construction of the defences. Determining which of these concerns is uppermost in the mind of households however, is probably better investigated in other ways rather than through hedonic analysis. Furthermore, it also seems likely these impacts differ across contexts. For example, the visual impact of a flood defence will depend upon the vista and this will differ between urban and rural areas. To determine the true benefits of flood defence projects, it is important not to confine any analysis only to those areas enjoying benefits from a reduced risk of flooding. Examining a larger area might be necessary in order to guarantee capture of other sorts of impacts.[17]

[16] Very recently glass floodwalls have been installed at several sites in England. Given that these are much more expensive this is affirmation that visual disamenity impacts are an important issue.
[17] It is possible that reducing the risk of flooding in some locations might increase the risk in others in a manner revealed only through hydrological and hydraulic modelling. Whether this is addressed simply by expanding the geographical area assumed impacted by the construction of a flood defence seems doubtful. Equally doubtful is whether any households affected by redirected flooding would be perfectly aware of the threat. Even though the Environment Agency takes care to avoid such a situation some households might nevertheless perceive an increase in the risk of flooding.

In this sub-section we present the same regressions as in Table 3, but we now define the area impacted by flood defences as 5-digit postcode area in which the defence is located. That is, we now focus on a much larger area, one which is quite likely to include properties not experiencing any significant reduction in the risk of flooding but potentially suffering disamenity impacts.[18] The results appear in Table 5.

Including properties not in the immediate vicinity of the flood defence will alter the extent to which the impacts of flood defences are capitalised into property prices in the area under scrutiny. It could be that some characteristics of flood defences that enhance the benefits of those living in the immediate vicinity of the construction actually worsen any disamenity impacts felt by households at greater geographical distances from the flood defence. For example, whilst many households in a 5-digit postcode area might experience only disamenity impacts from an increase in the standard of protection i.e. taller flood defences, households living in the much smaller 6-digit postcode area in which the flood defence is situated might experience a mixture of both positive and negative impacts. This might explain changes in the signs of some coefficients as the focus switches from the 6-digit postcode area to the 5-digit postcode area.

[18] A consequence of this is a sizeable increase in the number of treated observations.

Table 5. Repeat-sales model: The effect of flood defences on property prices

(*Area impacted: 5-digit postcode*) [1]

	Variables	(1) All	(2) Flood Plain
	Bracket sample		
	Bracket (B)	0.147***	0.186***
		(0.00154)	(0.00431)
(A) *Type of property (see note 2)*	B*sdetached	-0.0107***	-0.0280***
		(0.000641)	(0.00169)
	B*terraced	-0.0295***	-0.0483***
		(0.000676)	(0.00175)
	B*flat	-0.0307***	-0.0642***
		(0.00143)	(0.00399)
	B*free	0.0511***	0.0409***
		(0.00127)	(0.00362)
	B*rural	0.0242***	0.0455***
		(0.000568)	(0.00135)
	B*coastal	0.0172***	0.0189***
		(0.000443)	(0.00104)
	B*quartile	-0.0632***	-0.0702***
		(0.000277)	(0.000712)
	Bracket-defence sample		
	B*Defence (D)	**0.0613*** **	**0.0490***
		(0.0201)	**(0.0260)**
(B) *Type of property (see note 2)*	B*D*sdetached	-0.0327***	-0.0233**
		(0.00808)	(0.0118)
	B*D*terraced	-0.0407***	-0.0281**
		(0.00860)	(0.0121)
	B*D*flat	-0.0711***	-0.0613***
		(0.0168)	(0.0224)
	B*D*free	0.0257*	0.0362*
		(0.0154)	(0.0203)
	B*D*rural	-0.00636	-0.0332***
		(0.00606)	(0.00894)
	B*D*coastal	0.0688***	0.0767***
		(0.00982)	(0.0123)
	B*D*quartile	-0.0114***	-0.00856
		(0.00376)	(0.00523)
Defence design	B*D*sop	-6.28e-05***	-7.36e-05***
		(1.54e-05)	(2.12e-05)
	B*D*length	-1.77e-05**	-3.00e-05***
		(7.99e-06)	(1.09e-05)
	B*D*(sop*length)	-1.50e-07***	-1.38e-07***
		(2.74e-08)	(3.31e-08)
Type of defence (see note 3)	B*D*embankment	-0.0130**	-0.00368
		(0.00587)	(0.00822)
	B*D*bridgeabt	-0.0497	-0.0522
		(0.0483)	(0.0505)
	B*D*highground	-0.00832	-0.00296
		(0.0121)	(0.0164)
	B*D*demount	-0.0694***	-0.0528*
		(0.0180)	(0.0271)
	B*D*floodgate	-0.0125	0.0200
		(0.0137)	(0.0219)
Flood_ perception	B*D*months(sqrt) [4]	-0.00124***	-0.00232***
		(0.000425)	(0.000631)
	B*D*duration	9.93e-05***	0.000127**
		(3.45e-05)	(5.37e-05)
	B*D*months(sqrt)[4]*duration	7.45e-06***	9.63e-06**
		(2.85e-06)	(4.34e-06)

(Continued)

Table 5.Continued

Lyear (s)	-0.000421***	-8.34e-05
	(2.98e-05)	(7.69e-05)
Year (t)	0.000473***	0.000116
	(2.98e-05)	(7.67e-05)
Observations	7,217,966	1,135,690
Treated Obs.	14,716	7,417
County FE	YES	YES
R-squared	0.111	0.110

Notes: Robust standard errors in parentheses. *, ** and *** means rejection of the null hypothesis at the 10%, 5% and 1% significance level.

[1] Properties impacted by the construction of a flood defence are identified using the 5-digit postcode area where the defence was constructed.

[2] Omitted categories are dummy variables for detached property, urban location and fluvial flood risk.

[3] The omitted category is a dummy variable for floodwall.

[4] Square root of the number of months since the previous flood with respect to the second sale.

Turning now to the results for the 5-digit postcode areas, beginning with column (1), it can be observed that detached properties in urban areas impacted by the construction of a floodwall and threatened by fluvial flooding were resold on average, for a price 6.1% higher than those properties where exposure to flood risk remained unchanged. This is before accounting for those factors that modify the impact of the construction of flood defences. This coefficient is moreover significant at the 1% level of confidence. At the same time however, as the sample is restricted such that the comparison is made only with properties located in a floodplain in column (2) the statistical significance of the coefficient diminishes. Once more the results in column 2 are our preferred specification.

Considering now the differential effects for other sorts of properties there appear to be significant differences. Semi-detached properties, terraced properties and in particular flats appear to enjoy significantly lower benefits compared to detached properties. Once again however, as the sample is restricted the statistical significance of these differential impacts slips although in the case of flats the benefits of the construction of a floodwall in an urban area continue to be significantly smaller than for detached properties.

The coefficient on the variable *B*D*rural* in column (2) also indicates significantly lower benefits from flood defences constructed in rural areas compared to those in urban areas although in column (1) this variable is not significant. This result is similar to the one we observe in 6-digit postcode areas. The coefficient on the variable *B*D*coastal* indicates that in 5-digit postcode areas flood defences constructed in coastal locations offer significantly greater benefits other things being equal whereas this differential between the capitalisation of inland and coastal defences is not significant at the 6-digit postcode level.

The design characteristics of defences now play a very important role in determining the extent to which defences affect property prices. The results clearly indicate that *increasing* the standard of protection results in *lower* benefits to households and that this effect is more pronounced the greater the length of the defences. This finding contrasts with the sign and significance of the coefficients that we observe in Table 3 for the same variables when looking at properties located in the immediate vicinity of the defence (i.e. at the 6-digit postcode level). We interpret this result in terms of the disamenity impacts associated with physically more imposing flood defences. It is otherwise difficult to explain why flood defences offering a higher level of protection result in a decrease in property prices. We suggest that the benefits of flood protection and the negative impacts of flood defences find expression at different geographical distances. Properties located close to the defence are likely to experience large benefits from flood protection. In these locations, the characteristics of the defences do not appear to have any significant effect. Conversely, for properties located further away, the greater physical scale of defences worsens disamenity impacts more than it diminishes the risk of flooding.

We observe similar results when looking at the length of the defence. For properties in 5-digit postcode area, *increasing* the length of flood defences also results in significantly *lower* benefits. Again this effect is more pronounced the higher the standard of protection. Once more it appears that the benefits of larger structures are increasingly outweighed by the disamenity impacts. This effect is not significant in Table 3 with the narrower definition of the treatment area (the 6-digit postcode).

The coefficients on those variables controlling for differences in the form of defence suggest that the extent of capitalisation does not typically depend on the type of structure. The only exception is the case of demountable flood defences in column (1). The construction of this type of defence results in prices being around 6.9% *lower* compared to the benefits from the construction of floodwalls. Whilst the use of demountable defences generally avoids the disamenity impact that might be associated with floodwalls the deployment of demountable flood defences requires advance warning, and therefore there is always a chance that they would not be deployed in time.[19] In column (2) however, the statistical significance of this difference is somewhat reduced.

Variables controlling for differences in flood risk perception are again highly significant in both columns. More specifically, results indicate that the number of months elapsed since the most recent flood and the severity of the last flood event both affect the perceived benefits from flood defences.

To summarise, our results point to the existence of geographically differentiated trade-offs between flood protection and disamenity impacts. In 5-digit postcode areas, constructions which are larger and offer a higher standard of protection significantly reduce the beneficial impacts of flood defences on property prices whereas in 6-digit postcode areas constructions which are larger and offer a higher standard of protection have no statistically significant impact on prices. What does not change across 5 and 6-digit postcode areas however, is the

[19] In fact, this was the case in Upton-on-Severn, England, during July 2007, when a delay of the delivery of the components of a demountable defence due to the disruption to transport infrastructure resulted in considerable flood damage (Ackers et al. 2009).

importance of prior flood history in determining benefits or the fact that flat owners stand to gain little from the construction of flood defences. Interestingly nowhere does the evidence suggest that increasing the standard of protection provided by flood defences generates significantly greater benefits.

6.3. Robustness Tests

We undertake two tests of the robustness of the results. The first test simply removes outlier observations. The goal here is to determine whether our results are driven by a specific set of properties with extreme prices. The results appear in Table A2 of the appendix. These regressions are based on samples that exclude the 1% of observations with the highest and lowest prices. All the results are robust to this change and in some cases, the significance of the coefficients improves.

The second test of robustness consists of a placebo test. The objective is to determine whether the significant capitalisation of defences that we observed in Tables 3 and 5 might instead be driven by other factors not associated with the construction of flood defences. The placebo test consists of an experiment where the treatment group is formed by repeat-sales of those properties located in areas benefited by the construction of a flood defence but whose sales *do not* bracket its construction (denoted $\bar{B}$) i.e. where both sales occur either before or after the construction of the defence.

The results of the placebo test appear in Table 6. Columns (1) and (2) show the results for the area impacted by the defence defined by the 6-digit postcode where the defence is located. Columns (3) and (4) show the corresponding results with the area impacted by the defence defined by the 5-digit postcode. Any significant variable associated with the construction of flood defences would place in doubt the validity of our identification strategy. Fortunately, given the absence of any significant variables we argue that our main results in Tables 3 and 5 are indeed associated with the construction of flood defences and their design characteristics.

Table 6. Repeat-sales model. Robustness test: Placebo regression

		6-Digit [1]		5-Digit [2]	
		(1)	(2)	(3)	(4)
	Variables	**All**	**Flood Plain**	**All**	**Flood plain**
	Bracket sample				
	$\overline{Bracket}$ ($\bar{B}$)	0.200***	0.204***	0.189***	0.194***
		(0.000838)	(0.00227)	(0.000839)	(0.00228)
(A) Type of property (see note 3)	$\bar{B}$*sdetached	-0.0376***	-0.0462***	-0.0433***	-0.0519***
		(0.000344)	(0.000888)	(0.000345)	(0.000891)
	$\bar{B}$*terraced	-0.0528***	-0.0616***	-0.0507***	-0.0595***
		(0.000369)	(0.000935)	(0.000369)	(0.000939)
	$\bar{B}$*flat	-0.0712***	-0.0831***	-0.0775***	-0.0896***
		(0.000639)	(0.00175)	(0.000640)	(0.00176)
	$\bar{B}$*free	0.0369***	0.0353***	0.0436***	0.0419***
		(0.000518)	(0.00148)	(0.000520)	(0.00149)
	$\bar{B}$*rural	0.0265***	0.0419***	0.0224***	0.0378***
		(0.000305)	(0.000702)	(0.000306)	(0.000707)
	$\bar{B}$*coastal	0.00418***	0.0131***	0.00385***	0.0128***
		(0.000482)	(0.000672)	(0.000485)	(0.000676)
	$\bar{B}$*quartile	-0.0755***	-0.0775***	-0.0798***	-0.0818***
		(0.000166)	(0.000430)	(0.000166)	(0.000431)
	Bracket-defence sample				
	$\bar{B}$*Defence ($\bar{B}$*D)	**0.0163**	**0.00872**	**-0.00297**	**-0.0212**
		(0.0288)	**(0.0290)**	**(0.00986)**	**(0.0139)**
(B) Type of property (see note 3)	$\bar{B}$*D*sdetached	0.00697	0.0172	-0.00344	-0.00181
		(0.0168)	(0.0171)	(0.00555)	(0.00814)
	$\bar{B}$*D*terraced	0.000853	0.0116	-0.00684	0.00102
		(0.0170)	(0.0172)	(0.00554)	(0.00802)
	$\bar{B}$*D*flat	-0.0121	-0.00126	-0.0120	0.0159
		(0.0190)	(0.0191)	(0.00754)	(0.0105)
	$\bar{B}$*D*free	-0.0152	-0.0161	-0.00832	0.00193
		(0.0143)	(0.0146)	(0.00563)	(0.00804)
	$\bar{B}$*D*rural	0.0132	-0.00876	0.00506	-0.00846*
		(0.0107)	(0.0110)	(0.00353)	(0.00493)
	$\bar{B}$*D*coastal	0.00681	0.00171	0.00529	-0.00466
		(0.0105)	(0.0106)	(0.00422)	(0.00483)
	$\bar{B}$*D*quartile	-0.00482	-0.00215	0.000434	0.00437
		(0.00631)	(0.00633)	(0.00208)	(0.00279)
Defence_ design	$\bar{B}$*D*sop	-3.70e-05	-4.14e-05	9.29e-06	-4.11e-06
		(3.08e-05)	(3.06e-05)	(8.17e-06)	(1.12e-05)
	$\bar{B}$*D*length	-1.44e-05	-1.18e-05	-7.75e-06	-7.09e-06
		(1.73e-05)	(1.71e-05)	(4.98e-06)	(6.53e-06)
	$\bar{B}$*D*(sop*length)	2.07e-07	2.00e-07	4.77e-09	3.14e-08
		(1.48e-07)	(1.48e-07)	(2.29e-08)	(2.89e-08)
Type of defence (see note 4)	$\bar{B}$*D*embankment	-0.0135	-0.00818	-0.00508	0.00166
		(0.00892)	(0.00902)	(0.00331)	(0.00445)
	$\bar{B}$*D*bridgeabt	-	-	-0.0150	-0.0121
				(0.0179)	(0.0229)
	$\bar{B}$*D*highground	-0.0161	-0.00227	-0.00862	0.00669
		(0.0247)	(0.0272)	(0.00588)	(0.00959)
	$\bar{B}$*D*demount	0.00526	0.00918	-0.00896	0.00855
		(0.0390)	(0.0392)	(0.0185)	(0.0244)
	$\bar{B}$*D*floodgate	-0.0336	-0.0292	0.00609	0.0113
		(0.0297)	(0.0291)	(0.00847)	(0.0110)
Flood_ perception	$\bar{B}$*D*months(sqrt) [5]	0.000439	8.43e-05	0.000307	0.000181
		(0.000679)	(0.000700)	(0.000219)	(0.000326)
	$\bar{B}$*D*duration	6.48e-05	5.15e-05	1.52e-05	-3.66e-05
		(5.88e-05)	(6.03e-05)	(2.16e-05)	(3.06e-05)
	$\bar{B}$*D*months(sqrt)[5]*duration	-5.06e-06	-3.45e-06	-8.15e-07	1.27e-06
		(4.21e-06)	(4.24e-06)	(1.53e-06)	(2.19e-06)

(Continued)

Table 6.Continued

Lyear (s)	-0.00159***	-0.00141***	-0.00159***	-0.00141***
	(2.94e-05)	(7.57e-05)	(2.94e-05)	(7.57e-05)
Year (t)	0.00162***	0.00144***	0.00162***	0.00144***
	(2.93e-05)	(7.54e-05)	(2.92e-05)	(7.54e-05)
Observations	1,030,068	107,537	1,030,068	107,537
Treated Obs.	2,502	2,459	20,440	10,415
County FE	YES	YES	YES	YES
R-squared	0.173	0.170	0.149	0.147

Notes: Robust standard errors in parentheses. *, ** and *** means rejection of the null hypothesis at the 10%, 5% and 1% significance level.

[1] Properties located impacted by the construction of a flood defence are identified using the 6-digit postcode area where the defence was constructed.

[2] Properties impacted by the construction of a flood defence are identified using the 5-digit postcode area where the defence was constructed.

[3] Omitted categories are dummy variables for detached property, urban location and fluvial flood risk.

[4] The omitted category is a dummy variable for floodwall.

[5] Square root of the number of months since the previous flood with respect to the second sale.

7. Interpretation of Results

From the results given in column (2) of Tables 3 and 5 it is possible to estimate the typical effect on prices of the construction of flood defences *inter alia* for fluvial and coastal flooding as well as for urban and rural properties and for different types of properties.[20] Results corresponding to sample average values appear in Table 7. For the case of flats we report estimates only for urban areas since few flats are found elsewhere. We present separate estimates for 5-digit and 6-digit postcode areas.

The results in Table 7 suggest that the overall effect of the construction of flood defences on property prices varies considerably, ranging from a price increase of 16.7% for houses in 6-digit postcode urban areas protected to a decrease of 5.7% for flats in 5-digit postcode urban areas. Furthermore, providing flood protection appears to result in a price *decrease* of between 0.8 and 5.0% for houses located in rural 5-digit postcode areas, something we suggest is the result of the disamenity impacts of flood defences outweighing the benefits of flood protection. However, in 6-digit postcodes in rural areas the reverse is true; the benefits of flood protection appear to outweigh any disamenity impacts presumed present.

[20] For areas exposed to fluvial flood risk, there is an average of 188 months with respect to the previous flood, with and average duration of 58 days. For areas exposed to coastal flood risk, the average months with respect to the previous flood is 177 months, with an average duration of 32 days.

Table 7. Capitalisation of flood defences into property prices in England, 1996-2014
(*95% confidence interval and mean capitalisation rate in parentheses*)

	Type of property		Fluvial risk	Coastal risk
6-digit postcode	**House**	**Urban**	£28,829*** [£12,676 – £45,029] (12.6%)	£45,420*** [£20,521 – £70,675] (16.7%)
		Rural	£14,804* [-£2,768 – £32,399] (6.5%)	£28,784** [£2,736 – £54,723] (10.5%)
	Flat	**Urban**	-£8,290* [-£17,340 – £760] (-4.4%)	-£576 [-£14,165 – £13,006] (-0.3%)
5-digit postcode	**House**	**Urban**	£3,203 [-£6,635 – £13,042] (1.4%)	£15,048** [£1,833 – £28,511] (5.5%)
		Rural	-£11,509** [-£22,125 – -£915] (-5.0%)	-£2,326 [-£16,937 – £12,230] (-0.8%)
	Flat	**Urban**	-£10,819*** [-£15,858 – -£5,780] (-5.7%)	-£2,852 [-£9,127 – £3,460] (-1.5%)

Note: These estimates are based on column (2) in both Table 3 and 5. The monetary values are calculated using the sample average price of a house located in a fluvial or coastal flood risk area: £228,804 and £273,617, respectively. For the case of flats we use the average price of £190,142 for a flat located in a fluvial floor risk area. 95% confidence interval appears in brackets. Mean capitalisation rate appears in parentheses. *, ** and *** means rejection of the null hypothesis at the 10%, 5% and 1% significance level. All prices are in July 2014 GBP.

Finally, the construction of flood defences always results in a decrease in the price of flats ranging from 0.3 to 5.7%. We suggest that this is the result of two aforementioned effects: lower or no benefits from flood protection and the disamenity impact of flood defences.

Before closing, it is worth reiterating that the rates of capitalisation in Table 7 are based on the perceived change in the level of the risk of flooding. Obviously it would be interesting to investigate the extent to which the change in objective risk brought about by flood protection is perceived by homeowners. Furthermore, if there is to begin with a lack of perception of flood risk in an area then the construction of a flood defence itself conveys information. This might result in a situation in which the construction of a flood defence actually reduces property prices rather than increases them (or at least does not increase property prices as much as it otherwise might).

8. Conclusions

The construction of flood defences has been the traditional method of protecting communities against flooding. But despite the large amounts of money invested every year for this purpose, there has been a remarkable lack of research evaluating the ex-post benefits accruing from these projects. The objective of this paper has been to plug this gap in the literature. To accomplish this we use a DID repeat-sales methodology to measure the ex-post economic benefits of all flood defence projects undertaken in England over the period 1995 to 2014.

Evidence from this exercise suggests that the construction of flood defences is indeed capitalised into property prices although to what extent depends on multiple factors. Of particular importance is whether one considers only those impacts felt in the immediate vicinity of the flood defences or whether considers the impacts in the wider surrounding area.

The fact that in 5-digit postcode areas benefits appear to be significantly diminished by bigger defences offering a higher standard of protection is strong evidence of the existence of disamenity impacts. In 5-digit postcodes in rural areas households appear more affected by the disamenity impacts than benefited by any reduction in the risk of flooding although it could also be because some flood defences have the perceived effect of increasing the risk of flooding elsewhere.

Differences in the type of flood defence constructed do not seem to play a significant role. But the prior flood history of different locations plays a significant role, with higher benefits for those areas with a recent, more protracted experience of flooding.

The construction of flood defences does not ever seem to benefit flat owners. This is almost certainly because such properties (owners of ground floor and basement flats aside) do not benefit from a reduction in the probability of flooding to the same extent as other sorts of properties. They are however, still potentially affected by the disamenity impact of flood defences e.g. impeded access to water bodies.

Several important policy implications follow from this analysis. Although we detect evidence of disamenity impacts associated with the construction of defences, these are not currently considered in any formal way by the existing appraisal guidance for flood risk management projects in the UK. Ignoring these impacts is however likely to result in a misallocation of resources. Rectifying this implies moving from a measure of benefits based on avoided damage to property to the use of a more comprehensive representation of economic value. This move should simultaneously be accompanied by greater attention paid to impacts occurring outside the area benefited by a reduction in the risk of flooding. This will involve impacts associated with the construction of flood defences but unconnected to the risk of flooding.

Also of concern from a policy perspective, is the evidence that benefits are somewhat influenced by flood history. This raises the interesting question of whether flood defence projects should be evaluated on the basis of the objective or subjective probability of flooding. Two sites might possess the same objectively determined risk of future flooding but a flood defence project will generate greater benefits if implemented in a location with the more recent flood history. For the same reason of changed perceptions the use of demountable flood defences should be reconsidered, as there is some evidence suggesting that they might result in significant reductions in property prices.

Although our results provide evidence on the existence of disamenity impacts associated with the construction of flood defences, admittedly far more research is needed to determine the precise nature of these impacts. This might involve the use of CE in which the WTP for differently-designed flood defences is investigated. Special attention should be paid to the possibility of multi-functional flood defences and their potential to mitigate the adverse effects associated with standard flood defences. Already there appears to be some recognition of the potential importance of disamenity impacts. Several locations in the UK e.g. Wells-next-the-Sea, Norfolk now have a floodwall made out of glass.

References

Association of British Insurers (ABI). 2016. New figures reveal scale of insurance response after recent floods. Association of British Insurers [online: https://www.abi.org.uk/News/News-releases/2016/01/New-figures-reveal-scale-of-insurance-response-after-recent-floods], UK.

Ackers, J., C. Rickard, and D. Gill. 2009. Fluvial Design Guide. edited by Environment Agency. Environment Agency, United Kingdom.

Atreya, A., S. Ferreira, and W. Kriesel. 2013. Forgetting the Flood? An Analysis of the Flood Risk Discount over Time. Land Economics, 89(4):577-596.

Atreya, A., and Ferreira, S. 2015. Seeing is Believing? Evidence from Property Prices in Inundated Areas. Risk Analysis, 35(5):828-848.

Beltran, A., D. Maddison and R. Elliott. 2018. Is Flood Risk Capitalised in Property Values? Ecological Economics, 146: 668–685.

Bennett, O., and S. Hartwell-Naguib. 2014. Flood defence spending in England. In Library: SN/SC/5755, edited by House of Commons. UK.

Benson, C., and E. Clay. 2000. Developing countries and the economic impacts of natural disasters. Managing disaster risk in emerging economies:11-21.

Bichard, E., and N. Thurairajah. 2014. Trialling behaviour change strategies to motivate interest in property level flood protection. International Journal of Disaster Resilience in the Built Environment, 5(2):130-143.

Bin, O., and B. Kruse. 2006. Real estate market response to coastal flood hazards. Natural Hazards Review, 7(4):137-144.

Bin, O., B. Kruse, and C. Landry. 2008. Flood hazards, insurance rates, and amenities: Evidence from the coastal housing market. Journal of Risk and Insurance, 75(1):63-82.

Bin, O., and C. Landry. 2013. Changes in implicit flood risk premiums: Empirical evidence from the housing market. Journal of Environmental Economics and Management, 65(3):361-376.

Bin, O., and S. Polasky. 2004. Effects of flood hazards on property values: evidence before and after Hurricane Floyd. Land Economics, 80(4):490-500.

Blonn, P., M. Throneburg, and J. Grabowy. 2010. The Development and Evaluation of Alternative Erosion Control and Flood Control Projects to Support the Calumet-Sag Detailed Watershed Plan. Paper read at Watershed Management 2010, American Society of Civil Engineers.

Brouwer, R., S. Akter, L. Brander, and E. Haque. 2009. Economic valuation of flood risk exposure and reduction in a severely flood prone developing country. Environment and Development Economics, 14(03):397-417.

Brouwer, R., and R. Van Ek. 2004. Integrated ecological, economic and social impact assessment of alternative flood control policies in the Netherlands. Ecological economics, 50(1):1-21.

Bubeck, P., W. Botzen, and J. Aerts. 2012. A Review of Risk Perceptions and Other Factors that Influence Flooding Mitigation Behavior. Risk Analysis, 32(9):1481-1495.

Bye, P. and M. Horner. 1998. 1998 Easter Floods: Final Assessment by the Independent Review Team to the Board of the Environment Agency. Met Office Library, UK.

Carbone, J., D. Hallstrom, and K. Smith. 2006. Can natural experiments measure behavioral responses to environmental risks? Environmental and Resource Economics, 33(3):273-297.

Case, B., and J.M. Quigley. 1991. The Dynamics of Real Estate Prices. Review of Economics and Statistics, 73(1): 50–58.

Clapp, J.M., C. Giaccotto, and D. Tirtiroglu. 1991. Housing Price Indices Based on All Transactions Compared to Repeat Subsamples, Journal of the American Real Estate and Urban Economics Association, 19(3): 270-285.

Dachary-Bernard, J., T. Rambonilaza, and M. Lemarié-Boutry. 2014. The response of land markets to flood protection and flood experience: a hedonic price modeling on the Gironde estuary (France). Paper read at 88th Annual Conference of the Agricultural Economics Society, AgroParisTech.

Damianos, D., and L. Shabman. 1976. Land prices in flood hazard areas: Applying methods of land value analysis. edited by Virginia Water Resources Research Center. Virginia Water Resources Research Center, US.

Department for Environment Food and Rural Affairs (Defra). 2013. Urban and Rural Area Definitions for Policy Purposes in England and Wales: Methodology. Department for Environment Food and Rural Affairs, UK.

Dorfman, J., A. Keeler, and W. Kriesel. 1996. Valuing risk-reducing interventions with hedonic models: The case of erosion protection. Journal of Agricultural and Resource Economics, 21(1):109-119.

Environment Agency (EA). 2001. Lessons learned: Autumn 2000 floods. Environment Agency, UK.

Environment Agency (EA). 2010a. The costs of the summer 2007 floods in England. Environment Agency, UK.

Environment Agency (EA). 2013. Floods cost UK economy nearly £600 million. Environment Agency [online: http://webarchive.nationalarchives.gov.uk/20140223123725/http:/www.environment-agency.gov.uk/news/150962.aspx?page=2&month=11&year=2013], UK.

Environment Agency (EA). 2016. The costs and impacts of the winter 2013 to 2014 floods. Environment Agency, Report-SC140025/R1, UK.

Fell, H. and C. Kousky. 2015. The Value of Levee Protection to Commercial Properties. *Ecological Economics*, 119:181-188.

Filatova, T., D. Parker, and A. Veen. 2011. The implications of skewed risk perception for a Dutch coastal land market: insights from an agent-based computational economics model. Agricultural and Resource Economics Review, 40(3):405-423.

Gibbons, S., S. Mourato, and G. Resende. 2014. The amenity value of English nature: a hedonic price approach. Environmental and Resource Economics, 57(2):175-196.

Hallegatte, S., C. Green, R. Nicholls, and J. Corfee-Morlot. 2013. Future flood losses in major coastal cities. Nature climate change, 3(9):802-806.

Halvorsen, R. and Palmquist, R. 1980. Interpretation of dummy variables in semilogarithmnic equations. American Economic Review, 70: 474-475.

Huber, P. 1967. The behavior of maximum likelihood estimates under nonstandard conditions. Paper read at Proceedings of the fifth Berkeley symposium on mathematical statistics and probability.

Jongman, H. Kreibich, H. Apel, J. Barredo, P. Bates, L. Feyen, A. Gericke, J. Neal, J. Aerts, and P. Ward. 2012. Comparative flood damage model assessment: towards a European approach. Natural Hazards and Earth System Science, 12(12):3733-3752.

Jongman, B., S. Hochrainer-Stigler, L. Feyen, J. Aerts, R. Mechler, W. Botzen, L. Bouwer, G. Pflug, R. Rojas, and P. Ward. 2014. Increasing stress on disaster-risk finance due to large floods. Nature Climate Change, 4(4):264-268.

King, S., and J. Lester. 1995. The value of salt marsh as a sea defence. Marine Pollution Bulletin,30(3):180-189.

Kirby, A. and J. Ash. 2000. Fluvial Freeboard Guidance Note. Technical Report. Environmenta Agency, UK.

Kousky, C. 2010. Learning from extreme events: Risk perceptions after the flood. Land Economics, 86(3):395-422.

Kousky, C. and M. Walls. 2014. Floodplain conservation as flood mitigation strategy: Examining costs and benefits. Ecological Economics, 104, 119–128.

Koutrakis, E., A. Sapounidis, S. Marzetti, V. Marin, S. Roussel, S. Martino, M. Fabiano, C. Paoli, H. Rey-Valette, and D. Povh. 2011. ICZM and coastal defence perception by beach users: lessons from the Mediterranean coastal area. Ocean & Coastal Management, 54(11):821-830.

Kuminoff, N.V., Parmeter, C.F. and Pope, J.C., 2010. Which hedonic models can we trust to recover the marginal willingness to pay for environmental amenities? Journal of Environmental Economics and Management, 60(3), 145–160.

Kuminoff, N. and Pope, J. 2014. Do capitalization effects for public goods reveal the public's willingness to pay? International Economic Review, 55, 1227–1250.

Lamond, J., Proverbs, D., and Antwi, A. 2007. Measuring the impact of flooding on UK house prices: A new framework for small sample problems. Property Management, 25(4):344-359.

Lee, J., and M. Li. 2009. The impact of detention basin design on residential property value: Case studies using GIS in the hedonic price modeling. Landscape and Urban Planning, 89(1):7-16.

Leschine, T., K. Wellman, and T. Green. 1997. The economic value of wetlands: wetlands' role in flood protection in Western Washington: Washington State Department of Ecology.

MacDonald, D., J. Murdoch, and H. White. 1987. Uncertain hazards, insurance, and consumer choice: Evidence from housing markets. Land Economics, 63(4):361-371.

Meldrum, J. 2016. Floodplain Price Impacts by Property Type in Boulder County, Colorado: Condominiums Versus Standalone Properties. Environmental and Resource Economics, 64(4):1-26.

Merz, B., H. Kreibich, R. Schwarze, and A. Thieken. 2010. Review article" Assessment of economic flood damage. Natural Hazards and Earth System Science, 10(8):1697-1724.

Met Office and JBA. 2012. UK Flooding April to July 2012. JBA Risk Management Limited, UK.

Met Office. 2014. The Recent Storms and Floods in the UK. Centre for Ecology & Hydrology, Natural Environment Research Council, UK.

Met Office. 2016. Briefing Note: Severity of the December 2015 floods – preliminary analysis. Centre for Ecology & Hydrology, Natural Environment Research Council, UK.

Meyer, V., S. Priest, and C. Kuhlicke. 2012. Economic evaluation of structural and non-structural flood risk management measures: examples from the Mulde River. Natural Hazards 62(2):301-324.

Michaels, R. and Smith, V. (1990) Market segmentation and valuing amenities with Hedonic models: the case of hazardous waste sites. Journal of Urban Economics, 28: 223–242.

Ming, J., L. Xian-Guo, X. Lin-Shu, C. Li-juan, and T. Shouzheng. 2007. Flood mitigation benefit of wetland soil—A case study in Momoge National Nature Reserve in China. Ecological Economics, 61(2):217-223.

Miyata, Y., and H. Abe. 1994. Measuring the effects of a flood control project: hedonic land price approach. Journal of Environmental Management, 42(4):389-401.

Nagaraja, C. H., L. Brown, and S. Wachter. 2014. Repeat Sales House Price Index Methodology. Journal of Real Estate Literature, 22(1):23-46.

Oliveri, E., and M. Santoro. 2000. Estimation of urban structural flood damages: the case study of Palermo. Urban Water, 2(3):223-234.

Osberghaus, D. 2015. The determinants of private flood mitigation measures in Germany—Evidence from a nationwide survey. Ecological Economics, 110:36-50.

Palmquist, R. 1982. Measuring environmental effects on property values without hedonic regressions. Journal of Urban Economics, 11(3):333-347.

Palmquist, R. 2005. Property value models. Handbook of environmental economics, 2:763-819.

Pelling, M., A. Özerdem, and S. Barakat. 2002. The macro-economic impact of disasters. Progress in Development Studies, 2(4):283-305.

Penning-Rowsell, E., and M. Fordham. 1994. Floods across Europe. Flood hazard assessment, modelling and management. Middlesex University Press, London.

Penning-Rowsell, E., S. Priest, D. Parker, J. Morris, S. Tunstall, C. Viavattene, J. Chatterton, and D. Owen. 2014. Flood and coastal erosion risk management: a manual for economic appraisal: Routledge.

Phaneuf, D., and T. Requate. 2011. Property Value Models. In A Course in Environmental Economics: Theory, Policy and Practice. Available on-line [http://www.aae.wisc.edu/dphaneuf/Environmental%20Economics%20Book/Environmental%20Economics%20Book.html]: Cambridge University Press (forthcoming).

Phillips, Y. 2011. When the Tide is High: Estimating the Welfare Impact of Coastal Erosion Management. Paper read at 2011 Conference, August 25-26, 2011, Nelson, New Zealand.

Polyzos, S., and D. Minetos. 2007. Valuing environmental resources in the context of flood and coastal defence project appraisal: A case-study of Poole Borough Council seafront in the UK. Management of Environmental Quality: An International Journal, 18(6):684-710.

Rosen, S. 1974. Hedonic Prices and Implicit Markets: Product Differentiation in Pure Competition. Journal of Political Economy, 82(1):22.

Samarasinghe, O., and B. Sharp. 2010. Flood prone risk and amenity values: a spatial hedonic analysis. Australian Journal of Agricultural and Resource Economics, 54(4):457-475.

Schröter, K., H. Kreibich, K. Vogel, C. Riggelsen, F. Scherbaum, and B. Merz (2014), How useful are complex flood damage models?, Water Resour*es* Res*earch*, 50, 3378-3395,

Shabman, L., and K. Stephenson. 1996. Searching for the correct benefit estimate: empirical evidence for an alternative perspective. Land Economics, 72(4):433-449.

Sheng, Z., A. Sturdivant, A. Michelsen, and R. Lacewell. 2005. Rapid economic assessment of flood-control failure along the Rio Grande: A case study. Water Resources Development, 21(4):629-649.

Shiller, R.J. 1993. Measuring asset values for cash settlement in derivative markets: Hedonic repeated measures indices and perpetual futures. Journal of Finance, 48(3): 911–931.

Smith, D. 1994. Flood damage estimation- A review of urban stage-damage curves and loss functions. Water S. A, 20(3):231-238.

Steele, M. and Goy, R. (1997). Short holds, the distribution of first and second sales, and bias in the repeat-sales index. Journal of Real Estate Finance and Economics, 14:133-154.

Thompson, and H. Stoevener. 1983. Estimating Residential Flood Control Benefits Using Implicit Price Equations. Wiley Online Library.

Tobin, G., and T. Newton. 1986. A Theoretical Framework of Flood Induced Changes in Urban Land Values. Journal of the American Water Resources Association, 22(1):67-71.

Veronesi, M., F. Chawla, M. Maurer, and J. Lienert. 2014. Climate change and the willingness to pay to reduce ecological and health risks from wastewater flooding in urban centers and the environment. Ecological Economics, 98:1-10.

Ward, P., B. Jongman, F. Weiland, A. Bouwman, R. van Beek, M. Bierkens, W. Ligtvoet, and H. Winsemius. 2013. Assessing flood risk at the global scale: model setup, results, and sensitivity. Environmental Research Letters, 8:1-10.

White, H. 1980. A heteroskedasticity-consistent covariance matrix estimator and a direct test for heteroskedasticity. Econometrica: Journal of the Econometric Society, 48(4):817-838.

Winsemius, H., L. Van Beek, B. Jongman, P. Ward, and A. Bouwman. 2013. A framework for global river flood risk assessments. Hydrology and Earth System Sciences, 17(5):1871-1892.

Zhai, G., and T. Suzuki. 2008. Public willingness to pay for environmental management, risk reduction and economic development: evidence from Tianjin, China. China Economic Review, 19(4):551-566.

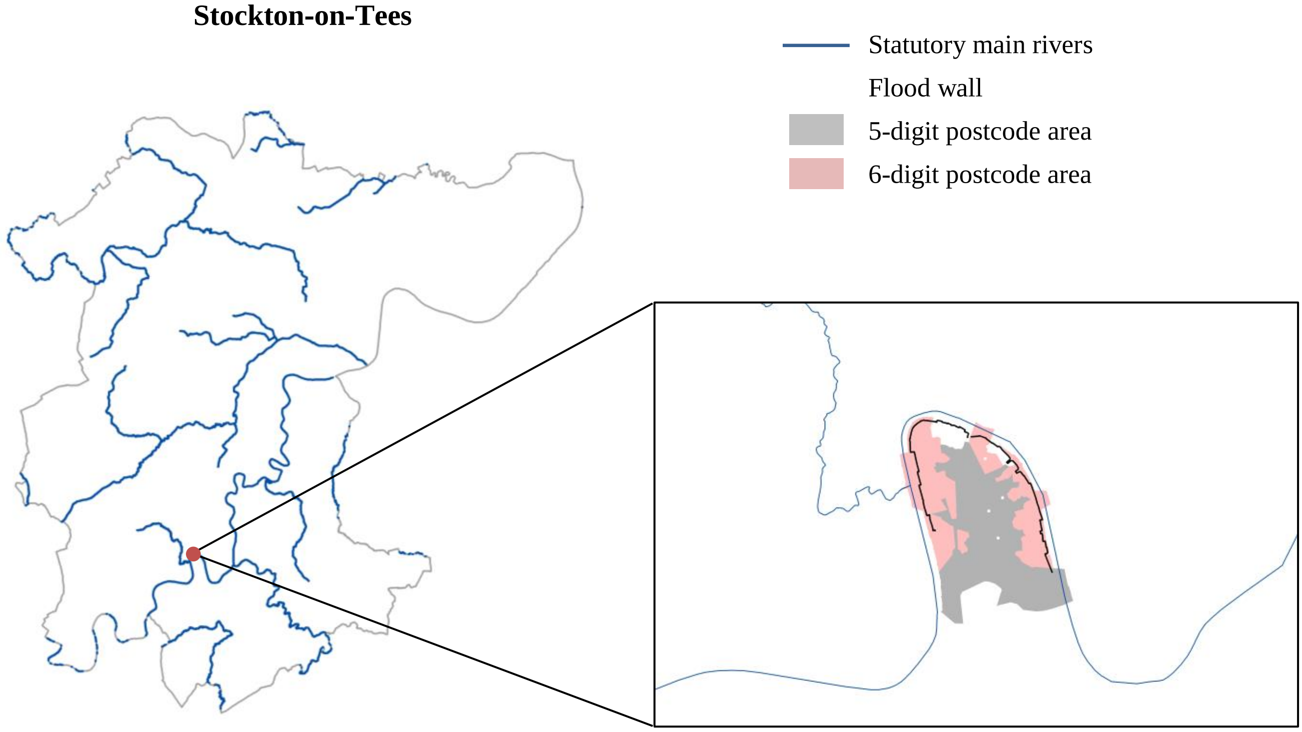
Appendix

Table A1. Summary characteristics of stock of flood defences
(*by type of defence and type of flood risk*)

	Number of defences	SOP (return period)	Length (meters)
By type of defence			
Embankment	764	115	412
Wall	713	177	194
High ground	132	65	682
Flood gate	38	35	3
Bridge abutment	8	106	18
Demountable defence	6	100	118
By type of flood risk			
Fluvial	1442	105	312
Tidal	224	338	456

Source: Based on data from the NFCDD.

Figure A1. Example: Area impacted by the construction of a flood wall in Stockton-on-Tees
(*5-digit and 6-digit postcode*)



Source: Own elaboration based on spatial data from the NFCDD.

Table A2. Repeat-sales model. Robustness test: Excludes extreme values

(*Excludes top 1% and bottom 1% of observations*)

		6-Digit [1]		5-Digit [2]	
		(1)	(2)	(3)	(4)
	Variables	**All**	**Flood Plain**	**All**	**Flood Plain**
	Bracket sample				
	Bracket (B)	0.166***	0.199***	0.165***	0.199***
		(0.00144)	(0.00407)	(0.00145)	(0.00413)
(A) Type of property (see note 2)	B*sdetached	-0.0105***	-0.0278***	-0.0103***	-0.0270***
		(0.000619)	(0.00163)	(0.000621)	(0.00164)
	B*terraced	-0.0251***	-0.0466***	-0.0247***	-0.0461***
		(0.000653)	(0.00169)	(0.000656)	(0.00171)
	B*flat	-0.0383***	-0.0654***	-0.0377***	-0.0650***
		(0.00133)	(0.00374)	(0.00134)	(0.00380)
	B*free	0.0416***	0.0355***	0.0415***	0.0343***
		(0.00117)	(0.00336)	(0.00117)	(0.00342)
	B*rural	0.0241***	0.0454***	0.0242***	0.0465***
		(0.000546)	(0.00129)	(0.000550)	(0.00131)
	B*coastal	0.0193***	0.0198***	0.0193***	0.0198***
		(0.000427)	(0.00101)	(0.000427)	(0.00102)
	B*quartile	-0.0673***	-0.0737***	-0.0672***	-0.0737***
		(0.000269)	(0.000692)	(0.000270)	(0.000700)
	Bracket-defence sample				
	B*Defence (D)	0.207***	0.194***	0.0527***	0.0418*
		(0.0390)	(0.0399)	(0.0196)	(0.0258)
(B) Type of property (see note 2)	B*D*sdetached	-0.0308	-0.0123	-0.0343***	-0.0253**
		(0.0204)	(0.0209)	(0.00782)	(0.0114)
	B*D*terraced	-0.0699***	-0.0494**	-0.0425***	-0.0281**
		(0.0218)	(0.0224)	(0.00828)	(0.0116)
	B*D*flat	-0.202***	-0.181***	-0.0638***	-0.0515**
		(0.0321)	(0.0324)	(0.0164)	(0.0221)
	B*D*free	-0.0241	-0.0264	0.0355**	0.0508**
		(0.0257)	(0.0264)	(0.0151)	(0.0202)
	B*D*rural	-0.0177	-0.0475***	-0.00669	-0.0364***
		(0.0146)	(0.0149)	(0.00588)	(0.00868)
	B*D*coastal	0.0123	0.0107	0.0659***	0.0774***
		(0.0161)	(0.0164)	(0.00979)	(0.0122)
	B*D*quartile	-0.0363***	-0.0320***	-0.0114***	-0.00944*
		(0.00990)	(0.0101)	(0.00364)	(0.00509)
Defence_ design	B*D*sop	7.86e-05	7.39e-05	-6.45e-05***	-8.02e-05***
		(6.90e-05)	(6.91e-05)	(1.53e-05)	(2.06e-05)
	B*D*length	-4.07e-05*	-3.83e-05	-1.95e-05**	-3.75e-05***
		(2.34e-05)	(2.35e-05)	(7.63e-06)	(1.01e-05)
	B*D*(sop*length)	3.93e-08	5.95e-08	-1.37e-07***	-1.22e-07***
		(2.25e-07)	(2.26e-07)	(2.71e-08)	(3.19e-08)
Type of defence (see note 3)	B*D*embankment	-0.0107	-0.00651	-0.0120**	-0.00155
		(0.0143)	(0.0146)	(0.00567)	(0.00793)
	B*D*bridgeabt	-	-	-0.0524	-0.0580
				(0.0482)	(0.0501)
	B*D*highground	-0.0189	-0.0184	-0.00327	0.00685
		(0.0241)	(0.0251)	(0.0114)	(0.0149)
	B*D*demount	0.0259	0.0321	-0.0693***	-0.0503*
		(0.0484)	(0.0482)	(0.0179)	(0.0270)
	B*D*floodgate	0.0336	0.0353	-0.0147	0.0155
		(0.0739)	(0.0741)	(0.0137)	(0.0218)
Flood_ perception	B*D*months(sqrt) [4]	-0.00290***	-0.00322***	-0.00126***	-0.00241***
		(0.000900)	(0.000914)	(0.000411)	(0.000608)
	B*D*duration	0.000152	0.000125	8.52e-05**	8.98e-05*
		(9.32e-05)	(9.42e-05)	(3.33e-05)	(5.13e-05)
	B*D*months(sqrt)[4]*duration	1.10e-05	1.32e-05*	8.93e-06***	1.28e-05***
		(6.98e-06)	(7.06e-06)	(2.77e-06)	(4.13e-06)

(Continued)

Table A2.Continued

Lyear (s)	-0.000177***	0.000136*	-0.000173***	0.000151**
	(2.90e-05)	(7.52e-05)	(2.90e-05)	(7.53e-05)
Year (t)	0.000234***	-0.000102	0.000230***	-0.000117
	(2.90e-05)	(7.51e-05)	(2.90e-05)	(7.51e-05)
Observations	7,073,555	1,113,592	7,073,555	1,113,592
Treated Obs.	1,804	1,774	14,574	7,357
County FE	YES	YES	YES	YES
R-squared	0.130	0.125	0.130	0.124

Notes: Robust standard errors in parentheses. *, ** and *** means rejection of the null hypothesis at the 10%, 5% and 1% significance level.

[1] Properties located impacted by the construction of a flood defence are identified using the 6-digit postcode area where the defence was constructed.

[2] Properties impacted by the construction of a flood defence are identified using the 5-digit postcode area where the defence was constructed.

[3] Omitted categories are dummy variables for detached property, urban location and fluvial flood risk.

[4] The omitted category is a dummy variable for floodwall.

[5] Square root of the number of months since the previous flood with respect to the second sale.