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Price recovery after the flood: risk to residential property values from climate change-related flooding*

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We take advantage of a combination of a severe weather event from 3 to 4 June 2015 and a local policy, to investigate the housing market response to climate change-related flooding hazard. The study focuses on a residential area in a low-lying coastal suburb of Dunedin, New Zealand, where the groundwater level is shallow and close to sea level. An unusually heavy rain event in June 2015 resulted in flooding of a significant portion of land in especially low-lying areas. The city council responded by reviewing processes for storm-water management and by imposing minimum-floor-level [MFL] requirements on new construction in the low-lying areas previously identified as at risk of flooding. Applying a 'diff-in-diff-in-diff' strategy in hedonic regression analyses, we find that houses in the MFL zone sell for a discount of about 5 per cent prior to the flood. This discount briefly tripled in the area that flooded, but disappeared within 15 months, indicating either very short memory among home-buyers or no long-run change in perception of hazard.

Key words: climate change, flooding, matching estimators, real estate valuation, sea-level rise, stranded assets.

JEL classifications: G17, Q51, Q54, R30, R32

1. Introduction

This paper reports estimates of the effects on house sale prices of increasing climate change-related flood hazard. The focus is on a residential neighbourhood built on low-lying land in a coastal suburb of the city of Dunedin in south-eastern New Zealand. Heavy rainfall in June 2015 coincided with a

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high tide and inadequate maintenance of aspects of the storm-water drainage system.[1] This resulted in inundation of a significant portion of land in especially low-lying areas, reinforcing the perception of current and possibly increasing risk of future flooding. The city council responded by reviewing processes for storm-water management and by imposing minimum-floor-level (MFL) requirements on new construction in the low-lying areas. In this paper, we report the response of housing market participants to the flood event and the subsequent change in development requirements.

The need for an MFL requirement had been recognised in the 1990s, and a floor level benchmark of 0.3 metre above the highest recorded sea level at that time was recommended for new residential construction in the coastal and harbour locations. This requirement is in response to research, indicating that, in the absence of major changes to flood defences, these areas are likely, over time, to flood more frequently and severely (DCC 2011). Accordingly, the South Dunedin neighbourhood with its obviously low elevation and proximity to the sea was identified as among areas at risk. However, it was assumed at the time that the dunes between the low-lying area and the sea in combination with the existing drainage system would protect this area from flooding. As a result, an MFL requirement was not implemented in this area until after the 2015 flood event.[2]

It has now become clear that South Dunedin is at risk of flooding. Ground levels in low-lying parts of this neighbourhood close to the sea are presently less than 0.5 metres above mean sea level. Measurements taken locally indicate that mean sea level and corresponding levels of high tides have been rising since 1900 at an average rate of 1.35 $\pm$ 0.15 millimetres per year (Denys *et al.* 2020). Ground elevation measured separately since 1996 using the global navigation satellite system shows local uplift associated with multiple distal earthquakes, which creates uncertainty in determination of relative sea-level rise in Dunedin. However, while relative rates of sea-level rise vary both locally and globally, absolute sea levels will rise generally at increasing rates due to climate change (Church *et al.* 2013), posing an increasing hazard to this (and other) low-lying land.

Sea-level rise combined with more frequent and extreme storms is forecast to increase the frequency and severity of coastal flooding worldwide (Woodruff and Irish 2013; PCE 2015; Storey *et al.* 2017). For example, a 30-centimetre rise in sea level could turn a one-in-100-year extreme-tide event, and any associated flooding, into an annual event in New Zealand's second and third largest cities, Christchurch and Wellington, and into a 'one-in-2-year' event in Dunedin (PCE 2015, p. 28). Of interest to local policymakers is when, and by how much, increases in climate-related risk affects asset values; answers to that question influence decisions about infrastructure projects and development regulations. Local decisions impact broader and longer-term

[1] See detailed description of the flood event in Appendix S1.
[2] Confirmed via personal email communications, available upon request.

concern that widespread impacts of climate change on asset values will affect financial systems (Carney 2015; Diaz-Rainey and Robertson 2017).

Of interest is how homebuyers responded to the 2015 flood and MFL zoning as potential harbingers of the future effects of climate change. Our data set consists of observations on sales of single-family residential properties in the close-in suburbs of Dunedin from 2000 through 2018. The data include a typical set of house and lot characteristics to which we add accessibility and neighbourhood characteristics. We estimate essentially difference-in-differences-in-differences (flooded area, MFL zoned area and control area) models using standard hedonic regression techniques on both the full sample of sales and on subsamples of sales matched on all observable characteristics. To our knowledge, we are the first to use a matching strategy in a difference-in-differences setting in pricing flood risk.

The results from both the full and matched samples indicate statistically significant discounts of at least 5 per cent on sales in the area where MFL requirements were imposed after the flood. Homebuyers appear to have been aware of the flood risk in this obviously low-lying area close to the sea. In the first few months after the flood event, the discount on sales *in the area that flooded* increased rather spectacularly to about 14 per cent, effectively tripling the discount in that area. But this additional discount then decreased gradually until it disappeared after only about 15 months. Market participants reacted sharply and then over a relatively short time period reset to their pre-flood expectations. This may be driven by homebuyers' perception that the flooding is and will continue to be a rare event, or that increasing flood risk had appropriately been capitalised into the housing market, which could include expectations that the local council will move quickly to improve critical infrastructure. We discuss policy implications of this reset later in the paper.

The remainder of the paper is organised as follows. In Section 2, we provide more details about the area. Section 3 describes the sales data and the regression models we use to estimate the effects of the MFL zone and the 2015 flood on house values. The main results and robustness tests are presented in Section 4. Section 5 concludes by discussing the limitations of our methods and avenues for future research.

2. Background

Flooding hazards are prominent among the physical risks associated with climate change. It is expected that by 2050 at least 570 cities and some 800 million people will be exposed to rising seas and storm surges.[3] Real estate constitutes the majority of retirees' wealth worldwide (Poterba 2007) and is an important source of household debt (Baldauf and Garlappi 2020). The risk

[3] See https://www.weforum.org/agenda/2019/01/the-world-s-coastal-cities-are-going-under-here-is-how-some-are-fighting-back/

of climate impacts to property values is a real concern in the island nation of Aotearoa New Zealand. More than 65 per cent of the population lives within 5 kilometres of the sea in predominantly densely populated areas, and real estate assets comprise 85 per cent of individual wealth, on average (Le and Gibson 2010; Joshi *et al*. 2016; Statistics NZ 2018).

There have been some general assessments of New Zealand asset exposure and risk from coastal inundation due to sea level rise (e.g. PCE 2015; Paulik *et al*. 2019; Paulik *et al*. 2021; Stephens *et al*. 2021). To date, research on the financial impacts of climate-change related flood hazards [CCRFH] in New Zealand has focused on insurability (Storey *et al*. 2017), historical insurance losses (Fleming *et al*. 2018; Frame *et al*. 2018), the burden of responsibility (Ellis 2018) and impacts on local government infrastructure (Simonson and Hall 2019). Attempts to quantify the value of real estate at risk usually focus on the end result: assets go from full valuation to zero when there is permanent inundation of the property (PCE 2015; Paulik *et al*. 2019).

However, a considerable amount of time will pass between the early effects of climate change and complete loss. We expect participants in local housing markets to be at least somewhat forward-looking, taking into account that the frequency and severity of flooding and flood damage will increase over time. If so, we expect sale prices to trend downward long before the property is permanently underwater (recognising that imperfect information and behavioural biases will likely influence the time path of prices). Good estimates of how the extent and timing of climate-related flood risk capitalise into real estate prices inform cost-benefit analysis of adaptation investments.

A growing international literature investigates how flood risks as a consequence of climate change are reflected in residential property values (Murfin 2012; Bernstein and Gustafson 2018; Baldauf *et al*. 2020). At first glance, these studies share similarities with the rich literature on the sale-price effects of *known flood risks* (affected by a periodic flood event or located within a flood plain) (Lamond and Proverbs 2005; Bin and Kruse 2008; Daniel and Florax 2009; Samarasinghe and Sharp 2010; Beltrán and Maddison 2018; Ortega and Taspinar, 2018). Climate change complicates this picture as it is about *changes in the risk of flooding over time* as opposed to *current, steady-state flood risks* as documented by Baldauf *et al*. (2020).

Projecting climate-related flood risk requires consideration of a variety of local characteristics, such as subsurface land characteristics and contours as well as impervious surfaces (Bernstein *et al*. 2018). In many cases, in the absence of fine-grained information about these physical site characteristics, projections rely on a simple ‘bathtub’ approach that assumes that groundwater or surface-water flood levels simply equate with sea level, or modelling of similar simplicity (Islam *et al*. 2016; Paprotny and Terefenko 2017; Mavromatidi and Briche 2018). Not surprisingly, most of the studies have taken advantage of the Sea-Level Rise Viewer tool provided by the National Oceanic and Atmospheric Administration [NOAA] in the United States, which provides estimates of each property's exposure to the increasing probability of flooding (Parris *et al.* 2012).

These studies produce mixed estimates of climate-related discounts. For instance, Bernstein *et al.* (2018) find that homes exposed to sea-level rise sell for about 7 per cent less than observably similar properties, and this discount has grown over time due to increasing concerns about the effects of climate change. Baldauf *et al.* (2020) find that homebuyer beliefs about risks from climate change matter: houses projected to be underwater in 'believer' neighbourhoods are sold at a discount to houses in 'denier' neighbourhoods (7 per cent for each standard deviation from the mean belief level). By contrast, Murfin and Spiegel (2020) find no evidence of a significant effect on prices after distinguishing the impact of sea-level rise (taking advantage of local variation in sea-level rise relative to vertical land motion) from other confounding effects such as elevation and distance from the coast.

Property-level projections like those provided by NOAA are not available in New Zealand. Forecasts of climate-related flood hazard are currently presented at more aggregated levels (PCE 2015; Paulik *et al.* 2019): information released from these models do not indicate which properties will be affected, when? or by how much? However, some low-lying areas are experiencing flooding that at least some homebuyers may perceive as related to climate change. Given its obviously low elevation and proximity to the sea, South Dunedin seems a candidate.

South Dunedin is an inner-city suburb located on a low-lying area of approximately 600 hectares. It is well populated as residents enjoy a variety of natural and built amenities: easy access across a dune to ocean beaches, a good surf break, a variety of recreational facilities (e.g. golf course, ice rink and tennis club), highly regarded schools, and proximity to both shopping and employment. However, most of its properties are built on land at elevations no more than 3 metres above mean sea level (Figure 1). High tides a metre above sea level in this area are common. Properties are protected from the sea by a narrow margin of elevated sand dunes, and from the harbour by an area of reclaimed land. As there are no longer any natural drainage outlets for rain-related surface water, properties are reliant on a stormwater system involving gravity flow and pumping. Groundwater levels in this area are influenced by the tides, precipitation, land contours, impervious surfaces and characteristics of the drainage infrastructure. With its low elevation, proximity to the coastline, dense population and high groundwater levels, the area is projected to be among the most vulnerable in New Zealand to sea-level rise (PCE 2015; MFE 2017).

In recognition of the risk of flooding due to extreme tides and storm surge (but not sea-level rise), the local council in the early 1990s recommended a minimum floor level (MFL) requirement for use by the Council's Building Control office when permitting new residential construction at coastal and harbour locations. The initial recommendation for the minimum floor level of new houses was 0.30 metre above the highest recorded sea level at that time.

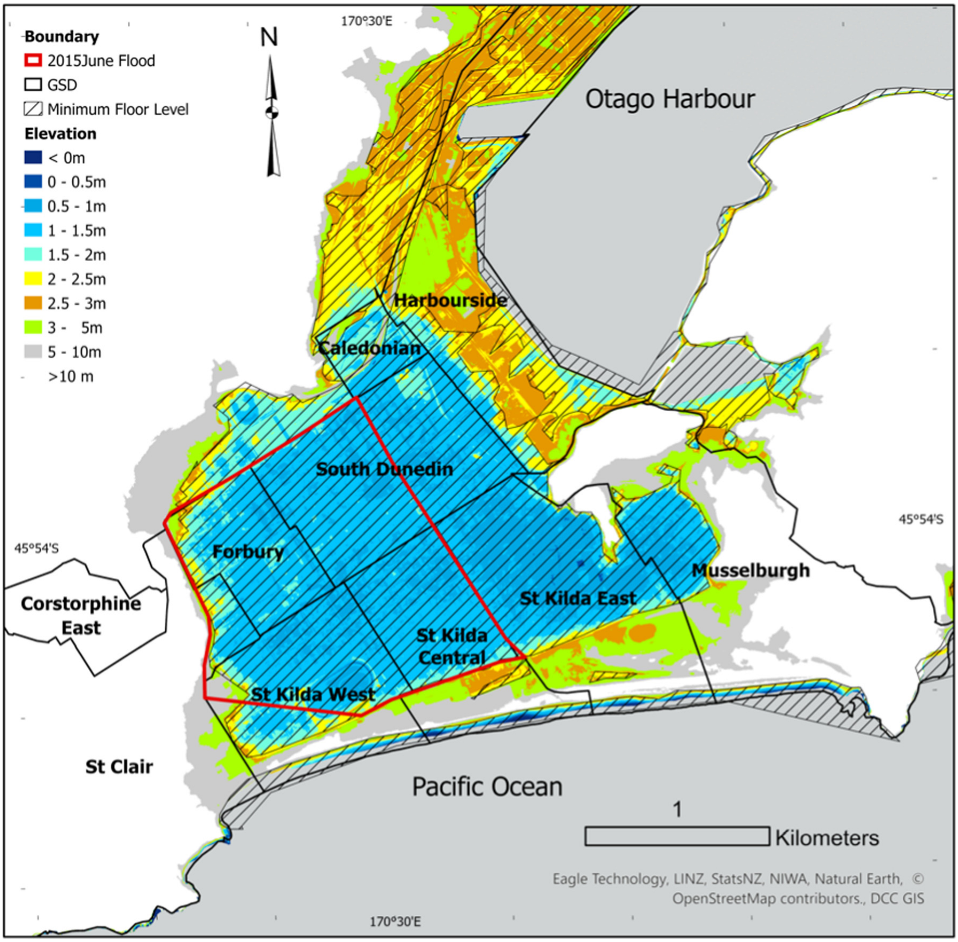

Figure 1 Greater South Dunedin. Notes: Greater South Dunedin is projected to be one of the most vulnerable areas to sea-level rise in New Zealand. This low-lying area suffered from an approximately 'one in 100-year' flood event in June 2015. New houses in the area are also subjected to building-code requirements for floor height (minimum floor level) (the hatched area). The coloured area shows the elevation of the ground in Dunedin 2009 surveyed by Light Detection and Ranging (LiDAR). Boundaries in black delineate census statistical areas. [Colour figure can be viewed at wileyonlinelibrary.com]

A Climate Change Effects factor of 0.50 metre was added in 2006 in accord with forecasts of sea-level rise by 2060 and was further adjusted upward in 2011 (DCC 2011). Minimum floor levels are presently based on mean sea level, astronomical tides, storm surge, annual exceedance probabilities, sea level rise and a freeboard offset. The extent to which buyers of existing homes are aware of these MFL recommendations is unknown though the relevant information would be included in a Land Information Memorandum [LIM] that homebuyers would be expected to consult prior to purchase. Consistent with existing research, we expect that, prior to the flood, sale prices of houses in low-lying areas were lower than observationally similar houses elsewhere.

The flooding event itself seems likely to increase the *perception* of risk of future flooding. In addition, in the aftermath of the 2015 flood, the council imposed (rather than recommended) MFL requirements. This MFL zone includes the area that flooded. This requirement was not implemented earlier, despite land elevation well below the recommended MFL benchmark, because council staff considered that the dunes between the residential area and the sea in combination with the pumped drainage system reduced the risk of flooding in that area (inadequate maintenance of the drainage system is blamed for contributing to the flooding). The MFL zone was put in place in the aftermath of the flooding due to expectations of rising sea levels—which are now recognised as affecting groundwater levels—and increasingly frequent rainfall events.

Given the flood's salience, we expect the sale-price discount in the flooded area, and perhaps in other parts of the MFL zone, to increase. Of interest, however, is whether any additional discount that appears shortly after the flood persists over time. It may if homebuyers perceive the flooding as a harbinger of worse things to come as sea levels continue to rise and heavy rain events become more common with climate change. On the other hand, homebuyers may come to perceive the flooding as a rare event due to what was described as a one-in-100-year rainfall event coinciding with a high tide. If so, the risk of increasing flood hazard may have appropriately capitalised into house prices, especially if flood insurance premiums do not change after the flood event. And homebuyers may expect the flooding to motivate the local council to improve infrastructure to reduce the risk of flooding. And the council did reveal that the aging drainage system is due for renewal in the not-distant future.

As a caveat, we recognise that it is difficult to attribute any extreme weather event to climate change (Field *et al*. 2012; Hulme 2014). While the 2015 flood in Dunedin may have been a severe rain event, it was not unprecedented and cannot be directly related to climate change nor to sea-level rise. Its effects were also likely exacerbated by infrastructure mis-management.[4] However, the flood raised community awareness of flood risk and serves as an excellent proxy of the scale and nature of damaging events whose frequency is being forecast to increase in the future, and the style of hazard cascades and associated problems likely expected by communities New Zealand-wide.[5] As such, any discount on sale prices prior to the flood event and any increase in that discount on sales since the event can be interpreted to reflect initial and revised expectations of homebuyers about future costs associated with climate change.

[4] See detailed description of the flood event in Appendix S1.

[5] Similarly, the media has frequently referred to the June 2015 flood as a test case for the rest of New Zealand about how disastrous climate change could turn out to be (Noted.co.nz, 2016; RNZ, 2016; Stuff, 2016; Otago Daily Times, 2021).

Homebuyer expectations may (or may not) have been influenced by studies conducted since the flood event. Both local and national reports point at the potential for climate change to increase the frequency and intensity of heavy rainfall events and for sea-level rise to cause extreme tides and flooding through either coastal inundation or groundwater rise. For example, modelling by the Otago Regional Council (ORC 2015, 2016) suggests that sea-level rise in the next century will cause the groundwater levels in South Dunedin to rise above their current levels, which may exacerbate surface water ponding during intense rainfall. Similarly, the National Institute of Water & Atmospheric Research [NIWA] calculates the area has up to 2,700 properties within 50 centimetres above the spring high tide mark and estimates a 30-centimetre rise in sea level may decrease the return period of a 'one-in-100-year' extreme high tide into a 'one-in-2-year' event (PCE 2015, p. 28). Importantly, a report by Climate Sigma estimates that sea-level rise of half of that amount (14 centimetres) is sufficient for a marked increase in flood risk, which may increase the median flood insurance premium from $1,600 to $7,900 for 3,100 properties in Dunedin. These properties may even suffer an insurance retreat in the next 15 years (Climate Sigma 2020). If homebuyers consider these factors when bidding for houses, we expect that flood-related discounts persist over time.

3. Data and methods

As the characteristics of the data influence the choice of analytical approach, we begin by describing the characteristics of the data. We then describe the hedonic sale-price models we use to estimate the sale-price discounts of interest. A concern, however, is that the ranges in the characteristics of the houses in the treatment sample (i.e. those in the MFL zone) are smaller than those in the control (rest-of-Dunedin) sample, so our hypothesis tests rely on our regression specification comporting closely with the unobservable 'true' specification. To treat this issue, the third section describes the approach we use to obtain a subsample of houses from the control group that matches the characteristics of those in the treatment group.

3.1 Data

We purchased data on all sales of single-family houses in the contiguously developed area of Dunedin from CoreLogic New Zealand, the largest provider of real estate data and analytics in New Zealand. The initial data set includes 34,081 transactions from 1 January 2000 through 12 September 2018, with detailed information about sale price, transaction date, land and structural characteristics and location.

We deleted observations from the original data set for several reasons. First, we restricted the sample to properties purchased by private individuals (though these properties may have been purchased as an investment property and rented), reducing the sample to 30,491 transactions. We excluded 123 observations with unusually large numbers of bedrooms (>20), bathrooms (>10) or car park slots (>10), 621 observations with outlier sale prices (outside 1–99 percentile), 239 observations with sale year before building year and 27 observations without geo-coded locations. Our final data set consists of 29,481 observations on transactions.

We added several neighbourhood and locational characteristics. Neighbourhood characteristics at the census meshblock level come from the 2013 New Zealand census: median household income, median population age, owner–occupier rate and proportion claiming primarily European ancestry.[6] We then measured the Euclidean distance from each property to the Central Business District [CBD] and the nearest coastline. The elevation of the centroid of each property was retrieved from Light Detection and Ranging [LiDAR] data at one-metre resolution.

To measure flood risks at the property level, we adopted a conservative approach to compensate for limits in the available data.[7] We used a location in the current MFL zone as an indicator of flood risk. Starting with digital boundaries from the Dunedin City Council (DCC 2011), we added a buffer of 1 metre to the polygon that defines the zone, and deemed all properties inside this boundary as exposed to flood risks. We identified properties affected by the June 2015 flood event by manually generating a boundary polygon from the flood depths recorded on the DCC web map and verified this boundary against the narrative in the Dunedin Natural Hazard Report (ORC 2016). All properties inside this boundary (with a 1-metre buffer) are deemed as located in the area inundated in the 2015 flood.

The final data set consists of 29,481 observations on transactions, of which 4,380 (14.9 per cent) are inside the MFL zone and 2,134 (7.24 per cent) are in the area inundated during the flood of 3–4 June 2015. There are 4,796 transactions citywide after the flood. Table 1 and 2 presents descriptive statistics that compare the treatment group (properties inside the MFL zone) against its default control group (properties in the rest of Dunedin).

As noted earlier, the distributions in house characteristics in the treatment group differ from those in the rest of the city. Houses in the treatment group are low-lying (+1.2 metres versus mean sea level) and have very different locational characteristics: none are built in a steep slope, they are less likely to have a wide view. Houses in the MFL zone are older, smaller, are built on smaller lots and have fewer rooms.

Figure 2 shows the trends in sale price per square metre of building floor area in the MFL zone and in the rest of Dunedin. Sale prices and volumes boomed in Dunedin from 2002 to 2007, fell moderately in the wake of the

[6] A meshblock is the smallest level of census geography. In urban areas, meshblock boundaries follow street centres and typically enclose the corresponding block of from 30 to 60 houses (Statistics New Zealand 2016 Statistical standard for meshblock).

[7] See Section 3.2. Identification strategy for the reasons behind this design.

Table 1 Descriptive statistics—Full sample

Variables	MFL Zone (4,380 obs.)		All others (25,101 obs.)	
	Mean	SD	Mean	SD
Nominal sale price (NZ$)	204,848	95,075	244,132	123,651
Real sale price (2006-NZ$)	189,487	78,102	227,330	104,917
Sale year	2008.62	5.34	2008.32	5.31
% In inundated area (%)	48.7		0.00	
% After flood (%)	18.6		15.9	
Land area (ha)	4.43	1.49	6.84	4.19
Floor area (sq. meters)	117.83	31	136.80	54
Age of house (years)	84.00	23.02	66.48	28.81
Number of bedrooms	3.07	0.63	3.22	0.82
Number of bathrooms	1.10	0.31	1.20	0.46
Number of carparks	0.90	0.65	1.05	0.76
Deck (%)	36.42	48.12	54.07	49.84
Off-street parking (%)	75.50	43.01	77.95	41.46
Wall materials (%)				
Brick	24.18		43.47	
Mix Material	3.13		6.97	
Other	5.55		4.87	
Roughcast	23.04		12.10	
Weatherboard	44.11		32.58	
Land contour (%)				
Level	98.24		25.68	
Easy/Moderate	1.76		57.69	
Steep	0.00		16.62	
View scope (%)				
Wide	0.00		17.04	
Moderate	0.48		35.64	
Slight	0.41		19.94	
None	99.11		27.37	
Focal point of view (%)				
Water	0.00		12.21	
Other	0.89		60.42	
No focal point	99.11		27.37	
Metres to CBD	2,998	363	3,042	1,803
Metres to coastline	828	336	1,835	1,046
Elevation (metres)	1.24	0.37	104.05	67.26
Census meshblock:				
Median age (year)	39.33	9.92	36.50	8.50
Median HH income ($k)	38.64	16.05	52.71	20.78
% Owner occupied (%)	51.10	16.08	57.32	17.83
% European origin (%)	82.68	8.65	82.51	9.98

Note: This table presents the descriptive statistics of the treatment group (properties inside the minimum floor level [MFL] zone) and the full control group (properties in the rest of Dunedin).

global financial crisis, rising again toward the end of the sample period. Sale prices per square metre are lower on average in the MFL zone, by an average of about 4.7 per cent, but the trend in sale prices parallels that in the rest of Dunedin. This MFL-zone discount grows after the 2015 June Flood to 7.8 per cent, again controlling only for total floor area.

Table 2 Descriptive statistics—Matched sample

Variables	MFL Zone (4,362 obs.)		Matched properties (3,344 obs.)	
	Mean	SD	Mean	SD
Nominal sale price (NZ$)	204,692	94,741	219,433	105,598
Real sale price (2006-NZ$)	189,365	77,726	205,132	87,333
Sale year	2008.61	5.34	2008.07	5.31
% In inundated area (%)	48.74		0.00	
% After flood (%)	18.59		15.10	
Land area (ha)	4.43	1.48	5.44	2.04
Floor area (sq. meters)	117.86	31	122.54	35
Age of house (years)	83.94	23.02	73.66	26.85
Number of bedrooms	3.07	0.63	3.06	0.64
Number of bathrooms	1.10	0.31	1.10	0.31
Number of carparks	0.90	0.65	1.01	0.62
Deck (%)	36.43	48.13	49.55	50.01
Off-street parking (%)	75.56	42.98	83.76	36.89
Wall materials (%)				
Brick	24.16		45.36	
Mix material	3.14		2.06	
Other	5.57		2.24	
Roughcast	22.99		15.07	
Weatherboard	44.13		35.26	
Land Contour (%)				
Level	98.23		56.46	
Easy/Moderate	1.77		43.54	
Steep	0.00		0.00	
View Scope (%)				
Wide	0.00		0.00	
Moderate	0.48		12.68	
Slight	0.41		10.29	
None	99.11		77.03	
Focal point of view (%)				
Water	0.00		0.00	
Other	0.89		22.97	
No focal point	99.11		77.03	
Metres to CBD	2,999	360	2,846	847
Metres to coastline	828	336	1,523	805
Elevation (metres)	1.24	0.37	58.52	49.85
Census meshblock:				
Median age (year)	39.34	9.90	38.21	9.67
Median HH income ($k)	38.62	16.03	45.65	16.90
% Owner occupied (%)	50.92	15.85	53.97	17.03
% European origin (%)	82.65	8.61	82.88	9.37

Note: This table presents the descriptive statistics of the treatment group (properties inside the minimum floor level [MFL] zone) and the matched control group (properties with the most comparable characteristics in the rest of Dunedin).

3.2 Identification strategy

Homeowners and buyers in the low-lying areas shown in Figure 1 cannot help but understand that the coast is near and that ground levels are close to sea level. They may however be unaware that the groundwater level may be

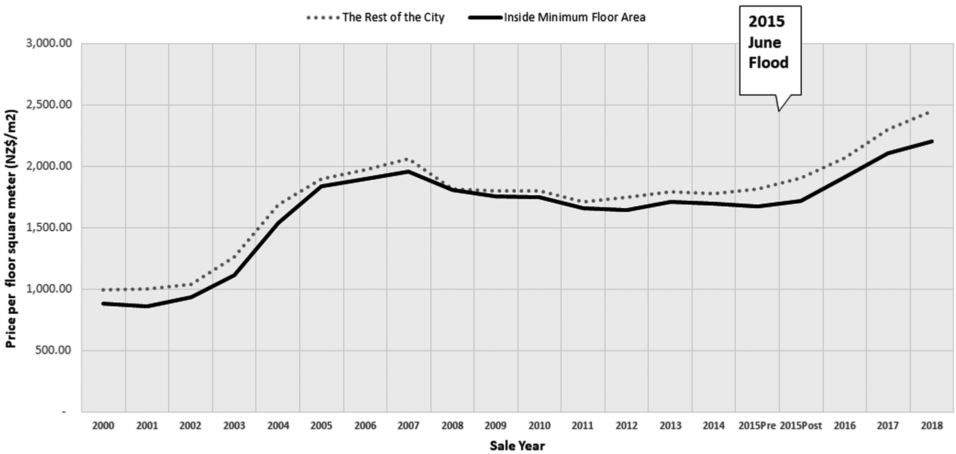

Figure 2 Trend in mean real sale price per square meter of floor area, minimum floor level zone (MFL) vs. rest of study area. *Notes*: This figure shows the trends in sale prices in the MFL zone (the hatched area in Figure 1) and the rest of Dunedin City. The sale prices are measured in NZD using Q2'2016 baseline and is divided by the building floor area (m^2).

connected to sea level. There are two key additional sources of information that homebuyers may consider when considering how much to offer for a house on the market:

1. The area inundated in the June 2015 flood event. The flooding of June 2015 provided a reminder of the area's susceptibility to local flooding. The most salient cause of the flooding was very heavy rain. But, related to sea-level rise, the rain occurred during an especially high tide. This affected surface water runoff, pump performance and raised groundwater levels, and thereby the extent of flooding. Thus, the flooding may have been perceived by homebuyers as a signal of increasing future risk of flooding due to sea-level rise.
2. The low-lying areas and the implementation of MFL requirements in the aftermath of the flooding specify boundaries around the areas that the local council has identified as at risk of current and future flooding as shown in the hatched area in Figure 1 (note that much of the area near the Otago Harbour is developed in large-scale commercial uses and not for residential uses). These requirements specify higher minimum floor levels for low-lying areas due to this event: 0.4 metre above the height of floodwaters in areas inundated in 2015 or 0.5 metre above the ground level for inundated areas where floodwater height is not known.

Our empirical strategy is to estimate any discounts on sale prices in each of these areas that are subject to flood risk due to proximity to the sea or sea-level rise as compared to other areas in Dunedin not subjected to this risk of flooding. Essentially, we estimate the price effects of actual inundation (flood event) and of flood expectations (location in the MFL zone). This differentiation is discussed in the literature (Daniel *et al*. 2009; Beltrán *et al*. 2018; Yi and Choi 2020; Hennighausen and Suter 2020).

We employ standard hedonic sale-price analysis to estimate the price differentials. Specifically, the sale price of a house can be expressed as a function of its characteristics.

$$P = f(S, N, L, E) \quad (1)$$

where the vector S consists of the structural characteristics of the house (such as floor area, age and number of rooms), N includes neighbourhood characteristics (household incomes, age, homeowner rate and ethnic group), L consists of locational attributes (distance to the city centre, to the beach, views and land contour), and E represents environmental amenities/ disamenities. In this study, our variable of interest E indicates the low-lying/ coastal flood risks in GSD.

Based on prior literature (MacDonald and Murdoch 1987; Atreya and Ferreira 2013; Bin and Landry 2013; Shr and Zipp 2019), the flood risk variable E is associated with an objective probability of flooding. The occurrence of a flooding state can cause direct tangible damages (repair or replacement of structures, injury and death) or indirect/intangible damages (loss of personal items with sentimental value, hassle due to displacement or damage to community structure). Therefore, the price differential caused by this flood risk ($\partial P/\partial E$) represents homebuyers' marginal willingness to accept the risk of loss from flooding. Without flood insurance, this amount is simply the sum of all potential losses to homeowners and buyers. With flood insurance, this amount is equal to the sum of the marginal insurance premium and the residual risk of non-insurable losses. Accordingly, we hypothesise that the location in the MFL zone is associated with a negative price differential ($\partial P/\partial E < 0$).

1A: Homebuyers require a discount to live in an area that the local council has identified as vulnerable to coastal flooding.

The June 2015 flood event adds to the information set available to homeowners and buyers: it signals that the area inundated is more flood-prone than other areas in the MFL zone.

1B: The perceived risk of future flooding increases in the area inundated, reducing sale prices further in this area after the flood.

Equations (2) through (4) implement Equation (1) to test the aforementioned hypotheses. Equation (2) estimates the discount in the area in which the MFL requirement has been imposed:

$$Ln(P_{i,t,A}) = \alpha_0 + \alpha_1' S_{it} + \alpha_2' N_{it} + \alpha_3' L_i + \delta_t + \beta MFL_i + \epsilon_{it} \tag{2}$$

where $P_{i,t,A}$ denotes the sale price of property i at transaction date t in area unit A. As is common in this context, the dependent variable is the natural log of sale price under the plausible assumption that flood damages a property in proportion to its market value. Year fixed effects (δ_t) control for general changes over time in house prices. The dummy variable, MFL_i, the variable of interest, equals 1 if property i is located inside the minimum floor level boundary and 0 otherwise. Its coefficient, β, represents the percentage discount on sale prices in the area the local government has identified as at risk of coastal flooding.

Equation (3) imposes a difference-in-differences (DID) strategy to estimate the extent to which the flood event influenced sale prices in the MFL zone:

$$\begin{aligned} Ln(P_{i,t,A}) = {} & \alpha_0 + \alpha_1' S_{it} + \alpha_2' N_{it} + \alpha_3' L_i + \delta_t \\ & + \beta_1 MFL_i + \gamma AF + \theta_1 MFL_i * AF_i + \epsilon_{it} \end{aligned} \tag{3}$$

Equation (3) adds an after-flood dummy variable, AF, to the model, which equals 1 if the transaction date t is after the flood event (3rd June 2015) and 0 otherwise. The coefficient on the interaction term, θ_1, is the estimate of interest as it represents the average difference in the discount in the MFL zone after the flood, all else constant.

Equation (4) modifies the DID approach in Equation (3) by adding a dummy variable F_i that indicates whether the property i is located in the area inundated during the June 2015 flood.

$$\begin{aligned} Ln(P_{i,t,A}) = {} & \alpha_0 + \alpha_1' S_{it} + \alpha_2' N_{it} + \alpha_3' L_i + \delta_t + \beta_{11} MFL_i + \beta_{12} F_i + \gamma AF \\ & + \theta_{11} MFL_i * AF_i + \theta_{12} MFL_i * F_i * AF_i + \epsilon_{it} \end{aligned} \tag{4}$$

As presented, the first line of Equation (4) consists of controls and the second line implements the triple difference-in-differences (DDD) model. As indicated earlier, we expect the flood to supply a dose of reality to any expectations created by the MFL zoning. An unexpected outcome occurs when: (i) a non-floodplain area is inundated, or (ii) a floodplain area is not inundated. Conveniently for our purposes, the entire area inundated in the 2015 flood lies within the predefined boundary of the MFL zone; all of the area that flooded is inside of the area forecast to be flood-prone.

Therefore, for estimation purposes, we divide the overall study area into three mutually exclusive areas: (i) the portion of the MFL zone that was inundated in the flooding event of 2015, $MFL_i * F_i$; (ii) the non-inundated area of the MFL zone, $MFL_i * (1 - F_i)$; and (iii) the rest of Dunedin covered by the data (non-inundated, non-MFL zone) $(1 - MFL_i)$. The entire study area divides neatly into six subgroups:

1. The non-inundated non-MFL zone pre-flood $(1 - MFL_i)*(1 - AF)$,
2. The non-inundated MFL zone pre-flood $MFL_i*(1 - F_i)*(1 - AF)$,
3. The inundated part of the MFL zone pre-flood $MFL_i*F_i*(1 - AF)$,
4. The non-inundated non- MFL zone post-flood $(1 - MFL_i)*AF$,
5. The non-inundated MFL zone post-flood $MFL_i*(1 - F_i)*AF$ and
6. The inundated MFL zone post-flood MFL_i*F_i*AF.

Accordingly, the constant α_0 represents the base group (1)—non-inundated, non-MFL zone pre-flood. β_{11} indicates the generic MFL zone effect and β_{12} indicates the locational effect of the inundated portion of the MFL zone that exists even before the flood (i.e. due to natural and built amenities). γ indicates the generic post-flood effect (the time trend). The coefficient θ_{11} is, as previously, the DID term that indicates the average difference in prices in the MFL zone after the flood event. For the DDD model, θ_{12} is the coefficient of interest that represents the average difference in sale prices of houses that are in that part of the MFL zone that was inundated during the flood event. Based on these coefficients, the respective locational effects of the six subgroups are as follows: (i) α_0, (ii) $\alpha_0 + \beta_{11}$, (iii) $\alpha_0 + \beta_{11} + \beta_{12}$, (iv) $\alpha_0 + \gamma$, (v) $\alpha_0 + \beta_{11} + \gamma + \theta_{11}$ and (vi) $\alpha_0 + \beta_{11} + \beta_{12} + \gamma + \theta_{11} + \theta_{12}$.

3.3 Matching methods

The application of the DID and DDD approaches in Equation (3) and Equation (4) exploits the randomness of the timing and spatial extent of the flooding. However, the strategy relies on finding the correct functional specification among the control variables in the first line. This is especially relevant in that, as mentioned earlier, the characteristics of properties inside the MFL zone differ to varying extents from those in the rest of Dunedin's close-in suburbs.

These concerns motivate an effort to focus on a control group of observations across which the ranges in observed characteristics are similar to those in the MFL sample. We select sales from the 'rest-of-Dunedin' control sample that match the observed characteristics of the MFL sample using the MatchIt package in R. In essence, this step aims to select a more comparable control group for the area with flood risks (i.e. the MFL zone) by improving the balance in the characteristics of the houses observed to have been sold.

As finding perfect matches on all characteristics is not possible, we use nearest neighbour matching. In its simplest form, a 1:1 nearest neighbour matching process selects one control observation *j* for each treated observation *i* with the smallest 'distance' from observation *i* in terms of its observable characteristics.

$$\begin{aligned} ExactDistance : D_{ij} &= \begin{cases} 0, \; if \, X_i = X_j \\ \infty, \; if \, X_i \neq X_j \end{cases} \\ MahalanobisDistance : D_{ij} &= \left(X_i - X_j\right)' \sum_{-1} \left(X_i - X_j\right) \\ PropensityScoreDistance : D_{ij} &= \left|e_i - e_j\right| \end{aligned} \tag{5}$$

where D_{ij} denotes the distance between observation i and observation j, X_i represents one of the observable variables in the matching condition, $\sum$ is the variance–covariance matrix of X, and e_i denotes the propensity score of individual i, defined as the probability of receiving the treatment given the observable variables. We match on the full set of variables in vectors S, N and L. We use Mahalanobis distance for continuous variables and exact distance (of course) for dummy indicators.

In recent studies, the matching technique has been combined with a parametric statistical model. For example, while Ho *et al.* (2007, p. 3) suggest that pre-processing data with matching 'produces inferences that are more robust and less sensitive to model assumptions', Blundell and Costa Dias (2000) argue that using matching in combination with DID regression models can generate substantial improvements in the quality of estimates in a non-experimental setting.

4. Results

4.1 Main results

Table 3 summarises the key results of ordinary least squares estimation of Equations (2) through (4). Panel A and Panel B report the estimates from the full sample and matched sample, respectively. The dependent variable is the natural logarithm of the real sale price, ln(P), so the coefficients are interpreted as the average percentage difference in sales prices, holding the observed covariates constant.[8]

Consider first the Base Model in each panel. This specification follows from Equation (2) to test the generic price effect of a location in the MFL zone from Hypothesis 1A. In both samples, the estimated coefficient on the dummy for a location in the MFL zone is negative, consistent with the hypothesis that homebuyers require a discount to live in an area with exposure to coastal/low-lying flood risks. The magnitudes of the point estimates indicate a plausible sale-price discount of about 5 per cent. The discount is higher in the matched sample with more balanced observable characteristics (6 per cent), but is generally in line with the price effect

[8] Coefficients of these covariates are presented in Table S1 of Appendix S2.

Table 3 Summary of the estimates of the average effects of the June 2015 flood on the discount potentially associated with sea-level rise

Model type	Base model	DID model	DDD model
Panel A: Full sample			
MFL zone (*MFL*)	**−0.052***** (0.006)	**−0.049***** (0.007)	**−0.046***** (0.008)
After flood (*AF*)		**0.045***** (0.012)	**0.045***** (0.012)
Area inundated (*F*)			**−0.007** (0.008)
MFL zone * After flood (*MFL∗AF*)		**−0.016*** (0.009)	**−0.005** (0.011)
MFL zone * Area inundated * After flood (*MFL∗F∗AF*)			**−0.021** (0.017)
N	29,098	29,098	29,098
R-squared	0.753	0.753	0.753
Panel B: Matched Sample			
MFL zone (*MFL*)	**−0.059***** (0.009)	**−0.057***** (0.010)	**−0.071***** (0.010)
After flood (*AF*)		**0.049**** (0.023)	**0.048**** (0.023)
Area inundated (*F*)			**0.033***** (0.008)
MFL zone * After flood (*MFL∗AF*)		**−0.014** (0.013)	**−0.003** (0.015)
MFL zone * Area inundated * After flood (*MFL∗F∗ AF*)			**−0.022** (0.016)
N	7,706	7,706	7,706
R-squared	0.750	0.750	0.751

Notes: The dependent variable is the natural log of real price *Ln (P)*. Panel A and Panel B, respectively, present the results from the full sample and the matched sample. The column level indicates the results from three identification strategies described in Equation 2 through Equation 4. The control set is 'S, N, L'. Coefficients are in bold. Robust standard errors are in parentheses. A number of observations and *R*-squared are in italics. $P < 0.1$; $^{**}P < 0.05$; $^{***}P < 0.01$.

associated with 100-year floodplains (4.6 per cent in the meta-study by Beltrán *et al.* (2018)).[9]

In dollar terms, this discount is equivalent to $12,500 given that the average sale price of houses in the MFL zone shortly before the flood was about $250,000. Meanwhile, the cost of the basic insurance option backed by New Zealand's Earthquake Commission [EQC] for any kind of natural hazard is around $345 (with limited coverage up to $150,000), and the cost of the risk-based flooding insurance is estimated to be around $1,600 (with full coverage

[9] For reference, both Bernstein *et al.* (2018) and Baldauf *et al.* (2020) find that the discount associated with sea level rise in the United States is around 7% (see Section 2). However, a direct comparison with these results may not be meaningful since the price effect of flood risk is subjected to different probability of flooding. We may expect that climate change deepens the price effect as it increases the return period of flooding in Dunedin.

for the replacement cost of a median house in Dunedin).[10, 11] This means that the flood risk discount corresponds roughly to the mid-range of the capitalised insurance premiums ($8,200–$38,200) discounted in perpetuity using the average real interest rate throughout the entire period (4.2 per cent). Given the range of insurance options as well as discount rates, it is hard to draw conclusions on whether the estimated average discount fully reflects the cost of insurance.[12]

The column labelled 'DID model' implements Equation (3) to test whether the June 2015 flood updates flood risk perception as stated in Hypothesis 1B. In this column, the coefficient of interest is that of the difference-in-differences term MFL Zone * After Flood. The point estimates in panels A and B are negative, consistent with the hypothesis: the sale price discount increased on average over the years after the flood. But this increase seems small at about 1.5 percentage points and is only weakly significant.

The price effect may be different between the areas inundated in the flood and the non-inundated part of the MFL area (Atreya and Ferreira 2015; Yi and Choi 2020; Hennighausen and Suter 2020). The column labelled 'DDD' model implements Equation (4) for this purpose. This specification accounts for any locational differences on sale prices prior to the flood in the area that flooded, and most importantly, the effect on sale prices of inundation as a portent of things to come in the future.

In the full sample, prior to the flood, the estimated discount in the area inundated in 2015 relative to the rest of the MFL zone is negligible and insignificant (a discount of less than 1 per cent). The corresponding estimate using the matched sample, however, indicates a significant *premium* in this area of around 3 per cent prior to the flood relative to the rest of the MFL zone. This likely reflects this area's built and natural amenities (well-populated, easy access to ocean beaches, recreational activities, schools, shopping and employment—see Section 2).

Of particular interest is the last coefficient in the column, that is the triple-difference term MFL Zone * Area Inundated * After Flood. This term measures the effect of the flood on sale prices in the part of the MFL zone that was inundated during the flood. The estimated coefficient is negative, as expected, and of similar magnitude in both the full and matched samples: the discount on sale prices in the area inundated by flood waters fell by about 2

[10] These figures are in NZ dollars [NZD]. On 1 Apr 2022, the exchange rate from NZD to USD is 0.6932, and the exchange rate from NZD to AUD is 0.9264 (Source: https://www.xe.com/).

[11] See https://www.stuff.co.nz/national/126547435/eqc-settlement-cap-and-levies-to-rise-next-year and see https://www.odt.co.nz/news/dunedin/dunedin-exposed-thousands-homes-face-insurance-hike

[12] Past literatures have found mixed results when investigating the relationship between the flooding risk discount and the capitalized flood insurance premiums. Some studies find that the discount is higher than the insurance amount due to uninsurable losses (Bin *et al*. 2008; Atreya *et al*. 2013), but some studies find that the price effect is smaller than the capitalized insurance premiums (Harrison *et al*. 2001).

per cent on average over the years after the flood. However, this estimate is not significant at conventional levels. It appears that concerns about the risk of flooding in this low-lying coastal area were largely taken into account by homebuyers in advance of the flooding of June 2015.

There is, however, an alternative explanation for the small after-flood effect. The existing literature suggests that the increase in the flood-risk discount following a particular flood event tends to be short-lived. Perhaps homebuyers tend to react strongly in the immediate aftermath of a flood, but then tend to forget the flood over time (Atreya *et al.* 2013; Bin and Landry 2013; Shr and Zipp 2019). Or perhaps the local authorities make changes to infrastructure or to maintenance practices that satisfactorily reduce the risk of flooding. In that case, we might expect to see a relatively sharp initial increase in the sale price discount shortly after the flood, which then diminishes over time.

To test this hypothesis, we estimate the DDD model restricted to a shorter period after the flood event. Our findings using both the full and matched sample are consistent with prior studies: a sharp initial discount diminishes over time (Figure 3). Specifically, within the first three months of the flood event, the average discount on sales in the inundated part of the MFL zone increases to 14.1 per cent, marginally significant at the 10 per cent level of confidence. Within a year, however, this discount gradually decreases to about 6 per cent, significant at the 95 per cent level. Beyond about 15 months from the event (with a discount of about 5 per cent, marginally significant at the 10 per cent level of confidence), the effect becomes small and statistically insignificant.[13]

4.2 Robustness tests

Spatial dependence may affect the estimation of hedonic house sale price models (Atreya *et al.* 2013; Bin and Landry 2013). We conduct two robustness tests to ensure that our estimates of the flood discount are robust to this issue. In the first test, we incorporate spatial information in the matching strategy. In addition to matching on observable factors (S, N, L), we also match on longitude and latitude, resulting in a control sample clustered near the MFL zone (Figure 4). This sample arguably controls better for unobserved neighbourhood effects at the cost of somewhat less precise matching on house characteristics. The pattern of results is consistent with that obtained from the original matched sample, but the point estimate of the discount on sales in the MFL zone is larger before the flood at 7.3 per cent but with no change after the flood. This suggests that the threat of a flood might have been more keenly appreciated by purchasers of houses in the MFL zone. The point estimate on the average increase in the discount in the

[13] See the detailed figures in Table S2 of Appendix S2. A breakdown of the sale price discount in three-month intervals after the flood in Appendix S2: Figure S1 and Appendix S2: Table S6 (more details appear in Section 4.2) continues to show the biggest price drops in the first 3 months after the flood. There are significant increases in the discount 9-12 months and 24-27 months after the flood event, perhaps due to the annual reminder of the event.

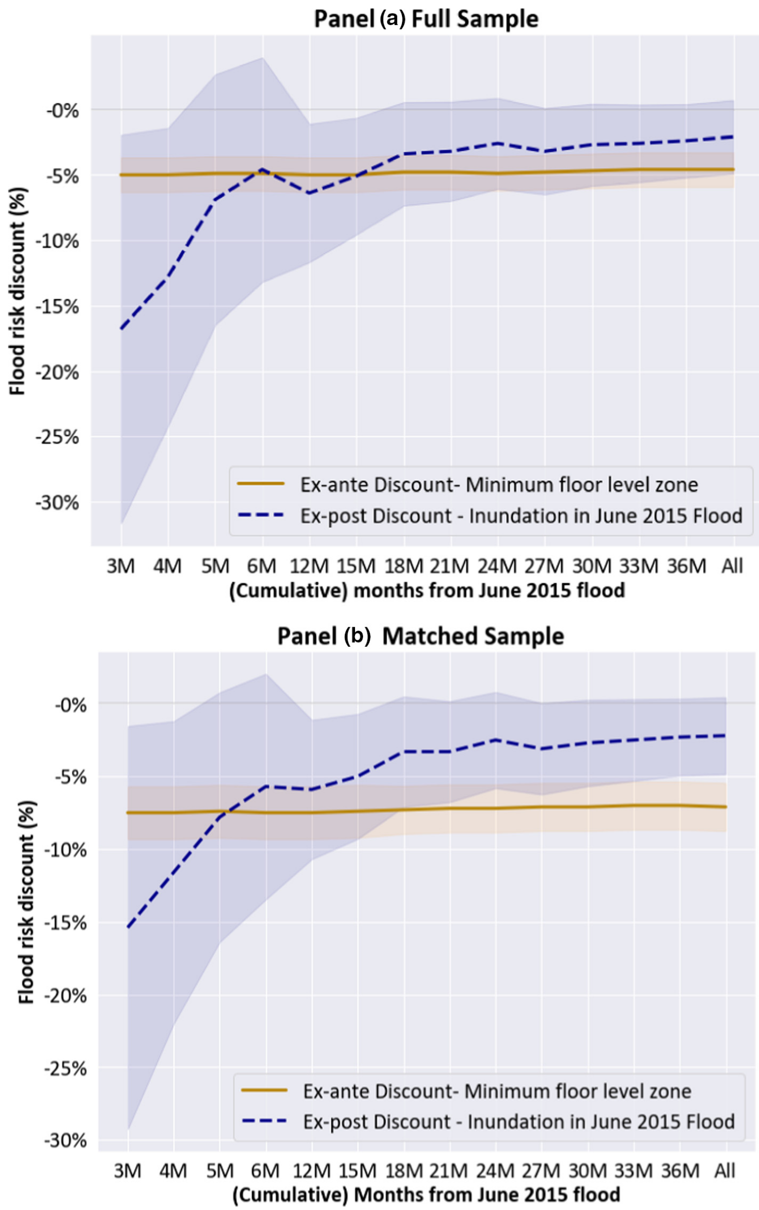

Figure 3 Estimated time trends in the sale price discount after the June 2015 flood. *Notes*: This figure shows the estimated time trends in the sale price discount after the June 2015 flood. The line shows the coefficient estimates, the shaded area shows the 10–90% confidence interval. The ex-ante discount comes from the 'Minimum Floor Level Zone (MFL)', the ex-post discount comes from the 'Minimum Floor Level Zone * After Flood * Inundated (MFL * F * AF)' in Appendix S2: Table S2.The ex-post discount demonstrates the additional discount in the inundated part of the MFL area within 3 months, 4 months, 5 months, 6 months, 12 months, 15 months, 18 months and beyond. [Colour figure can be viewed at wileyonlinelibrary.com]

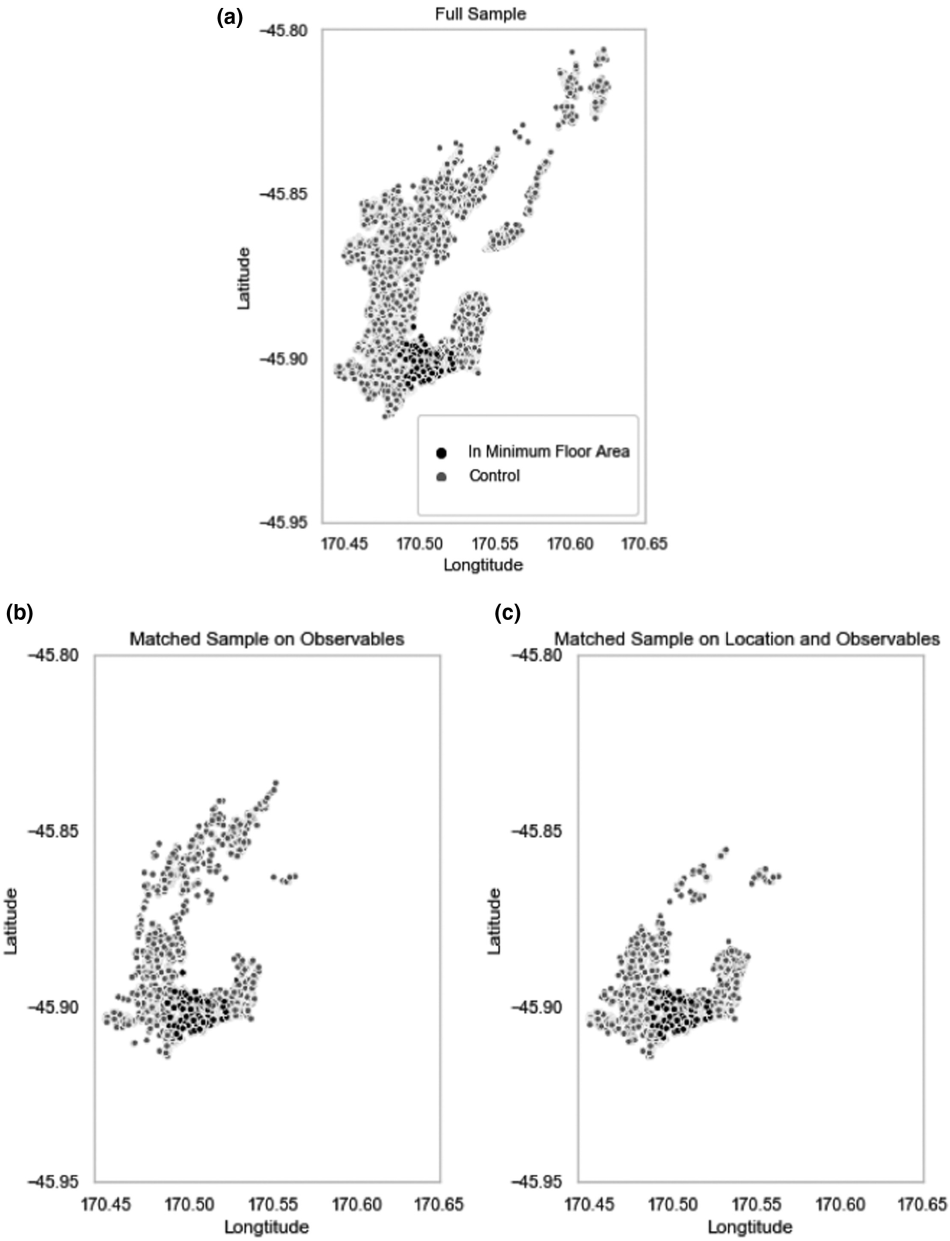

Figure 4 Locations of the treatment and control group with different matching strategies. *Notes*: This figure shows the geo-coded locations of the properties in the treatment group (MFL zone) and the control group in: (a) the full sample, (b) the matched sample using observable characteristics and finally (c) the matched sample using location and observable characteristics.

inundated area after the flood is essentially unchanged from that obtained from the original matched sample.[14]

[14] See the detailed results in Table S3 of Appendix S2.

Second, we re-estimate the main results in Table 3 using the spatial autoregressive combined model [SARAR]. This model accounts for spatial dependence in the dependent variable as well as in the error term via spatial weighting matrices.[15] By construction, a spatial matrix W of dimension $n \times n$ assigns higher weights (effects) on sales of houses nearby (n is the number of properties). Following Atreya *et al.* (2013), we employ two alternative parameterisations for W. One is a queen contiguity matrix that assigns a weight of one for neighbour properties and zero otherwise; the other is a truncated inverse-distance matrix that assigns a weight of 1/distance for properties that lie within a cut-off zone (500 m in this case), and zero otherwise. The construction of these matrices requires unique centroids so only the most recent transaction on each property is retained. For the most part, the signs and significance levels of the flood risk effect remain consistent with the OLS estimations.[16]

Third, we also check the robustness of the diminishing effect of the June 2015 flood. Instead of restricting the sample, we employ the adjusted version of the after-flood dummy variable (*adj. AF)* to indicate the shorter period after the flood event. That is, *adj. AF* is equal to one whether the transaction happens within the first 3 months (or 6 months and 9 months) and zero whether it happens either before the flood or more than 3 months (or 6 months and 9 months) after the flood. Therefore, the temporary effect of the flood event within the first 3 months (as compared to the entire period) is indicated by the interaction term between the inundated part of the MFL zone and this dummy variable. This strategy yields similar diminishing patterns as in Figure 3.[17]

Fourth, a set of dummy variables that indicate every 3-month interval after the flood is employed to provide more detailed estimates of the diminishing effect of the flood event (0–3 months, 3–6 months, 6–9 months, etc.). The coefficients of interest are the interaction terms between the inundated floodplain indicator (MFL × F), and this set of variables. The results indicate

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[15] Specifically, the SARAR model modifies the base model in Equation (2) by allowing the error term $\epsilon_{it}$of house i to depend on each error term $\epsilon_{jt}$of nearby house j via a spatial matrix W_1 (thus, $\epsilon_{it} = \rho W_1 \epsilon_{jt} + u_{it}$), where $u_{it}$is i.i.d. The sale price of house i depends on the sale price of nearby house j using a spatial matrix W_2 (thus $\lambda W_2 ln(P_{j,t})$).Normally, $W_1 \neq W_2$, but if there are one or more explanatory variables, the same matrix could be used ($W_1 = W_2 = W$). $Ln(P_{i,t,A}) = \rho W * \ln(P_{j,t}) \alpha_0 + \alpha_1' S_{it} + \alpha_2' N_{it} + \alpha_3' L_i + \delta_t + \beta MFL_i + \boldsymbol{\lambda W_1 \ln(P_{j,t}) + \rho W_2 \epsilon_{jt} + u_{it}}$

[16] A summary of this estimation is shown in Table S4 of Appendix S2. Prior to estimation, the significance of spatial dependence is confirmed using a Moran's I test on OLS residuals. The sample size is reduced by half (full sample reduces from 29,098 obs to 14,546 obs, and matched sample reduces from 7,706 obs to 3,659 obs). Generalized spatial two-stage least squares (GS2SLS) is employed to produce consistent estimates in the presence of heteroscedasticity (Arraiz *et al.* 2010; Atreya *et al.* 2013; Drukker *et al.* 2013). Results remain consistent if the spatial dependency is incorporated only in the dependent variable using a spatial autoregressive model or only in the error term using a spatial error model. Results are provided upon request.

[17] See the detailed results in Table S5 in Appendix S2.

a sharp discount in the first three months after the flood on sales in the area that flooded. This discount disappears at a fluctuating rate over ensuring 3-month intervals.[18]

In prior literature (Atreya *et al.* 2013; Bin and Landry 2013; Shr and Zipp 2019), researchers employ a time decay function to estimate the diminishing effect of the flood. In the fifth robustness test, we replicate this strategy by constructing a continuous time variable (T) that represents the number of 3-month intervals from the flood event.[19] We estimate several functional relationships: f(T) = T, f(T) = natural logarithms of T or f(T) = ratio of T. The interaction terms between the inundated part of the MFL zone and these time decay functions are all positive, indicating that the flood effect diminishes over time.[20] However, they are all insignificant across the full sample and the matched sample. This may result from the short time period after the flood event (3 years); prior studies show that the diminishing effect occurs over a longer period (Atreya *et al.* 2013; Bin and Landry 2013; Shr and Zipp 2019). Moreover, each functional form imposes a time course that may not fit reality.

We also re-ran our main analyses on sales over a time period more balanced before vs. after the flood: 2012–2018. This reduces the size of the full sample from 29,098 to 9,493 observations and the matched sample from 7,706 to 2,516 observations. The point estimates of interest remain essentially unchanged.[21]

In the original data calibration, observations with sale prices outside 1–99 percentiles are deemed outliers and discarded from the sample (See Section 3.1). To ensure that the main results are not biased by this decision, we re-ran the regression with inclusion of these outliers. We observe that the flood risk discount has a similar pattern with and without outliers. In the matched sample, the estimated discount on sales in the MFL zone increases from 5.9 per cent to 9.0 per cent, but the signs and significance levels remain consistent with the main analyses.[22]

We modify the matching criteria by using propensity score as the distance measurement on all observables S, N and L and rerun all analyses from Equation (2), Equation (3) and Equation (4). All of the signs and significance levels of the flood risk effect remain similar to the original matching design.[23]

It is possible that property developers (or home owners) became aware of potential flooding risks after the recommendation of the MFL policy, and thus chose to raise the floor heights when constructing new houses in the

[18] See the detailed results in Table S6 and Figure S1 in Appendix S2.

[19] The value is 0 if happens prior to the flood event. The result holds if we employ different time intervals such as the number of days, the number of months or the number of years (notice that this time variable is integer by rounding to the nearest interval).

[20] See the detailed results in Table S7 in Appendix S2.

[21] See the detailed results in Table S8 in Appendix S2.

[22] See the detailed results in Table S9 in Appendix S2.

[23] See the detailed results in Table S10 in Appendix S2.

low-lying areas (or were mandated to do so in the aftermath of the 2015 flood). In such cases, these properties should be deemed safer from floods and sold at a premium compared to otherwise-similar older houses.

In the final robustness check, we add a layer of differencing to Equation (2), Equation (3) and Equation (4) to test this price effect.We use a dummy indicator B that equals 1 if the property is built after the recommendation (implementation) of the MFL zone and 0 otherwise.[24] We find that houses inside the MFL Zone that were built after the recommendation of this policy ($MFL * B$) sell at a statistically significant *premium* of about 10 per cent in the full sample and about 6 per cent in the matched sample. The premium is not significantly different for the areas inundated in the flood as compared to the non-inundated areas ($MFL * F * B$) and does not change after the June 2015 flood event ($MFL * F * A * B$). It is possible that these newer houses do not have elevated floors despite being built inside the low-lying areas after the MFL recommendation. On the other hand, property developers might be well aware of potential flooding risks ahead of the MFL policy and raise the floor heights accordingly. Therefore, the result of this robustness check should be interpreted as an indicator but not as strong evidence that homebuyers pay more for built-in flood defence. A similar analysis produces a premium (though insignificant) on sales of houses built after the implementation of the MFL zone.[25]

5. Conclusion

In this paper, we estimate the effect on the sale prices of houses vulnerable to climate-change-related flood risk in a New Zealand residential property market. Areas vulnerable to flooding had been identified in studies conducted and published prior to a flood event in 2015. Following the flood event, minimum floor-level requirements were imposed on new construction in a zone that include the area that flooded. Houses in the zone that predate this particular flooding event and subsequent implementation of the MFL zone have correspondingly lower floor levels. Given the low-lying nature of the area, its proximity to the coast and the MFL zoning we expect that these pre-zone houses sell at a discount to compensate for the risk of flood damage, all else the same. And, indeed, the evidence from hedonic sale price regressions indicates a discount in the MFL zone averaging 5 per cent.

What does this discount imply about homebuyer expectations of flood-related costs? The average sale price of houses in the area later zoned for required minimum floor levels was about \$250,000 shortly before the 2015 Dunedin flood. Assuming properties sell for a discount of 5 per cent relative

[24] See the detailed results in Table S11 in Appendix S2.

[25] This is probably driven by a relatively small number of observations of new houses (5 houses) inside the MFL zone that are built after 2015. See the detailed results in Table S11 in Appendix S2.

to an otherwise similar property outside of the zone, the dollar value of the discount averages $12,500. This discount corresponds roughly to the mid-range of insurance premiums discounted in perpetuity, but it is hard to draw any conclusions on whether it fully reflects insurance cost. Somewhat surprising is that prior to the damaging earthquakes that struck Christchurch in 2011 insurance against damage due to natural hazard did not vary with hazard risk. This has gradually changed over the ensuing decade, and so hazard insurance premiums are likely to rise in this area in the future.

Of particular interest is the effect on sale prices in the years after the flood event in June 2015. The flood coincided with heavy rainfall combined with an unusually high tide, resulting in the flooding of part of the MFL zone and heightened community awareness of flood hazard on this low-lying coastal land. By itself, we might expect this salient event to increase homebuyers' concerns about the threat of changing flood hazards. As groundwater levels are to some extent influenced by tides and the general level of the sea, the flood can reasonably be considered a harbinger of a future with higher sea levels, more frequent rain events and more flooding. Our estimates indicate a large (but insignificant at conventional levels) additional discount of more than 10 per cent on sale prices shortly after the flood. But this additional discount dissipated quickly, effectively disappearing within 15 months of the flood.

Our data cannot address the reasons that the additional post-flood discount disappeared. Speculating, homebuyers may perceive that flooding is rare and expect that local government bodies will react to this most recent flood event by improving local infrastructure and its maintenance to better protect against future flooding. And, indeed, the flood event prompted discussion around the state of the drainage systems. There were promises of more effective maintenance, and parts of the storm and wastewater systems in the area are due for replacement over the next decade. Our statistical results may possibly be due to unobserved changes in house condition: some of the houses sold shortly after the flood may have uninsured damage that reduced sale prices. The fade in the discount is also consistent with behavioural biases that generate strong reactions to recent and salient events. We expect that the same mechanism may apply more generally in the early stages of climate change, where market participants react strongly to periodic but still rare flooding events, and then concerns soon fade.

However, over time and in the absence of investment in defences, climate change-induced rise in sea levels and increased frequency of heavy rain events will combine to increase the frequency and extent of inundation. How might local, and possibly central, governments respond? Bear in mind that the study area is well-endowed with natural and produced amenities popular, has a relatively large population, and that the confluence of events that led to the recent flooding is still relatively rare; it likely will be some time before retreat is necessary. In the meantime, the local council will have the opportunity to improve the drainage system and its maintenance. As described earlier, the council has imposed flood-related requirements on new construction. Perhaps possible, but costly, is construction of an impermeable barrier between the groundwater and the sea. This raises perhaps the most important policy questions: How far should the council or central government go to defend this relatively valuable area? and, of course, who should pay?

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Data availability statement

The data that support the findings of this study are available from CoreLogic. Restrictions apply to the availability of these data, which were used under license for this study. Data are available from the authors subject to permission from CoreLogic.

References

Arraiz, I., Drukker, D.M., Kelejian, H.H. and Prucha, I.R. (2010). A spatial Cliff-Ord-type model with heteroskedastic innovations: small and large sample results, *Journal of Regional Science* 50, 592–614.

Atreya, A., Ferreira, S. and Kriesel, W. (2013). Forgetting the flood? An analysis of the flood risk discount over time, *Land Economics* 89, 577–596.

Atreya, A. and Ferreira, S. (2015). Seeing is believing? Evidence from property prices in inundated areas, *Risk Analysis* 35, 828–848.

Baldauf, M., Garlappi, L. and Yannelis, C. (2020). Does climate change affect real estate prices? Only if you believe in it, *The Review of Financial Studies* 33, 1256–1295.

Beltrán, A., Maddison, D. and Elliott, R.J. (2018). Is flood risk capitalised into property values? *Ecological Economics* 146, 668–685.

Bernstein, A., Gustafson, M. and Lewis, R. (2018). Disaster on the horizon: the price effect of sea level rise, *Journal of Financial Economics* 134, 253–272.

Bin, O., Kruse, J.B. and Landry, C.E. (2008). Flood hazards, insurance rates, and amenities: evidence from the coastal housing market, *Journal of Risk and Insurance* 75, 63–82.

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

Blundell, R. and Costa Dias, M. (2000). Evaluation methods for non-experimental data, *Fiscal Studies* 21, 427–468.

Carey-Smith, T., Henderson, R. and Singh, S. (2018). *High Intensity Rainfall Design System: version 4*. National Institute of Water & Atmospheric Research Ltd, Wellington, NZ. Client Report 2018022CH. Prepared for: Envirolink, p. 73.

Carney, M. (2015). Breaking the tragedy of the horizon–climate change and financial stability. Speech given at Lloyd's of London. [Online] Available from URL: https://www.bankofengland.co.uk/ [Accessed 10 March 2018].

Church, J., Clark, P., Cazenave, A., Gregory, J., Jevrejeva, S., Levermann, A., Merrifield, M., Milne, G., Nerem, R., & Nunn, P. (2013). Chapter 13: Sea level change, in Stocker, T.F.

(eds), *Climate Change 2013: The Physical Science Basis. Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change*. Cambridge University Press, Cambridge and New York, pp. 1137–1216.

Climate Sigma (2020). Sea level rise and the withdrawal of residential insurance in Aotearoa New Zealand. Available from URL: https://deepsouthchallenge.co.nz/wp-content/uploads/2021/01/Insurance-Retreat-December-2020-Final-Report.pdf [Accessed 1 May 2021].

Cox, S.C., Ettema, M.H.J., Mager, S.M., Glassey, P.J., Hornblow, S. and Yeo, S. (2020). Dunedin groundwater monitoring and spatial observations. Lower Hutt (NZ): GNS Science GNS Science Report 2020/11, p. 86. https://doi.org/10.21420/AVAJ-EE81. Available from URL: https://www.gns.cri.nz/gns/content/download/14311/75858/file/ground_water_monitoring_observations.pdf [Accessed 25 Mar 2022]

Daniel, V.E., Florax, R.J. and Rietveld, P. (2009). Floods and residential property values: a hedonic price analysis for the Netherlands, *Built Environment* 35, 563–576.

DCC (2011). *Methodology for Determining Minimum Floor Levels. Review of Minimum Floor Levels*. Dunedin City Council. Available from URL: https://www.dunedin.govt.nz/__data/assets/pdf_file/0004/295465/MWH-Methodology-for-Determining-Minimum-Floor-Levels-2011.pdf [Accessed 14 January 2019].

Denys, P.H., Beavan, R.J., Hannah, J., Pearson, C.F., Palmer, N., Denham, M. and Hreinsdottir, S. (2020). Sea level rise in New Zealand: the effect of vertical land motion on century-long tide gauge records in a tectonically active region. *Journal of Geophysical Research: Solid Earth* 125, e2019JB018055. https://doi.org/10.1029/2019JB018055.

Diaz-Rainey, I., Robertson, B. and Wilson, C. (2017). Stranded research? Leading finance journals are silent on climate change, *Climatic Change* 143, 243–260.

Drukker, D.M., Egger, P. and Prucha, I.R. (2013). On two-step estimation of a spatial autoregressive model with autoregressive disturbances and endogenous regressors, *Econometric Reviews* 32, 686–733.

Elder, V. (2016). Flood's 'true' cost $138 million. Otago Daily Times. Available from URL: https://www.odt.co.nz/news/dunedin/dcc/flood's-true-cost-138-million [Accessed 2021 July 10].

Ellis, E. (2018). How should the risks of sea-level rise be shared? Available from URL: https://www.deepsouthchallenge.co.nz/sites/default/files/2018-11/How%20should%20risks%20of%20SLR%20be%20shared%20Lisa%20Ellis%20Final%20Report.pdf [Accessed 1 March 2019].

Field, C.B., Barros, V., Stocker, T.F. and Dahe, Q. (2012). *Managing the Risks of Extreme Events and Disasters to Advance Climate Change Adaptation: Special Report of the Intergovernmental Panel on Climate Change*. Cambridge University Press, Cambridge.

Fleming, D.A., Noy, I., Pástor-Paz, J. and Owen, S. (2018). Public insurance and climate change (part one): past trends in weather-related insurance in New Zealand. Motu Economic and Public Policy Research. Motu Working Paper 18-09.

Frame, D., Rosier, S., Carey-Smith, T., Harrington, L., Dean, S. and Ilan, N. (2018). *Estimating Financial Costs of Climate Change in New Zealand - An Estimate of Climate Change-related Weather Event Costs*. Commissioned report, The Treasury, Wellington.

Harrison, D., Smersh, T.G. and Schwartz, A. (2001). Environmental determinants of housing prices: the impact of flood zone status, *Journal of Real Estate Research* 21, 3–20.

Hennighausen, H. and Suter, J.F. (2020). Flood risk perception in the housing market and the impact of a major flood event, *Land Economics* 96, 366–383.

Ho, D.E., Imai, K., King, G. and Stuart, E.A. (2007). Matching as nonparametric preprocessing for reducing model dependence in parametric causal inference, *Political Analysis* 15, 199–236.

Hulme, M. (2014). Attributing weather extremes to 'climate change': a review, *Progress in Physical Geography: Earth and Environment* 38, 499–511.

Islam, A., Mitra, D., Dewan, A. and Akhter, H. (2016). Coastal multi-hazard vulnerability assessment along the Ganges deltaic coast of Bangladesh–A geospatial approach, *Ocean & Coastal Management* 127, 1–15.

Johnstone, N.P. (2016). An appraisal of recent reporting of South Dunedin hazards. Available from URL: https://dunedinstadium.files.wordpress.com/2016/08/a-review-of-orc-report-the-natural-hazards-of-south-dunedin-11.pdf [Accessed 11 July 2021].

Joshi, S.R., Vielle, M., Babonneau, F., Edwards, N.R. and Holden, P.B. (2016). Physical and economic consequences of sea-level rise: a coupled GIS and CGE analysis under uncertainties, *Environmental and Resource Economics* 65, 813–839.

Lamond, J., Proverbs, D. and Antwi, A. (2005). The effect of floods and floodplain designation on the value of property: an analysis of past studies. Paper presented at the Proceedings of the second Scottish conference for postgraduate researchers of the built and natural environment, Glasgow Caledonian University, November.

Le, T.V.T., Gibson, J.K. and Stillman, S. (2010). Household wealth and saving in New Zealand: evidence from the longitudinal Survey of Family, Income and Employment. Motu Economic and Public Policy Research. Motu Working Paper 10-06.

MacDonald, D.N., Murdoch, J.C. and White, H.L. (1987). Uncertain hazards, insurance, and consumer choice: evidence from housing markets, *Land Economics* 63, 361–371.

Macfie, R. (2016). Flood fiasco: eye of the storm New Zealand, *Listener* 254, 22–29.

Mavromatidi, A., Briche, E. and Claeys, C. (2018). Mapping and analyzing socio-environmental vulnerability to coastal hazards induced by climate change: an application to coastal Mediterranean cities in France, *Cities* 72, 189–200.

MFE (2017). *Adapting to Sea-level Rise*. Ministry for the Environment. Available from URL: http://www.mfe.govt.nz/climate-change/what-government-doing/adapting-climate-change/adapting-sea-level-rise [Accessed 14 January 2019].

Murfin, J. (2012). The supply-side determinants of loan contract strictness, *The Journal of Finance* 67, 1565–1601.

Murfin, J. and Spiegel, M. (2020). Is the risk of sea level rise capitalized in residential real estate? *The Review of Financial Studies* 33, 1217–1255.

ORC (2015). *Coastal Otago Flood Event 3 June 2015*. Otago Regional Council. Available from URL: https://www.orc.govt.nz/media/1662/coastal-otago-flood-event-3-june-2015.pdf [Accessed 14 January 2019].

ORC (2016). *The Natural Hazards of South Dunedin*. Otago Region Council. Available from URL: https://www.orc.govt.nz/media/2217/the-natural-hazards-of-south-dunedin-report-july-2016.pdf [Accessed 14 January 2019]

Ortega, F. and Taspinar, S. (2018). Rising sea levels and sinking property values: Hurricane Sandy and New York's housing market. *Journal of Urban Economics* 106, 81–100.

Paprotny, D. and Terefenko, P. (2017). New estimates of potential impacts of sea level rise and coastal floods in Poland, *Natural Hazards* 85, 1249–1277.

Parris, A.S., Bromirski, P., Burkett, V., Cayan, D.R., Culver, M.E., Hall, J., Horton, R.M., Knuuti, K., Moss, R.H. and Obeysekera, J. (2012). Global sea level rise scenarios for the United States National Climate Assessment, NOAA Technical Report. National Oceanic and Atmospheric Administration, United States. Available from URL: https://repository.library.noaa.gov/view/noaa/11124 [Accessed 19 March 2019]

Paulik, R., Stephens, S., Wadhwa, S., Bell, R., Popovich, B. and Robinson, B. (2019). Coastal flooding exposure under future sea-level rise for New Zealand. NIWA Client Report 2019119WN, prepared for The Deep South Science Challenge. Available from URL: https://deepsouthchallenge.co.nz [Accessed 8 April 2022].

Paulik, R., Stephens, S., Wild, A., Wadhwa, S. and Bell, R.G. (2021). Cumulative building exposure to extreme sea level flooding in coastal urban areas, *International Journal of Disaster Risk Reduction* 66, 102612.

PCE (2015). *Preparing New Zealand for Rising Seas: Certainty and Uncertainty*. Parliamentary Commissioner for the Environment. Available from URL: https://www.pce.parliament.nz [Accessed 31 May 2020].

Poterba, J.M. (2007). *International Comparisons of Household Saving*. University of Chicago Press, Chicago.

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

Shr, Y.-H.-J. and Zipp, K.Y. (2019). The aftermath of flood zone remapping: the asymmetric impact of flood maps on housing prices, *Land Economics* 95, 174–192.

Simonson, T. and Hall, G. (2019). Vulnerable: the quantum of local government infrastructure exposed to sea level rise. Available from URL: http://www.lgnz.co.nz/assets/Uploads/0bb3c3d32a/Planning-for-Sea-Level-Rise-v7-FINAL.pdf [Accessed 1 March 2019].

Statistics NZ (2018). Are New Zealanders living closer to the coast? Available from URL: http://archive.stats.govt.nz [Accessed 1 March 2019].

Stephens, S.A., Paulik, R., Reeve, G., Wadhwa, S., Popovich, B., Shand, T. and Haughey, R. (2021). Future changes in built environment risk to coastal flooding, permanent inundation and coastal erosion hazards, *Journal of Marine Science and Engineering* 9, 1011.

Storey, B., Noy, I., Owen, S., Townsend, W., Kerr, S., Salmon, R., Middleton, D., Filippova, O. and James, V. (2017). Insurance, housing and climate adaptation: current knowledge and future research. Motu Note #27. Available from URL: https://www.motu.nz/assets/Documents/our-work/environment-and-agriculture/climate-change-impacts/Insurance-Housing-and-Climate-Adaptation.pdf [Accessed 1 March 2019]

Woodruff, J.D., Irish, J.L. and Camargo, S.J. (2013). Coastal flooding by tropical cyclones and sea-level rise, *Nature* 504, 44–52.

Yi, D. and Choi, H. (2020). Housing market response to new flood risk information and the impact on poor tenant, *The Journal of Real Estate Finance and Economics* 61(1), 55–79.

Supporting Information

Additional Supporting Information may be found in the online version of this article:

Appendix S1. Description of the 3–4 June 2015 flood event.
Appendix S2. Supplemental Tables and Figures.