Does Climate Change *Adaptation* Matter? Evidence from the City on the Water *

Matteo Benetton Simone Emiliozzi Elisa Guglielminetti Michele Loberto
Alessandro Mistretta

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Abstract

This paper leverages the unexpected successful activation of a sea wall built to protect Venice from rising tides to estimate the capitalization into property values of public investment in resilience infrastructure. Using a difference-in-differences hedonic approach with high-frequency microdata on residential and commercial properties, we show that properties above the sea wall activation threshold experience a permanent reduction in flood risk and expected damages, reflected in higher prices. To account for city-wide effects and potential ex-post government bailouts, we analyze the effect of the second-largest flood in Venice centuries-long history on properties prices relative to the mainland as well as data on government claims matched with property elevations. Our findings indicate that capitalized benefits and projected government savings cover approximately 52% (101%) of the sea wall costs in a status-quo (sea-level-rise) scenario. Lastly, we calculate a break-even discount rate of 1.1%, which increases to 2.5% under sea-level-rise projections.

JEL codes: Q54; R21; R38; O18; H54

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1 Introduction

An estimated 10 million people around the globe experience coastal flooding each year and this fraction could increase five-fold by 2080 as a result of climate change, with estimated damages exceeding $1 trillion by 2050 (Adger et al., 2005; Hallegatte et al., 2013; Hinkel et al., 2014). An important factor of uncertainty behind these estimates is the endogenous adaptation by households and firms, as well as countervailing policy by governments to reduce the damages from climate change. While a large literature has studied global mitigation via emission controls and carbon taxes, local adaptation is becoming increasingly important and might play a major role going forward (Bouwer et al., 2007; Barrage, 2020; Fried, 2021; Conte et al., 2021; Desmet et al., 2021; Hong et al., 2023; Bilal and Rossi-Hansberg, 2023; Cruz and Rossi-Hansberg, 2024; Fairweather et al., 2024). Empirically grounded estimates of the costs and benefits of adaptation investment are therefore valuable for both researchers estimating climate models and policy makers considering alternative strategies to confront climate change.[1]

This paper utilizes the city of Venice as a laboratory to study the costs and benefits of public investments in resilience infrastructure. Built on stilts, Venice has been exposed to sea level changes since its foundation, with high tides and flooding becoming worse in recent years, potentially threatening the city existence.[2] Our main empirical analysis exploits the unexpected successful activation of a sea wall to identify the causal effect of a permanent shock to amenities (a reduction in flood risk) on both residential and commercial property prices. Combining time-series variation from this event with granular cross-sectional variation in properties stilts elevation and high-frequency data on properties listings, our analysis is able to address well-known econometric issues affecting cross-sectional studies, which struggle to separate the price effects of sea level rise from the value of correlated characteristics (Greenstone, 2017; Giglio et al., 2021). Furthermore, the combination of the city unique location and structure makes flooding a very salient risk, lowering concerns about lack of information affecting capitalization (Hino and Burke, 2021; Gourevitch et al., 2023).[3]

[1] In the United States flood protection infrastructure alone is forecasted to account for 60% of the $500 billion adaptation cost by 2100 (Hummel et al., 2021).

[2] Recent climate change studies have warned that Venice might be underwater by 2100, as a result of an expected increase of the Mediterranean Sea by up to 110 cm – over three feet (Lionello et al., 2021; Zanchettin et al., 2021).

[3] Our high-frequency data on house listings cover only recent years. However, one advantage of looking at the city of Venice is the availability of precise data on high tides and flooding, which we believe is a strength of our analysis, given the usually short time series and large uncertainty about inundation projections due to measurement

We begin our analysis with motivating evidence looking at high tides and house listings around the first activation of the sea wall in October 2020.[4] Figure 1 shows an increasing number of high tides in Venice between 2018 and 2021, with the month of November 2019 witnessing the highest number since accurate measurement of tides started in 1870. Not surprisingly, the trend in high tides has been reflected in the fraction of house listings mentioning high-tide and flood risk (attention index), which doubled from about 8% in 2018 to almost 16% by 2020. The sea wall activation in October 2020 represented a stark inversion in the upward trend. This inversion in the attention index is consistent with a surprise effect from the sea wall successful activation – which we further document in the paper – after many years of delayed works and uncertainty on its ability to effectively protect the city. Two years after the first activation of the sea wall, the fraction of house listings mentioning high-tide and flood risk has decreased from 16% to below 10%. Since December 2020 the city of Venice has never experienced a tide greater than 110 cm as a result of the protection offered by the sea wall.

We implement a difference-in-differences hedonic design, exploiting two sources of heterogeneity in properties' exposure to flood risk (and hence to the benefits of the sea wall). Our first identification strategy uses variation based on the floor of the property, as ground floors are likely to benefit more from the activation of the sea wall relative to higher floors, all else equal. We find that after the activation of the sea wall ground floor properties experience an increase in price of about 7% relative to higher floor properties in the same neighborhood. This result is entirely driven by properties located in low-elevation areas (110-140 cm) and thus more exposed to flooding, which appreciate by 9%. Second, we focus on higher floors and exploit variation in properties stilts elevation, as a measure of differential exposure to the sea wall. Although less likely to be directly flooded than ground-floor ones, higher-floor properties are indirectly affected by flooding of common areas and the street to access the premises. After the activation of the sea wall, we find that the price of low-elevation properties increases by about 4% relative to the price of high-elevation properties in the same neighborhood.

Additional analyses allow us to sharpen the interpretation and check the robustness of our re-

error (Gesch, 2009; Keys and Mulder, 2020).

[4]The event was a milestone in a multi-decades effort to make the city of Venice more resilient to increasing high tides and related flooding events. The Major of Venice described the first activation of the sea wall as a "historic day for Venice" and for residents the event felt "like the first step of Armstrong on the moon." (Source: https://www.cnn.com/travel/article/venice-flood-barrier/index.html).

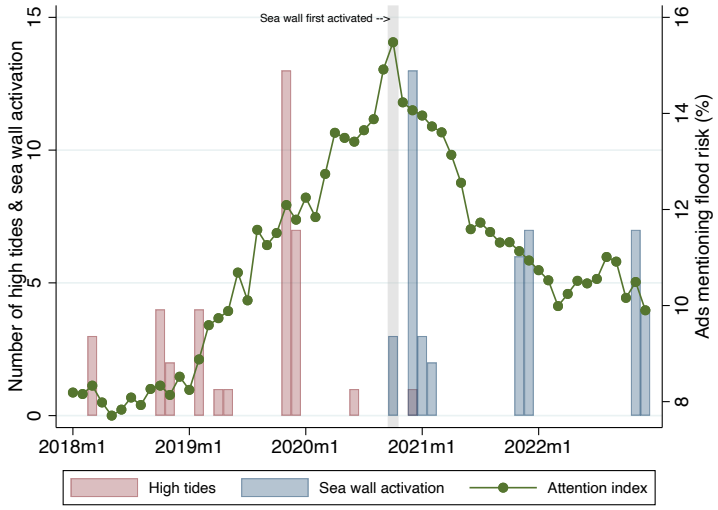


Figure 1: High tides, adaptation and attention to flood risk

Note: The green line shows a measure of climate attention which is a dummy equal to one if the property description mentions flooding or high tide. The Italian words used to compute the attention index are: "marea", "maree", and "acqua alta". The red vertical bars show the number of times the sea level in Venice was higher than 110 cm. The blue vertical bars show the number of times the sea wall has been activated in the respective month.

sults. We test for parallel trends of sale prices for properties more and less exposed to flooding before the activation of the sea wall. We estimate a placebo specification assuming the sea wall was activated one year before the true date, as an additional test to lower concern about anticipation effects and possible interaction with the seasonality of the housing market. We also check that property characteristics do not change as a result of the activation of the sea wall, limiting concern about changes in the pool of properties that are correlated with our exposure measures. Finally, we emphasize that our results are unlikely to be contaminated by endogenous supply side responses, such as new construction, which are often a factor that may bias the causal estimates from event studies on house prices, as housing supply in Venice is extremely inelastic due to building constraints.

We then study commercial properties around the first activation of the sea wall using an event study specification.[5] We find that after the activation of the sea wall commercial properties experience an increase in their price per square meter by about 15% relative to before. The effect

[5]Commercial properties are disproportionately more on ground floors, which prevents us from exploiting variation across floors. Moreover, the limited number of listed commercial properties and their concentration in low-elevation areas does not give us enough power to estimate a difference-in-differences design across elevation levels, similar to the one for residential properties.

is even larger for shops, which appreciate by 25%. While the different empirical design makes the comparison with residential properties only suggestive, a larger appreciation for commercial properties following the activation of the sea wall is consistent with commercial properties prices incorporating the benefits of lower direct damages from flooding - similar to residential properties and especially ground floors - as well as additional benefits from lower damages to the merchandise and an increase in tourist demand.[6]

We compute the overall valuation gain from the sea wall on the stock of both residential and commercial properties by combining our empirical estimates with census data on the total square footage of different buildings in Venice. We find that the benefits capitalized in property prices amount to almost €1 billion, of which approximately 45% comes from residential properties and 55% from commercial properties.

We also exploit a second source of quasi-experimental variation coming from the November 12th 2019 extremely high tide – the second highest level ever recorded in the history of Venice – to get an indirect quantification of the potential city-wide benefits of the sea wall, which could have prevented the flood if successfully activated. We compare (treated) properties in the city center with comparable (control) properties located in the mainland, which belong to the same metropolitan city of Venice, but critically are not exposed to flooding. Overall, we find that after the event the entire city center experienced a significant 4% (20%) decline in residential (commercial) property values.

A key advantage of our capitalization approach is that it provides a present-value measure of benefits that is market-based, empirically identified, and does not require assumptions on discount rates. At the same time, the expectation of government bailouts following extreme events can lead to moral hazard, as homeowners may not fully bear the costs of natural disasters. As a result, property values may not fully incorporate these potential costs. While government bailouts are likely both incomplete and delayed – the claims of the November 2019 flood have not yet been fully paid almost five years after the event – they are likely to bias downward our capitalization estimates of the benefit of the sea wall (by overvaluing the Venice properties stock relative to a world without government intervention).

To address this potential concern, we leverage individual-level data on claims for government

[6] We also validate the plausibility of our estimates with an analysis of the impact of high tides on annual tourist revenues.

funds following the November 12th 2019 flood. We link these claims to the property and its elevation to construct a proxy for damages covered by the government. We then exploit the availability of two different measurements of the tide each day – one in the city center of Venice and one in an offshore platform – to construct counterfactual (i.e., without sea wall) tides in the city of Venice in the two years after the first activation of the sea wall. Combining the estimated damages and the counterfactual tides we find that the active sea wall prevented about €52 millions in annual damages during the first two years. We also study damages in two alternative scenarios based on: (i) historical tides in the last 10 years; and (ii) expected tides in 50 years due to sea level rise.

In the last part of the paper, we compare the benefits capitalized in property prices and measured by government savings to the costs of the sea wall.[7] The cost-benefit analysis yield several findings. First, focusing only on the benefits capitalized in residential and commercial properties the project benefits cover approximately 25% of the costs. This estimate is almost insensitive to the choice of the discount rate, since the latter only affects the present value of the maintenance costs, and represents a lower bound on the benefits from the sea wall. Second, adding to the privately capitalized benefit the savings for the government from lower expenses to cover damages, the benefits cover approximately 55% of the actual costs, which increase to 101% in a scenario with sea level rise. Third, we compute the break-even discount rate (i.e., the rate that makes the sea wall a zero net-present-value project), given the cost and estimated benefits at the time of the first activation. In our baseline scenario, we obtain a break-even interest rate of 1.1%, while with sea level rise the break-even rate becomes almost identical to our baseline rate of 2.5%.[8]

Our work has relevant policy implications. First, while the precise magnitudes are specific to the context that we study, we think that the capitalization result and the cost-benefits analysis could be informative about the return on public investment in adaptation, which has attracted increasing attention from both policy makers and economists around the world. Second, our results are important for better understanding how to finance adaptation policies. The benefits from the sea wall are heterogeneous across property owners, suggesting that targeted property tax increases might represent a way to finance adaptation policies. Third, our work is related to the recent debate

[7] We do not take into account in our cost-benefit analysis the inestimable historical and artistic heritage of Venice because any estimate on the monetary benefits would be at most suggestive.

[8] Our choice of the baseline discount rate is motivated by the work of Drupp et al. (2018), Giglio et al. (2021) and Hahn et al. (2024), among others.

on the choice of the discount rate for assessing public investments in adaptation.[9] While we do not take a stand about the optimal discount rate, we provide empirical evidence on how small changes in the discount rate dramatically affect the cost-benefit analysis of a large public investment in adaptation with huge upfront costs. Fourth, our results comparing privately capitalized benefits to government savings highlight more broadly how government ex-post interventions can impact the capitalization of ex-ante public investments in infrastructure resilience.

Overview. The rest of the paper is organized as follows. The remainder of the section discusses the relevant literature. Section 2 discusses the setting. Section 3 describes the data and provides a simple framework for the empirical analyses. Section 4 presents the main empirical results using residential and commercial properties prices and the capitalization analysis. Section 5 reports the results of additional analyses of benefits from the sea wall. Section 6 presents cost-benefit calculations and Section 7 concludes.

1.1 Related Literature

Our work is related to the large literature that exploits property prices to infer the benefits from policies improving local amenities, such as pollution abatement and air quality (Chay and Greenstone, 2005; Greenstone and Gallagher, 2008; Currie et al., 2015; Keiser and Shapiro, 2019), school quality (Black, 1999; Cellini et al., 2010), and investment in transportation infrastructure (Gupta et al., 2022b; Tsivanidis, 2018; Severen, 2019). Our paper is one of the first to study the capitalization of a large public investment in climate change adaptation to mitigate the damages from flooding and sea level rise.

Hence, our paper contributes to the growing literature on mitigation and adaptation policies in relation to climate change (Barreca et al., 2016; Hsiang, 2016; Partridge et al., 2017; Balboni, 2019; Hong et al., 2023; Dechezleprêtre et al., 2022; Kocornik-Mina et al., 2020; Desmet et al., 2021; Fried, 2021; Carleton et al., 2022; Hsiao, 2022; Boomhower, 2023; Baylis and Boomhower, 2024). Our work is most closely related to recent papers studying damages and housing prices following the implementation of resilience infrastructure projects, such as dunes (Dundas, 2017),

[9] For a summary of the debate see Giglio et al. (2021) and Carleton and Greenstone (2022), among others. The decision in April 2023 by the US Office of Management and Budget's (OMB's) to reduce the risk-adjusted discount rate for public projects from 3% or 7% to 1.7% fueled the debate even further.

dams (Gandhi et al., 2022), levies (Bradt and Aldy, 2023), and a mix of them (Kelly and Molina, 2023).[10]

We complement these works by exploiting granular high-frequency listing data on both residential and commercial properties and quasi-experimental variation from an unexpected adaptation shock. Furthermore, we combine our capitalization results with proxies for damages, by studying claims for government funds after an extreme flood. The comparison indicates that capitalized benefits likely represent a lower bound on the sea wall's gain and broadly highlights how government ex-post interventions can impact the capitalization of ex-ante investments in adaptation.

Finally, our paper contributes to the growing empirical literature on the effect of climate change and environmental risk on the housing market. A key identification challenge is that housing is a unique combination of location and structure (Murfin and Spiegel, 2020; Giglio et al., 2021). Cross-sectional analyses then struggle to identify causal effects, given the difficulties in controlling for all price-relevant characteristics that might also be correlated with current or future flood risk. Indeed, a survey of existing evidence by Beltrán et al. (2018) shows huge heterogeneity in price effects. To address this identification issue, some papers have focused on the response of house prices to *flood events*, such as the Hurricane Katrina in New Orleans or Hurricane Sandy in New York, with mixed results (Vigdor, 2008; Ortega and Taspinar, 2018; Addoum et al., 2024). Other recent works have instead combined cross-sectional variation in exposure with time-series variation in attention and households belief about climate change, to study the capitalization of *future flood risk* through sea level rise in housing values (Bernstein et al., 2019; Baldauf et al., 2020; Keys and Mulder, 2020; Giglio et al., 2021; Bakkensen and Barrage, 2022; Bakkensen et al., 2023).

We contribute to this growing literature in two ways. First, we combine cross-sectional variation in properties exposed to high tides with time-series variation from an event study that only changes flood risk.[11] Second, all the aforementioned papers study an *increase* in actual or expected risk of flooding. Our work provides a new angle by studying the effect on property values of an actual large flood and a *decrease* in flood risk, because of infrastructure investment. Thus, our results

[10] In Kelly and Molina (2023) infrastructure projects include drainage, pumping stations, reservoirs, seawalls, road elevation, shoreline stabilization. In the wildfire adaptation literature, Baylis and Boomhower (2024) quantify the benefits of California's mandated wildfire building codes, highlighting reduced risk of structural loss for homeowners and positive spillovers to neighboring properties.

[11] As we mentioned above, one additional advantage of our setting is that information frictions are unlikely to be a concern, given the centuries-long experience of Venice with floods.

provide an additional explanation for the wide range of estimates of capitalization of future flood risk in house prices: unobserved differences in adaptation investments.

2 Setting

2.1 High Tides and Flooding in Venice

The city of Venice has been exposed to sea level changes since its foundation. The city is built on 118 small islands that are separated by canals and linked by over 400 bridges. The city is often threatened by high flood tides coming from the Adriatic Sea and these events have become more frequent and extreme in recent years, as a result of both sea level rise and subsidence of the surface of Venice (Lionello et al., 2021).

The left panel of Figure 2 shows that the high-tides phenomenon occurs several times a year and has been part of the city's history for centuries. The red bars show the number of high tides (defined as a tide greater or equal to 110 cm or approximately 3.6 feet) since the end of the 19th century. Up until the 1950s high tides in Venice happened on average every two years, while low tides were more frequent, occurring three times per year. The situation has reversed since then. In the second half of the 20th century, Venice has experienced on average three high-tide events per year, while low tides have almost disappeared (only two low tides have been recorded in 1989). The first twenty years of the 21st century have been even more dramatic, with an average number of high tides per year fluctuating around nine.

The right panel of Figure 2 reports the maximum level of high tides registered in each year since 1870. Not only the number of high tides but also their level has increased over time. Tides higher than 150 cm were unheard of before 1950, while the first twenty years of the 21st century have already witnessed three of them. Of the 17 years with tides higher than 140 cm, nine are in the 21st century (Ferrarin et al., 2022).[12]

The high-tide phenomenon has material implications for Venice. When the sea level is at 110 cm, about 12% of Venice is flooded, while tides reaching 140 cm cause 60% of the city to go underwater. On November 12th 2019 the sea level reached almost 190 cm, which is the second highest level ever

[12]Panel (a) of Figure A1 shows the maximum tide for each day in 1924 – the first year for which we have daily data on tide level – and 2019 – the last year before the activation of the sea wall. In 95% of the days of the year the maximum tide was higher in 2019 than in 1924, with an average difference of 33 cm or about one foot.

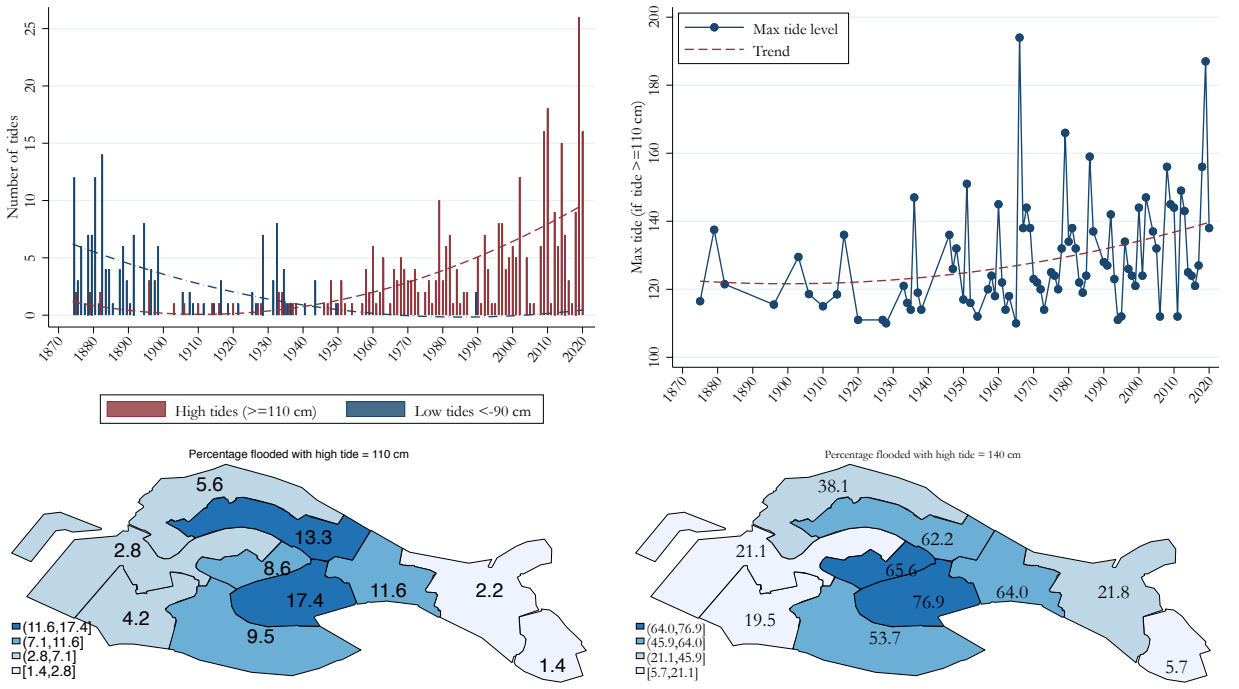


Figure 2: High Tides and Flooding in Venice

Note: The top left figure shows the number of high and low tides since 1870. High tides are defined as episodes in which the tide reaches levels greater or equal than 110 cm; low tides are defined as episodes in which the tide is lower than -90 cm. The top right figure shows the maximum level of high tides registered in each year since 1870 and a quadratic trend. The bottom figures show the fraction of different areas of Venice that are flooded for sea levels equal to 110 cm and equal to 140 cm.

recorded in the history of Venice, causing about 90% of the city center to be flooded.[13] The bottom panels of Figure 2 shows significant heterogeneity in flooding across different areas of Venice for two different levels of high tides.[14] For example, the San Marco area is about 17% flooded with a high tide of 110 cm and almost 80% with a high tide of 140 cm, while Castello – to the far right – is barely affected by a high tide of 110 cm, and is about 6% flooded when the tide reaches 140 cm.

High tides and associated floods impose a substantial burden on Venice, affecting everyday life (e.g., schools opening), economic activity (e.g., tourism) and damaging the stock of capital and housing. The burden of reparations falls on residents (and potentially the government) as private insurers refuse to write policies on homes that have an extremely high likelihood of claiming damages every year. The increasing frequency and size of recent high tides is going to make these costs higher

[13] The highest level ever recorded was 194 cm in 1966 (See: https://www.comune.venezia.it/it/content/le-acque-alte-eccezionali).

[14] Figure A3 in the Appendix shows the names and areas of the different neighborhoods in Venice main island. Panel (b) of Figure A1 shows flooding based on elevation level.

for residents and the government, in line with the recent trend observed for other environmental risks in other parts of the world.[15]

2.2 The Venice Sea Wall

Since the extreme high tides of 1966, the city of Venice has invested in adaptation strategies to cope with the increasing frequency and level of high tides. The major step in this direction has been the construction of a sea wall called MOSE (Modulo Sperimentale Elettromeccanico - Experimental Electromechanical Module) to protect Venice from flooding.

Discussions about a sea wall date back to the Eighties, but a public announcement was made only in 1992 and construction work began in 2003, with an estimated completion date of 2011. The project experienced delays and a huge political scandal in 2014 which pushed the completion date beyond 2021 and costs up to €6.4 billion, plus an estimated €10 million in annual maintenance and operating costs. Despite the long history of the project, its first successful activation on October 3rd, 2020 has been an unexpected surprise for the city and its inhabitants.[16] Important reasons behind the uncertainty about the effectiveness of the sea wall were its innovative approach and repeated delays in the construction process.

The Venice sea wall is a system of four mobile barriers composed of 78 gates located in three inlets into the Venice lagoon.[17] In normal times, the barriers are not visible because they are submerged on the seafloor. When high tides are expected, the gates are temporarily raised and block the tide. The decision to raise the barriers is taken when the sea level in Venice is expected to exceed a given threshold, established at 110 cm for a fully operational sea wall.[18] This infrastructure is different from a classic Dutch sea wall, which could have done permanent damage to the lagoon ecosystem and impaired the activity of the port of Venice. Furthermore, on October 3, 2020 the sea wall was still under construction and it was never tested before during a high tide episode. The

[15] For example, Issler et al. (2020) show that while insurance companies have been able to absorb fire losses in California, the increasing frequency and size of recent events cast doubt on their ability to continue to provide such protection.

[16] We present our evidence of an unexpected shock when discussing our empirical strategy in Section 4.

[17] The left panel of Figure A6 in the Appendix shows the location of the barriers at the three inlets relative to the city of Venice.

[18] Though still in an experimental phase – where the activation threshold could have been higher, at 130 cm – the *de facto* threshold has always been 110 cm. Detailed data on sea levels measured at different points indeed reveal that since the end of 2020 the barriers have been raised when the measured tide in the open sea was often below or very close to 110 cm.

sea wall has been activated almost 50 times within three years after the inaugural raising of the floodgates, preventing high tides from flooding the city of Venice.

3 Data and Framework

3.1 Sources and Summary Statistics

We combine several data sources for our analysis. Our primary data are from the largest online portal for real estate services in Italy: https://www.immobiliare.it/. We have weekly snapshots of all ads visible on the website every Monday for the municipality of Venice. From the snapshot, we observe detailed information about the physical characteristics, the location, and the asking price of a dwelling. We also know the date when the seller created and removed the ad. In Appendix B we report the list of all the dwelling characteristics we observe and additional details on the steps we take to construct our final dataset. An important caveat is that we do not observe the final transaction prices for each sold dwelling. However, we collected additional information on average transaction prices from the Italian tax office and we find a 0.99 correlation between asking and transaction prices, consistent with previous evidence (Loberto et al., 2022).[19]

We combine our main dataset with two additional sources. First, we exploit the coordinates of the dwelling to infer the elevation of the property. We obtain access to a database created by the city of Venice in collaboration with a private company, which contains a three-dimensional representation of the historic city center paving with centimeter accuracy. We then match this highly-detailed information on altimetry of the paving to each property in our main dataset located in the historical city center of Venice. Second, we obtain information on the frequency and level of high tides as well as on the activation of the sea wall from the historical archive of the city of Venice.

The dataset is a panel of housing ads from 2018 to 2022. Table 1 shows the summary statistics for the main variables in our database at the monthly level. The average residential property price is €558 thousands, and there is a lot of heterogeneity across properties whose value range from €20 thousands to €6.5 millions. The average price per square meter is slightly above €5,000, again

[19] Figure A8 in the Appendix shows that average transaction and listing prices for different areas are close to the 45 degree line.

Table 1: Summary Statistics

	Observations	Mean	Std. Dev.	Minimum	Median	Maximum
Panel A: Property characteristics						
Price (€.000)	47,688	558.65	408.82	20.00	450.00	6,500.00
Price (€/m2)	47,688	5,013.57	1,494.93	571.43	4,800.00	14,444.44
Floor area (m2)	47,688	112.46	67.67	30.00	95.00	570.00
Ground floor (dummy)	47,688	0.09	0.29	0.00	0.00	1.00
Single family (dummy)	47,688	0.05	0.22	0.00	0.00	1.00
Flat (dummy)	47,688	0.95	0.22	0.00	1.00	1.00
Need renovation (dummy)	47,688	0.12	0.33	0.00	0.00	1.00
Good status (dummy)	47,688	0.33	0.47	0.00	0.00	1.00
Very good status (dummy)	47,688	0.49	0.50	0.00	0.00	1.00
New property (dummy)	47,688	0.03	0.17	0.00	0.00	1.00
Elevator (dummy)	47,688	0.10	0.30	0.00	0.00	1.00
No garage (dummy)	47,688	0.99	0.08	0.00	1.00	1.00
No garden (dummy)	47,688	0.80	0.40	0.00	1.00	1.00
Elevation (cm)	38,853	131.01	25.56	80.31	124.83	285.30
Flood probability (%)	38,853	0.45	0.81	0.00	0.19	10.18
Panel B: Tide and sea wall variables						
Max tide Venice (cm)	48	100.50	21.24	72.00	94.00	187.00
High tides Venice (number)	48	0.77	2.25	0.00	0.00	13.00
Sea wall activation (number)	60	0.57	2.09	0.00	0.00	13.00

Note: The Table shows the main variable in our analysis. Price is the listing price of the property in thousand €and €/m2. Elevation is the level of historic city center paving of the street or square where the property is located. Flood probability is the daily probability that the building is flooded based on the elevation and the daily level of tides since 1923. Climate attention is a dummy equal to one if the property description mentions flooding, high tide or the sea wall. Max tide is the highest tide recorded in Venice in each month. High tides is the number of high tides ($\geq$ 110 cm) recorded in Venice in each month. Sea wall activation is the number of times each month the sea wall has been operated.

with a wide range of variation from a minimum of about 570€/m2 to a maximum of 14,000€/m2. The average floor area is approximately 110 square meters. About 9% of properties in our data are ground floors. The vast majority (95%) are flats, and most properties are in good (33%) or very good (49%) conditions. Only 3% are new properties and 12% needs renovation.[20] The vast majority of properties have no garage (99%) or garden (80%), while about 10% are in buildings with an elevator.[21]

The average elevation of properties relative to the reference point is about 130 cm, with a wide range of variation.[22] The lowest elevation is just above 80 cm, while the highest reaches almost

[20] Complete renovations are classified as new properties. The 3% of properties classified as new likely capture complete renovations, rather than new construction on previously undeveloped land.

[21] In the final sample used in the regressions, we remove listings with extreme values for price per square meter (those below the 2.5 percentile or above the 97.5 percentile). More details are available in Appendix B.

[22] Since 1897 the measurement of the sea level and paving elevation is relative to the zero tide of Punta della

290 cm. Historical sea level data indicates varying flood probabilities based on these properties elevations. The average daily flood probability for houses in our sample is about 0.5%. However, some properties are never flooded while some properties have a daily flood probability of more than 15%.

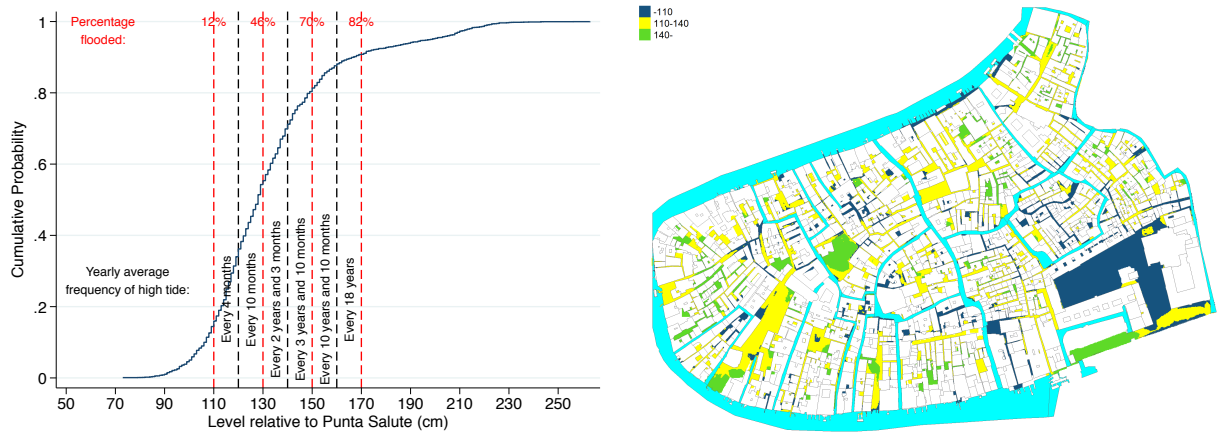
Panel B of Table 1 reports the main variables from the historical archive of the city of Venice. The average maximum tide across months in Venice during our sample period was 100 cm, ranging from a low of about 70 cm to a high of almost 190 cm. The average number of tides per month greater than 110 cm was about 0.7. Most months experience no high tides, but some months have more than ten high tides. The sea level has a strong seasonal component and high tides tend to hit Venice in the Winter season from October to March. We also report the average number of times per month the sea wall has been activated. Most months the sea wall is not active because either the sea level is low or the months are in the pre-activation period. Some months experience several activations of the sea wall. For example, in December 2020 the sea wall was raised 13 times.

3.2 Descriptive Evidence

Do house prices in Venice reflect high tide risk? We begin by investigating the relation between flood risk and house prices using variation across properties based on their elevation and floor. Panel (a) of Figure 3 shows the cumulative distribution of houses in the city center of Venice based on their elevation relative to the reference point. We also report the yearly average frequency of high tide based on historical estimates from 1924 to today. About 18% of properties have an elevation below 110 cm, which leads to frequent flooding each year. The majority of properties have an elevation between 110 cm and 140 cm, and are flooded from three times a year to once every two years. Finally, the remaining 30% of properties are located at 140 cm or above the reference level and experience flooding only every four years or more. Panel (b) of Figure 3 shows large variation in elevation, going from less than 110 cm to more than 140 cm, even within a narrowly defined neighbourhood.

We study the relationship between flood risk and house prices per square meter using the variation in Figure 3 and controlling for other determinants of house prices. Table A1 in the Appendix shows the estimates in the year before the activation of the sea wall. Given the limited

Salute. Figure A7 in the Appendix shows the location of houses in our dataset in Venice main island.



(a) Properties across elevation (b) Elevation in San Marco Neighbourhood

Figure 3: Distribution of properties across elevation levels

Note: Panel (a) shows the cumulative distribution of houses in our dataset based on their elevation relative to the reference point of Punta della Salute. We also report the yearly average frequency of high tide based on historical estimates from 1924 to today. Panel (b) shows the elevation of streets and squares in the San Marco neighbourhood.

time-variation, these estimates may be affected by the well-known misspecification issues in cross-sectional studies and we do not argue they have a causal interpretation. Yet, they can provide useful guidance on the extent flood risk affected house prices before the activation of the sea wall. We find that: (i) a higher flood probability is associated with lower house prices; (ii) properties on the ground floor have significantly lower asking prices; and (iii) ground floor properties in areas with a higher flood risk are listed at a *relative* higher discount than ground floor properties in areas with a lower flood risk.

3.3 Framework

We propose a simple framework to look at the effects of the sea wall on property prices through the lens of an asset pricing equation (Poterba, 1984). Assume that a representative household is indifferent between owning and renting a property of type h. We can then write the property sale price in year t ($P_{h,t}$) as the present discounted value of expected future rents $R_{h,t}$ net of maintenance costs $C_{h,t}$:

$$P_{h,t} = \mathbb{E}_t \left[\sum_{j=0}^{\infty} \xi_{h,t+j}^{j} (R_{h,t+j} - C_{h,t+j}) \right], \tag{1}$$

where $\xi_{h,t}$ is the stochastic discount factor of expected future cash flows. Notice that the discount factor depends on the level of the risk-free rate and the risk premium, that in our context is also related to the risk induced by exposure to climate disasters (Dietz et al., 2018; Giglio et al., 2021). For the sake of simplicity, consider the case of constant net cash flows and discount rates. Equation (1) simplifies to:

$$P_{h,t} = \frac{\bar{R}_{h|t} - \bar{C}_{h|t}}{\bar{i}_{h|t}}, \tag{2}$$

where $\bar{R}_{h|t}$, $\bar{C}_{h|t}$, $\bar{i}_{h|t} = 1 - \bar{\xi}_{h|t}$ are expected future values of rents, maintenance costs and interest rates given the available information at time t. Therefore, the price variation induced by the activation of the sea wall for a property of type h can be expressed as:

$$\Delta P_h = \overbrace{\frac{\bar{R}_{h|after} - \bar{C}_{h|after}}{\bar{i}_{h|after}}}^{P_{h,after}} - \overbrace{\frac{\bar{R}_{h|before} - \bar{C}_{h|before}}{\bar{i}_{h|before}}}^{P_{h,before}} = \frac{1}{\bar{i}_{h|before}}\left[\Delta\bar{R}_h - \Delta\bar{C}_h\right] - \frac{\Delta\bar{i}}{\bar{i}_{h|before}} P_{h,after}. \tag{3}$$

Equation (3) shows that the revaluation of property of type h after the activation of the sea wall can be traced back to (a combination of) three factors: (i) higher expected future rents ($\Delta\bar{R}_h > 0$), (ii) lower expected future damages ($\Delta\bar{C}_h < 0$), and (iii) a reduction in the discount factor ($\frac{\Delta\bar{i}}{\bar{i}_{h|t}} < 0$).

Our main analysis in Section 4 will focus on variation in the left side of equation (3), namely property prices, to capture the private benefits from the sea wall that are capitalized. For example, changes in property prices (ΔP_h) capitalize expected changes in repair costs ($\Delta\bar{C}_h$) that are paid directly or indirectly – via higher insurance prices or local taxes – by households. However, changes in property prices after the activation of the sea wall will not incorporate lower bailout costs for a government that is acting as an "insurer of last resort" using national rather than local funding (which is the case in our context). For this reason, we also study separately changes in expected government claims to (partially) cover damages to properties following high tides. We return to the pros and cons of alternative approaches, when comparing the costs and benefits of the sea wall in Section 6.

4 Capitalization Analysis of the Sea Wall

Our empirical strategies to study the capitalization of the sea wall on property prices exploit time-series variation around the first activation of the sea wall, often combined with cross-sectional measures of exposure to this variation. Hence, we begin by discussing several pieces of evidence in favor of a surprise effect coming from the first successful activation of the sea wall on October 3rd 2020.

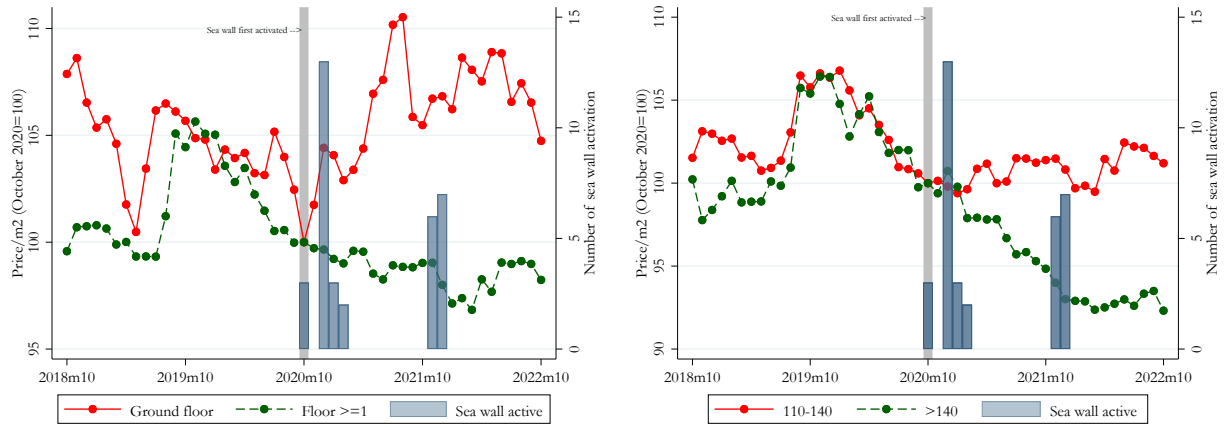
First, Figure 1 shows that attention to flood risk – measured by the fraction of house listings mentioning high-tide and flood risk – was increasing up until October 2020 and has declined since. The increase in attention to flood risk before the first activation is surprising if the sea wall was expected to work in the near future. On the other hand, the increasing pattern before the activation, as well as the stark inversion after, favor an unexpected shock, which caught the population of Venice by surprise, after many years of delayed works and uncertainty on its ability to effectively protect the city.

Second, if the sea wall was expected to be operating in the near future, forward-looking house prices, especially for properties likely to benefit the most, should have reflected it even ahead of the first successful activation. Figure 4 shows that this is unlikely to be the case. Panel (a) shows the average price per square meter in a two-year window around the first activation of the sea wall for ground floor and higher floor properties. Panel (b) repeats the analysis for higher-floor properties only splitting the sample by elevation between 110 and 140 cm vs higher levels. The price is normalized to 100 in October 2020, which is the month when the sea wall was first activated. In both figures the price of properties that likely benefited more from the sea wall – ground floors and properties located at lower elevation – show similar trends to other properties. If the sea wall's activation was anticipated, prices for more exposed properties would have increased ahead of the planned activation. Conversely, the divergence in prices between more and less exposed properties only emerges after the first unexpected successful activation of the sea wall.[23]

Third, the municipality of Venice publishes every day in its website the current level of tides and the forecast for the following day.[24] Figure A4 in the Appendix shows the briefing from the

[23]The declining trend of overall prices in the city center starting around February 2020 is due to the Covid-19 pandemic. A similar decline in house prices in city centers and a parallel increase in prices away from the center has been documented by Gupta et al. (2022a) in the US as a result of the Covid-19 pandemic.

[24]See https://www.comune.venezia.it/it/content/centro-previsioni-e-segnalazioni-maree.



(a) By Floor (b) By Elevation

Figure 4: Prices per m^2 around the first activation of the sea wall

Note: The figure shows the average price per square meter in a four-year window around October 2020, which is the month when the sea wall was first activated. The price is normalized to 100 in October 2020. Panel (a) shows the average prices for ground and upper floor properties. Panel (b) shows the average prices for properties at different elevation levels. The blue vertical bars show the number of times the sea wall has been activated in the respective month.

official municipality of Venice website about the tide level on the day before (October 2nd) and the day of (October 3rd) the first activation of the sea wall. On October 2nd, the expected tide for the following day was 135-140 cm and there was no mention of the sea wall at all. On October 3rd the briefing mentioned the successful activation of the sea wall, which was decided overnight, and a level of the tide in the city center of 70 cm.

Fourth, we look at searches reported in Google Trends focusing on the region of Veneto, where Venice is located, from 2004 to 2024. We search for both high tides ("acqua alta") and sea wall ("Mose"). Figure A5 in the Appendix reports the results. Not surprisingly, we find spikes in Google searches for high tides in months when Venice experienced abnormally high tides, with a peak in the month of November 2019, when Venice experienced its second largest flood in its history. Turning to searches for sea wall, we find that for most of the twenty-year period they are relatively less common than searches for high tides. Notable exceptions are: (i) June 2014, when a major political bribery scandal related to the sea wall became public and lead to the arrest of several politician, including the Venice Major; and (ii) October 2020.[25] Hence, before its unexpectedly successful

[25]For more information on the scandal see https://www.bbc.com/news/world-latin-america-27692334 and https://www.ft.com/content/bb45eac2-f2fb-11e3-85cd-00144feabdc0.

activation in October 2020, the sea wall attracted relatively limited attention, except for negative coverage related to political scandal and long delays.[26]

Overall, our evidence consistently points to the *successful* activation of the sea wall in October 2020 as an unexpected shock. While we cannot explicitly test for an announcement effect since our data do not go back to 1992, we think that anticipation effects during the decade-long construction period, even if present, are likely to be small. The combination of technical novelty, political scandals and long track of delays and unsuccessful activations created lingering uncertainty about the project.[27] Hence, while there was little doubt that eventually the sea wall would have been completed, there was large residual uncertainty over the ability of the sea wall to protect the city until its first successful activation on October 3rd 2020.

4.1 The Effects of the Sea Wall on Residential Properties

4.1.1 Empirical Strategy

Our first identification strategy exploits the first successful activation of the sea wall and its differential effect on ground-floor properties. To isolate the differential effect of the sea wall on ground-floor properties, we estimate the following difference-in-difference specification:

$$y_{ilkt} = \alpha\, Ground\ Floor_i + \beta\, Ground\ Floor_i \times Sea\ Wall_t + \theta X_i + \gamma_{lk} + \gamma_t + \epsilon_{ilkt}, \tag{4}$$

where y_{ilkt} is the (log) house price per square meter for house i in location l of type k in period t; $Ground\ Floor_i$ is a dummy equal to one if property i is on the ground floor; $Sea\ Wall_t$ is a dummy equal to one in all months after October 2020, when the sea wall was first activated; γ_{lk} is an interacted location-type fixed effect; γ_t is a time fixed effect; and ϵ_{ilkt} is an error term capturing unobservable determinants of house prices.[28] We define property type as the interaction of a house

[26] The increase in searches for sea wall in November 2019, while much lower than the increase in searches for high tides, is driven by the lack of a sea wall several years after construction started.

[27] Examples of failed attempts to raise the barriers during the construction process can be found in 2016 (https://www.huffingtonpost.it/archivio/2016/08/23/news/venezia_il_mose_fa_flop_nel_test_di_funzionamento_due_paratoie_non_si_alzano_bloccate_da_sabbia_e_detriti-5756930/) and 2019 (https://www.repubblica.it/cronaca/2019/12/29/news/venezia_mose_in_alto_mare-301066980/).

[28] Location in our setting is a neighborhood, which is based on the urban partition developed by the Italian tax office. The population in a neighborhood in the city of Venice is between about 1,800 and 9,000 people. Thus, a neighborhood in our setting is comparable to a census tract in the US, which generally has 2,500 to 8,000 residents. We discuss the characteristics of neighborhoods in detail in Appendix B.

type (single-family or multi-family) and maintenance status (to be renovated, good conditions, very good conditions, new-built). As additional house characteristics we include floor surface, number of bathrooms, a dummy for garage and garden type, a dummy for the presence of an elevator, and several measures of distance of the property from tourist attractions (San Marco Cathedral, Rialto Bridge, Canal Grande), bridges and public boat stations. The main coefficient of interest is β which captures the differential effect of the sea wall on ground floor properties.

Our second identification strategy exploits variation in prices after the activation of the sea wall across properties based on their elevation relative to the sea level. For this analysis, we focus on apartments on the upper floors, which represent about 90% of observations in our sample of residential properties. We estimate the following difference-in-difference specification:

$$y_{ilkt} = \alpha Low\ Elevation_i + \beta Low\ Elevation_i \times Sea\ Wall_t + \theta X_i + \gamma_{lk} + \gamma_t + \epsilon_{ilkt}, \tag{5}$$

where $Low\ Elevation_i$ is a dummy equal to one if property i has an elevation between 110 and 140 cm and all other variables are as in equation (4). The main coefficient of interest is β which captures the differential effect of the sea wall on lower elevation properties.

In the estimation of equations (4) and (5) we focus on properties with an elevation above 110 cm, which is the level of predicted tide when the sea barriers are activated, as we discussed in Section 2. Properties with lower elevation will also potentially benefit from the activation of the sea wall. On the one hand, properties with elevation level below 110 cm still experience flooding from relatively low tides that do not trigger the sea wall activation. On the other hand, these properties benefit from the sea wall, as they are protected from potentially even more damaging floods from high tides that lead to the sea wall activation. Hence, our estimates could be interpreted as a lower bound on the effect of the sea wall on property values.[29]

Finally, a possible concern when looking at our two approaches jointly, is that some properties that are in the control group when estimating (4), namely higher-floor properties at low elevation, are in the treated group when estimating (5). This could lead to a violation of the Stable Unit Treatment Value Assumption (SUTVA). To address this concern we implement a triple-difference specification by estimating (4) separately for high and and low elevation properties, thus allowing a comparison of the difference-in-difference estimates across ground-floor properties at different ele-

[29] We discuss these issues further in the costs and benefits analysis of Section 6.

vations. Additionally, we explicitly test for potential spillover effects across properties differentially exposed to the sea wall.

4.1.2 Main Results

Table 2 shows the main results. First, columns (1) and (2) report the results using all properties. In line with the results of Table A1 we find evidence of a ground floor discount. Ground floor properties sell at 8% less than comparable houses at higher floors. This ground floor discount could be due to higher risk of flooding as a result of high tide as well as other unobservable factors affecting differentially ground floor properties (such as exposure to sunlight).

Our main coefficient of interest is the interaction term between the ground floor dummy and the post-sea wall dummy. After the activation of the sea wall, we find that ground floor properties in Venice experience an increase in price per square meter of about 350€. The effect is significant and large in magnitude. The results using the log of the price per square meter are similar in magnitude. With the first successful activation of the sea wall, ground floor properties increase their price per square meter by about 7%.

We might expect higher house price gains from the sea wall for ground floor properties in locations more exposed to flood risk. For this reason, columns (3)-(4) and (5)-(6) of Table 2 report the estimates of equation (4) splitting the data for properties below and above an elevation of 140 cm relative to the reference point. First, we find that the ground-floor discount is statistically significant and larger in magnitude at lower elevation, which increases the exposure to high tides. Second, and most importantly, we find that the gains in ground floor property prices following the activation of the sea wall are driven by properties with lower elevation, which appreciate by 9%.[30] The differential effect of the sea wall on ground floor properties located in high-elevation areas of the city is never significant and small in magnitude.

Finally, columns (7) and (8) of Table 2 show the main results for higher floor properties at different elevation levels. The activation of the sea wall led to an increase in the price of properties

[30] One potential concern is that ground floor dwellings might have been exposed to more investment than higher floors, following the floods – and associated damages – in November 2019. In the estimation we control for the maintenance status of the property which captures renovation work that has been done to the property before listing. We also estimate specification (4) separately for properties in good conditions and properties in very good conditions (i.e. recently renovated) and find similar effects in magnitude for both groups. If anything, we find slightly more significant and larger estimates for non-renovated properties in good conditions, but this additional sample split lowers further our statistical power. The results are available upon request.

Table 2: Effects of the sea wall on residential properties

	All properties		Elevation<=140		Elevation>140		Higher floors	
	(1) Level	(2) Log	(3) Level	(4) Log	(5) Level	(6) Log	(7) Level	(8) Log
Ground floor	-344.16***	-0.08***	-471.90***	-0.11***	-210.48	-0.04		
	(126.98)	(0.03)	(135.10)	(0.03)	(161.36)	(0.03)		
Ground floor × Sea wall	349.61**	0.07**	501.10**	0.09**	30.14	0.00		
	(136.01)	(0.03)	(196.72)	(0.04)	(113.54)	(0.02)		
Elevation: 110-140							-39.12	-0.01
							(87.96)	(0.02)
Elevation: 110-140 × Sea wall							198.83***	0.04***
							(71.72)	(0.01)
FE location-type	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
FE year-month	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Controls	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Mean Y	4870.08	8.46	4956.72	8.48	4693.87	8.43	4949.46	8.48
SD Y	1151.53	0.23	1181.75	0.24	1065.73	0.22	1139.64	0.23
R2	0.34	0.35	0.34	0.36	0.42	0.44	0.33	0.34
Obs.	26342	26342	17670	17670	8670	8670	21290	21290

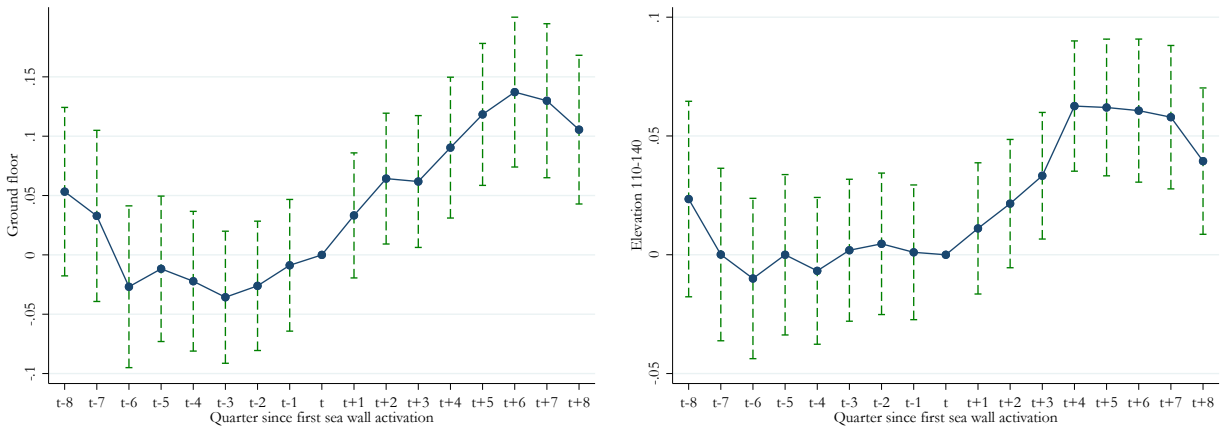
Note: The Table shows the estimates from equations (4) and (5) for the period October 2018 - December 2022. In columns (1), (3), (5) and (7) the dependent variable is the asking price in euro per square meter; in columns (2), (4), (6) and (8) the dependent variable is the log of the asking price in euro per square meter. Ground floor is a dummy equal to one for properties located on the ground floor. Sea wall is a dummy equal to one in all months after October 2020, when the sea wall was first activated. Location-type fixed effects are interacted fixed effect for location and property type. Controls include floor surface, number of bathrooms, a dummy for garage and garden type, a dummy for the presence of an elevator, and several measures of distance of the property from tourist attractions (San Marco Cathedral, Rialto Bridge, Canal Grande), bridges and public boat stations. Standard errors are double clustered at the location-type and year-month level. *, **, and *** denote significance at the 10%, 5% and 1% levels, respectively.

with an elevation between 110 and 140 cm, relative to those at higher elevation levels. The effect is statistically significant and large in magnitude. After the activation of the sea wall, the price per square meter of low-elevation properties increases by almost €200, or 4% relative to the average price per square meter. The results using the log of the price per square meter are also significant and similar in magnitude.

4.1.3 Additional Analyses and Robustness

We now briefly discuss the results of several additional heterogeneity and robustness analyses related to our main results in Table 2. We present a more detailed discussion in Appendix C.

Parallel trends. One possible concern with the results in Table 2 is that prices for ground floor properties or lower elevation properties were already behaving differently before the activation of the sea wall. We estimate a version of equations (4) and (5) in which we interact the dummy



(a) Across Floors (b) Across Elevation

Figure 5: Parallel Trends

Note: Panel (a) shows the coefficients on the interaction terms between ground floor and quarter for properties with an elevation up to 140 cm relative to the reference point. The estimated coefficients are based on equation (4) replacing the interaction term between ground floor and sea wall with interaction dummies of ground floors with time for quarters before and after the quarter of the first activation of the sea wall. Panel (b) shows the coefficients on the interaction terms between elevation 110-140 cm and quarter. The estimated coefficients are based on equations (5) replacing the interaction term between elevation 110-140 cm and sea wall with interaction dummies of elevation 110-140 cm with time for quarter before and after the quarter of the first activation of the sea wall. The vertical bars are 95% confidence intervals.

for exposure (ground floors and low elevation) with time dummies for quarters before and after the quarter of the first activation of the sea wall.

Panel (a) of Figure 5 shows the coefficients on the interaction term between ground floor and quarter for properties with low elevation, while Panel (b) of Figure C2 shows the coefficients on the interaction term between elevation 110-140 cm and quarter for higher-floor properties. The interaction terms are not significant and close to zero in the periods before the activation of the sea wall for all properties, consistent with the parallel trend assumption. After the activation of the sea wall: (i) the price of ground floor properties with low elevation shows an increasing trend over time; and (ii) higher floors properties with low elevation (110-140 cm) experience a significant increase in prices per square meter.[31]

Elevation bins. We also estimate a version of equation (5) with 10 cm-bins for elevation levels. Panel (b) of Figure C2 reports the coefficients on the interactions of elevation bins with the post sea wall period. Relative to properties with an elevation higher than 150 cm, houses with an elevation

[31] Panel (a) of Figure C2 shows that none of the interaction terms is significant for ground-floor properties in high elevation areas.

120-130 cm experience the largest increase in prices per square meter, followed by properties with an elevation 130-140 cm and 110-120 cm. The relatively lower – even if not statistically different – increase of the properties with an elevation 110-120 cm could be the result of uncertainty on the activation threshold of the sea wall, which may leave properties with lower elevation levels still exposed to flooding. Properties with elevation 140-150 cm do not experience a differential increase after the activation of the sea wall relative to properties with elevation higher than 150 cm, consistent with lower benefits from the sea wall for properties located at higher elevation levels.

Placebo sea wall. We estimate a version of equations (4) and (5) in which we interact the exposure dummies with a dummy equal to one for all months after October 2019, which is one year *before* the sea wall was first activated. We restrict our sample to a one-year interval around October 2019 to avoid including periods after the first activation of the sea wall. If the effect of the sea wall we identify in Table 2 is due to some differential behavior of ground floor properties in certain parts of the year or to some longer-term trend rather than the sea wall itself, we may find similar effects the year before the sea wall was truly activated for the first time. Table C1 in the Appendix shows the results. We do not find any significant effect from the placebo sea wall, confirming that the main results in Table 2 are driven by the sea wall activation rather than seasonal or anticipation effects.

Rent prices. We exploit information from the same data provider on rent prices per square meter and estimate equations (4) and (5) using now rent prices as dependent variable. Table C2 in the Appendix shows the results. We find that after the activation of the sea wall rent prices of ground floor properties do not increase relative to higher floor properties. The estimates are more noisy, since only a few properties on the ground floor are rented, which limits the power of our analysis. When we look at higher floors and exploit variation based on elevation we find that after the activation of the sea wall rent prices of low-elevation properties increase by about 6% relative to rents of higher-elevation properties. This effect is consistent with renters benefiting from less flooding in the area where they live, which can impair the quality of living in an area.

Selection. A potential concern to our identification approach is that the pool of properties is changing after the activation of the sea wall in a way that is correlated with our exposure measures (common changes are absorbed by the time fixed effects). Despite our very rich set of controls and

neighborhood-property type fixed effect, the difference-in-difference estimate could then confound the price effect of the sea wall activation with omitted time-varying property characteristics. To lower this concern we study if property characteristics change as a result of the activation of the sea wall. Table C3 in the Appendix shows the results. We cannot reject the null hypothesis that properties after the activation of the sea wall are similar to before in terms of fraction of ground floors, maintenance status and size.

Spillovers. One possible concern for the interpretation of our results is that the value of the properties included in the control group of our specifications (4) and (5) is negatively affected by the appreciation of ground floor and low-elevation properties. This could happen in an equilibrium framework if the housing demand for the center of Venice was fixed and the activation of the sea wall triggered a relocation from treated to control properties. To mitigate this concern we assess the strength of spillovers by conducting a "leave-out-mean" exercise in the spirit of Huber (2022). We estimate how the price of the properties included in the control groups changed after the activation of the sea wall depending on the amount of competition they face from similar properties who benefited more from the sea wall.[32] Table C4 shows the results. We could not detect any significant spillover, suggesting that displacement of demand from the control to the treated group is unlikely to affect our estimates. In line with our framework summarized by equation (3), the differential appreciation of treated properties can be explained by differential changes in risk and expected damages (with associated maintenance costs), even holding overall housing demand for Venice fixed.

4.2 The Effects of the Sea Wall on Commercial Properties

4.2.1 Empirical Strategy

Our main analysis is based on detailed data about residential properties. However, it is likely that commercial properties also benefited from the activation of the sea wall. One possible approach

[32]For any property in our control groups, we compute the number of comparable properties, defined as the properties similar in size (±15%) located in the same neighborhood that were put on sale in the two years before the activation of the sea wall and that would have been included in the treatment group if they were posted on the website after October 2020. We prefer to define a set of "would-be-treated" properties instead of focusing on the properties that were actually treated to avoid any possible confounding effect stemming from the potential endogenous response of the supply of houses on sale. The results, however, hold also when including the properties that were actually treated.

to capture the gains for commercial properties could be to use our estimates for ground-floor residential properties in Table 2, since commercial properties like restaurants and shops are likely on the ground floor of buildings in Venice. This approach, however, could underestimate the benefit for commercial properties for at least two reasons. First, high tides can damage the furniture and merchandise of commercial activities, whose reparation and replacement cost is potentially higher than the corresponding one for ground floor of residential properties. Second, high tides can impair tourist flows, thus affecting revenue generation for commercial properties.

To provide a more thorough analysis of the effect of the sea wall on commercial properties, we exploit the variation in listing prices for commercial properties after the first activation of the sea wall. Most notably, we estimate the following event-study specification:

$$y_{ilkt} = \alpha Sea\ \ Wall_t + \beta_1 Covid_t + \beta_2 Reopening_t + \theta X_i + \gamma_{lk} + \epsilon_{ikt} \tag{6}$$

where y_{ilkt} is the (log) asking price per square meter of commercial property i located in area l of type k in period t; $Sea\ \ Wall_t$ is a dummy equal to one in all months after October 2020, when the sea wall was first activated; $Covid_t$ is a dummy equal to one in March-May 2020 to capture the effect of Covid-19 shutdown; $Reopening_t$ is a dummy equal to one in June-August 2020 to control for the reopening of the economy after the lockdown; X_i are commercial properties characteristics; and γ_{lk} are location-type interacted fixed effects. Commercial property types are hotel, bar, shop, office and storage. As additional commercial property characteristics we include the floor area, and a series of dummy variables capturing the presence of shop windows, heating or air conditioning, prestigious type of ceiling ("travi"), garden, septic tank, flue and commercial license; we further include a dummy variable that takes value of one if the ad content mentions that the property is usually protected from high tide. The coefficient of interest is α, which captures the effect of the sea wall on commercial properties.

The main difference of the empirical specification (6) relative to our identification strategy for residential properties (given by equations (4) and (5)) is the lack of cross-sectional identifying variation for commercial properties. First, as mentioned above, commercial properties are disproportionately more on ground floors, which prevents us from exploiting variation across floors.[33]

[33] In our dataset more than 80% of commercial ads do not contain information on the floor; among the remaining ads, 86% are located entirely on the ground or mezzanine floor.

Second, the differential effect across elevation levels might be less strong for commercial properties because: (i) the vast majority is located in low elevation areas (below 140 cm); and (ii) they benefit more from tourist flows. Third, only a few transactions of commercial properties take place in our event window, giving us limited power when using cross-sectional variation. Since we only exploit time-series variation, we also control for the Covid-19 shock and subsequent rebound, whose large impact on tourism could be reflected in commercial property prices.

4.2.2 Results

Table 3 reports the results. Columns (1)-(4) report the results for all commercial properties. We find that after the activation of the sea wall commercial properties experience an increase in their price per square meter by about 14% relative to before. The effect is very similar in magnitude once we include our rich set of controls for commercial properties.[34] Columns (5)-(8) focus on our largest category of commercial properties: shops. We find that shops within the same location experience an increase in their price per square meter by about 24% after the activation of the sea wall. The magnitudes are almost unaffected when adding commercial property characteristics, suggesting that the effects are not driven by higher quality of the properties on sale over time.

Overall, we find that after the activation of the sea wall commercial properties experience an increase in prices that is statistically significant and large in magnitude. The increase in prices for commercial properties is even larger than the one for ground-floor residential properties in Table 2. While a comparison of the effects is complicated by the different identification strategies, a larger appreciation for commercial properties following the activation of the sea wall is consistent with commercial property prices incorporating the benefits of lower direct damages from flooding - similar to residential properties and especially ground floors - as well as additional benefits from less damages to the merchandise - especially for shops – and an increase in tourist demand.

To provide a validation of our empirical results on commercial properties we exploit historical variation in high tides and estimate their impact on tourist flows. Tourist revenues can proxy for the temporary loss of economic activity in a city where tourism plays a vital role[35] Appendix D

[34] When examining price levels, the impact of the sea wall is also significant and larger in magnitude. However, given the high standard deviation of price levels, in what follows we prefer to be conservative and consider the estimates based on log prices.

[35] In 2019 approximately 6 million tourists visited Venice generating revenues in the order of €1.6 billion.

Table 3: Effect of sea wall on commercial properties

	All properties				Shops only			
	(1) Level	(2) Log	(3) Level	(4) Log	(5) Level	(6) Log	(7) Level	(8) Log
Sea Wall	2045.11**	0.12**	2265.68**	0.14**	3408.28**	0.23**	3533.07**	0.24**
	(856.21)	(0.06)	(905.95)	(0.06)	(1369.20)	(0.10)	(1415.21)	(0.10)
Covid (March-May 2020)	-1358.32	-0.21	-851.14	-0.15	-1986.71	-0.32	-1794.50	-0.34
	(900.87)	(0.14)	(966.33)	(0.14)	(1531.94)	(0.23)	(1606.36)	(0.22)
Covid (June-August 2020)	-1768.17**	-0.18	-1365.31	-0.14	-3757.48***	-0.38**	-3435.36**	-0.35*
	(886.46)	(0.11)	(938.57)	(0.11)	(1420.77)	(0.17)	(1584.27)	(0.19)
FE location-type	Yes	Yes	Yes	Yes	No	No	No	No
FE location	No	No	No	No	Yes	Yes	Yes	Yes
Controls	No	No	Yes	Yes	No	No	Yes	Yes
Mean Y	7779.02	8.53	7779.02	8.53	10477.83	8.81	10477.83	8.81
SD Y	12388.04	0.87	12388.04	0.87	15663.01	0.93	15663.01	0.93
R2	0.21	0.32	0.22	0.33	0.16	0.13	0.16	0.16
Obs.	992	992	992	992	569	569	569	569

Note: The Table shows the estimates from equation (6) for the period June 2018 - December 2022. In columns (1), (3), (5) and (7) the dependent variable is the asking price in euro per square meter; in columns (2), (4), (6) and (8) the dependent variable is the log of the asking price in euro per square meter. Sea wall is a dummy equal to one in all months after October 2020, when the sea wall was first activated. Location-type fixed effects are interacted fixed effect for location and property type. *, **, and *** denote significance at the 10%, 5% and 1% levels, respectively.

shows the results which we only briefly discuss here. We find that high tides discourage tourist flows in the following days, reducing the number of tourist nights by about 5%. Using external estimates of the average expenditure by tourist in Venice, we perform a back-of-the-envelope calculation of the additional revenues that may be generated annually by the sea wall via increased tourist flows, which amount to about €29 millions. Discounting these gains at a rate of about 5.5% we obtain a number which is on the same order of magnitude of the capitalized gains using our empirical estimates from Table 3.

4.3 Capitalization of the Sea Wall in Property Values

We conclude this Section combining the empirical estimates for residential and commercial properties to compute the overall gain from the sea wall on the stock of properties in Venice. We implement several steps to quantify valuation gains and how they are distributed across property types and locations.

First, we obtain from census data the overall residential areas in the city of Venice and define six categories based on three elevation levels (<110, 110-140, >140 cm) and two floor groups (ground

floor vs higher floors).[36] The overall area of shops located in the historical city center is taken from the municipality of Venice.[37] Panel A of Table 4 reports some descriptive statistics: the total residential area is about 3.3 millions of square meters, with residential areas with an elevation between 110 cm and 140 cm accounting for almost 60% of the total, consistent with the distribution of properties in our listing data from Figure 3. Residential areas below 110 cm and above 140 cm account for 15% and 25% of the total respectively. For commercial properties we assume they all belong to the ground floor. The overall commercial area amounts to about 139 thousand square meters.

Second, Panel B of Table 4 shows the average price per square meter from our listing dataset.[38] The average price per square meter for ground floor is 4.6 thousands €/m2, while the average price per square meter for higher floors is 4.9 thousands €/m2. Ground floor properties have an average unconditional discount of about 6% relative to higher floors properties, which is in line with our results in Section 3. The most expensive properties per square meter are higher floor in low elevation areas reaching 5 thousands €/m2, while the least expensive are ground floor in high elevation areas at about 4.4 thousands €/m2.[39] In line with the valuations provided by the Tax Revenue Agency, commercial property prices are more than two times higher than comparable residential properties: in our data the average shop price stands at 10.6 thousands €/m2.

Third, we compute the percentage gain from the sea wall, combining the estimates from Tables 2 and 3. For example, Panel C of Table 4 shows that the largest gain among residential properties, equal to 13%, comes from ground floor properties with an elevation between 110 cm and 140 cm.[40]

Fourth, we multiply the average area in square meters by the average price per square meter and

[36] The census data do not distinguish between ground and higher floors, so we use the proportion in our listing dataset and attribute 9% of residential area to the ground floor.

[37] See the website `https://dati.venezia.it/?q=node/306`.

[38] As discussed in Section 3, the correlation between the local-level average listing prices and the local-level average transaction prices from the Italian tax office is 0.99 and Figure A8 in the Appendix shows that average transaction and listing prices for different areas are close to the 45 degree line. We also replicate the same calculation behind Table 4 using the local-level average transaction prices from the Italian tax office and obtain remarkably similar results.

[39] The monotonically decreasing *unconditional* price per square meter with elevation is the result of low elevation areas being closer to attractive and expensive locations, such as the San Marco square and the Rialto bridge. Once we control for location fixed effects and distance from San Marco and the main bridges, the relation between elevation and price per square meter becomes monotonically increasing, as we show in Table A1.

[40] The total gain combines the 9% differential increase for ground floor properties with the 4% increase for upper-floor properties with an elevation between 110 cm and 140 cm – columns (4) and (8) of Table 2, respectively. We assume there is no gain for all properties with an elevation below 110 cm and discuss below the implications for our estimates.

Table 4: Capitalization of sea wall in property values

	Residential properties				Commercial properties	
	<110	110-140	>140	Total	All properties	Shops only
			Panel A: area (m2 thousands)			
Ground floors	50.9	188.1	84.8	323.8	471.2	138.8
Upper floors	464.1	1726.8	750.8	2941.7		
Total	515.0	1915.0	835.6	3265.5	471.2	138.8
			Panel B: avg. price (€/ m2)			
Ground floors	4725	4588	4471	4595	7667	10652
Upper floors	5054	4958	4671	4894		
Average	4890	4773	4571	4744	7767	10652
			Panel C: gain from sea wall (%)			
Ground floors	.	13%	0		15%	25%
Upper floors	.	4%	0			
			Panel D: overall gain from sea wall (€M)			
Ground floors	.	112.2	0.0		534.6	369.6
Upper floors	.	342.4	0.0			
Total		454.6			534.6	369.6

Note: The Table shows: i) Panel A: the estimates of total residential area in the center of Venice according to 2011 census data and the estimates of total commercial area according to open data provided by the municipality of Venice. For residential properties, the split between ground and upper floors reflects the share of housing ads for these types of houses in our listing dataset. For commercial properties, the following categories are included: a) shops; b) bars and restaurants; c) hotels; d) hairdressers and beauticians. For categories c) and d) the information on the surface is not available. Therefore we assume an average size of 15 m2 for each hotel room and an average size of 20 m2 for each property used by hairdressers or beauticians. ii) Panel B: the average price per square meter from our listing dataset; iii) Panel C: the average price gain from the implementation of the sea wall according to the estimates in Tables 2 and 3; iv) Panel D: the overall effect of sea wall, i.e. the product between the corresponding cells in Panel A, B and C.

the percentage gains to compute the increase in value for each category. Panel D of Table 4 shows that the sea wall led to an increase for ground floors with an elevation of 110-140 cm by about €110 millions. The largest city-wide gains come from upper floors with an elevation of 110-140 cm that contributed for almost €350 millions, and from shops that appreciated by €370 millions. Summing across all affected categories, we obtain an overall increase in residential properties values from the activation of the sea wall of almost €460 millions; by adding the effects on commercial properties we obtain an overall gain of almost €1 billion. We compare the magnitudes of our capitalization results relative to the cost of the sea wall and to expected damages from future floods in Section 6.

5 Exploring Additional Effects from the Sea Wall

5.1 The Aggregate Impact on The Venice City Center

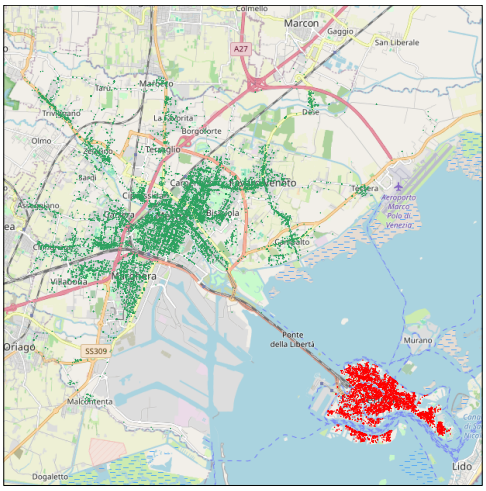
Our main analysis in Section 4 captures the benefits from the sea wall capitalized in residential property prices exploiting variation within-neighborhood over time across properties with differential exposure to flood risk. By construction, the approach is not able to quantify aggregate benefits to the entire historical city center of Venice, because they are absorbed by time fixed effects. We address this limitation, which could lead to underestimation of the overall benefits of the sea wall, with an additional analysis that leverages information on properties in the mainland. The latter also belong to the same metropolitan city of Venice, but critically are not exposed to flooding.

Panel (a) of Figure 6 shows in red properties in the city center main island and in green properties in the mainland. Panel (b) of Figure 6 shows that properties in the city center and the mainland experienced similar trends before the November 12th 2019 flood but they diverged afterwards. The event was (almost) unprecedented - the only higher tide ever recorded in the century-old history of Venice was in 1966 - and affected the whole city - the tide reached 187 and almost 90% of the city center was flooded. Hence the event can be interpreted as a shock for the whole historical city center of Venice, which is located on the main island. This event prevents us from estimating the aggregate impact of sea wall activation on the historic center of Venice by comparing house price trends with those in the mainland because the parallel trend assumption is clearly violated. However, the shock allows us to get an indirect quantification of the potential benefits of the sea wall, which could have prevented the November 12th flood, if successfully activated.

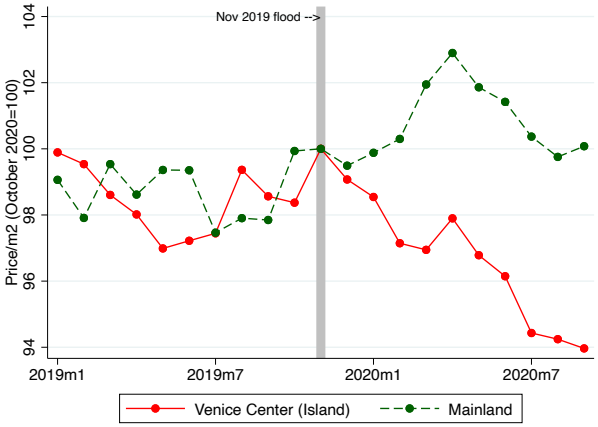
We estimate the following difference-in-difference specification:

$$y_{ilkt} = \alpha \mathit{City\ Center}_i + \beta \mathit{City\ Center}_i \times \mathit{Post\ Flood}_t + \theta X_i + \gamma_{lk} + \gamma_t + \epsilon_{ilkt}, \tag{7}$$

where $\mathit{City\ Center}_i$ is a dummy equal to one if property i is located in the city center; $\mathit{Post\ Flood}_t$ is a dummy equal to one in all months after November 2019, when the extreme high tide was recorded; and other control variables and fixed effects are as in equation (4). The main coefficient of interest is β which captures the differential effect of the flood due to the extreme high tide on properties in the city center. We end the post period in the month of the activation of the sea wall,



(a) Properties location



(b) Prices per m^2

Figure 6: Venice center (island) vs mainland around November 2019 flood

Note: Panel (a) shows the location of properties in the city center main island (treated group) and in the mainland (control group). Panel (b) shows the average price per square meter in a 10-month window around November 2019, which is the month of the 2nd highest tide in the history of Venice. The price is normalized to 100 in November 2019.

to avoid confounding effects, and estimate (7) in a symmetric window around the event.[41]

Table 5 reports the results. Column (1) shows that after the November 2019 flood properties in Venice city center experience a decrease in price per square meter of about 160€. The effect is significant and large in magnitude. After the flood, prices per square meter in exposed properties decrease by about 4% relative to control properties. In columns (3) to (6) we explore differential effects across property types that are more exposed to floods. Columns (3) and (4) report the results of a triple-difference empirical specification, in which we include an additional interaction term for ground floor properties; while columns (5) and (6) focus on the Venice city center and estimate a difference-in-difference specification across elevation levels. We do not detect a significant differential change in ground floor and low elevation properties in line with the parallel trends before the activation of the sea wall across heterogeneous properties within the city center (See Figure 4).

Finally, in columns (7) and (8) of Table 5 we report the result for commercial properties. Despite the relatively low number of observations, we find that commercial properties in Venice city center

[41] To address the potential confounding impact of the COVID-19 pandemic on our Difference-in-Difference estimates in (7) of the price differential between Venice's historical city center and mainland we perform a robustness check. We re-estimate (7) using a shorter sample ending in March 2020, coinciding with the start of Italy's national lockdown. The results remain qualitatively similar but are less precise due to the smaller sample size.

Table 5: Effects of the 2019 flood on properties in the Venice city center

	Residential						Commercial	
	(1) Level	(2) Log	(3) Level	(4) Log	(5) Level	(6) Log	(7) Level	(8) Log
Venice Center × After Flood	-157.95***	-0.04***	-150.58***	-0.03**			-2322.66**	-0.20*
	(53.82)	(0.01)	(51.46)	(0.01)				
Ground floor			44.57	0.02				
			(47.85)	(0.02)				
Venice Center × Ground floor			-595.89***	-0.13***				
			(172.46)	(0.04)				
Ground floor × After Flood			68.32	0.04*				
			(42.22)	(0.02)				
Venice Center × Ground floor × After Flood			61.48	-0.01				
			(99.69)	(0.03)				
Elevation ≤ 140					-10.68	-0.01		
					(118.83)	(0.02)		
Elevation ≤ 140 × After Flood					-23.78	-0.01		
					(98.27)	(0.02)		
FE year-month	Yes	Yes	Yes	Yes	Yes	Yes	No	No
FE location-type	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Controls	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Mean Y	2817.16	7.79	2817.16	7.79	4944.25	8.47	4112.32	7.78
SD Y	1668.99	0.54	1668.99	0.54	1358.76	0.27	6450.13	1.00
R2	0.80	0.81	0.80	0.82	0.31	0.34	0.40	0.67
Obs.	24382	24382	24382	24382	6433	6433	579	579

Note: The Table shows the estimates from equations (7) for the period January 2019 - September 2020. In columns (1), (3), (5) and (7) the dependent variable is the asking price in euro per square meter; in columns (2), (4), (6) and (8) the dependent variable is the log of the asking price in euro per square meter. Ground floor is a dummy equal to one for properties located on the ground floor. After flood is a dummy equal to one in all months after November 2019, when the extreme high tide was recorded. Location-type fixed effects are interacted fixed effect for location and property type. Controls include floor surface, number of bathrooms, a dummy for garage and garden type, a dummy for the presence of an elevator. Standard errors are double clustered at the location-type and year-month level. *, **, and *** denote significance at the 10%, 5% and 1% levels, respectively.

experience a decrease in price per square meter of about 2300€. The effect is only marginally significant, but the point estimate is large. After the flood, prices per square meter in exposed properties decrease by about 20% relative to control properties in the mainland. These estimates are also of the same order of magnitude as our estimates in Table 3, using time-series only variation around the activation of the sea wall.

While they belong to the same metropolitan area, the mainland and the city center are very different and these differences are reflected in property prices. For example, the average price per square meter is about double in the city center relative to the mainland. Hence, a concern with the results in Table 5 is that prices in Venice city center and the mainland were already behaving

differently before the flood. For example, because of different population or tourist dynamics between the two areas. We estimate a version of equations (7) in which we interact the dummy for properties located in the city center with time dummies for months before and after the months of the extremely high tide. Figure E1 in the Appendix shows the coefficients on the interaction term. The interaction term is not significant and close to zero in the periods before the flood, consistent with the parallel trend assumption, and becomes negative and significant thereafter, in line with the estimates in Table 5 of a causal effect of floods on property values.

Overall, we find that after the 2019 extreme tide and ensuing flood the entire city center experienced a large and significant decline (relative to the mainland) in property values in the order of 4% (20%) for residential (commercial) properties. The lack of significant differential effects on prices for properties that likely experienced more damages (e.g., ground floor and low elevation) is potentially explained by the nature of the shock, which was an extreme event that affected all properties in the city center. Hence, two mechanisms are likely at play with differential implications for more- and less-exposed properties. On the one hand, properties more exposed to flooding experienced a price decline due to larger direct damages. On the other hand, properties historically less exposed to flooding experienced a price decline due to a stronger learning mechanism. Most notably, the extreme flood increased the perceived risk of large-scale flooding even for properties which were previously thought to be immune, thus reducing the willingness to pay for them. Hence, the change in property prices we estimated in this section provides an indirect measure of the potential benefit from protecting the city center from increasing high tides.

5.2 Accounting for Government Bailouts After Extreme Events

The analyses in Sections 4 and 5.1 capture the benefits from the sea wall that are capitalized in forward-looking property prices following the asset pricing framework given by equation (3). Private capitalized benefits might however underestimate overall benefit if the government acts as "insurer of last resort", (partially) covering repair costs, especially after extreme events. To address this issue, we construct a flow-based measure of government expected savings from the sea wall, that complements our present-value measures of capitalized benefits.

We obtained detailed data on claims for government funds following the November 12th 2019 flood, which is the second highest level ever recorded in the history of Venice, causing about 90%

of the city center to be flooded. The data come from almost 5,000 properties – 37% are residential and 63% commercial – which used a government-sponsored fund to cover cost of essential fixes to houses – the limit for residential properties is €5,000 – and restart economic activity – the limit for commercial properties is €20,000 – after the flood.[42] The advantage of this data compared to other sources used in the literature is the level of geographical precision that – combined with the unique structure of Venice based on stilts – allows us to exploit very granular variation in elevation across neighboring properties.[43]

Figure 7 shows that variation in average claims per property is negatively correlated with elevation, as we expected.[44] While informative, claim data may not be an exact measure of actual damages for several reasons. On the one hand, only the worst properties based on unobservable characteristics may request claims and residents might have an incentive to ask the maximum claim irrespective of the true damage.[45] Both these forces will lead to claims overestimating average damages per square meter. On the other hand, for some properties the government limit of €5,000 for residential and €20,000 for commercial might be binding and low compared to the actual damage. In this case average claims will underestimate average damages. Additionally, total claims might underestimate total damages if some residents are not aware of or skeptical about the government policy.

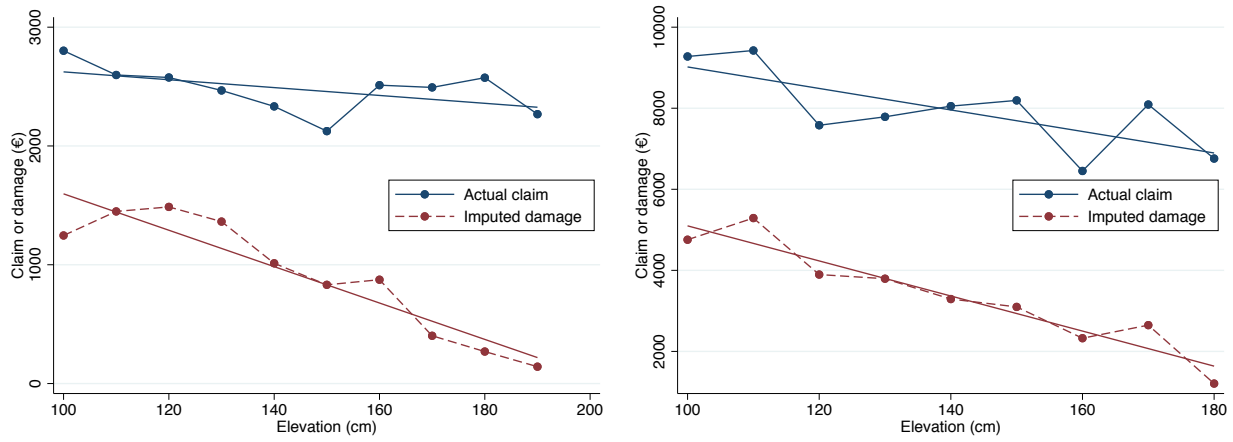
For these reasons, we construct a measure of average imputed damages combining total claims at different elevation levels with administrative data on the number of exposed properties. Appendix E explains the details of the calculation. Figure 7 shows that average imputed damages are lower than average claims, consistent with selection leading to likely overestimating the average damage per property. The average imputed damage for residential properties is about €900, while the average imputed damage for commercial properties is higher at about €3,400. Interestingly, the slope of imputed damages relative to elevation levels is steeper than the slope of actual claims. Since we know the exact level of the November 2019 high tide, we can estimate for each elevation bin an approximate level of water depth. The average damage can then be interpreted as a function

[42] The government also offered additional funds for non-urgent expenses to cover the damages. More details of the policy can be found at https://www.metropolitano.it/acqua-alta-risarcimenti/. As already noted above, private insurance against flooding in Venice is almost non-existent.

[43] For example, recent work by Kocornik-Mina et al. (2020) exploits elevation data from the GTOPO30, a global digital elevation model with a horizontal grid spacing of 30 arc seconds (approximately 1 kilometer).

[44] Figure E3 in the Appendix shows the binscatter.

[45] Figure E2 shows that about 20% (7%) of residential (commercial) properties claimed the highest possible amount.



(a) Residential (b) Commercial

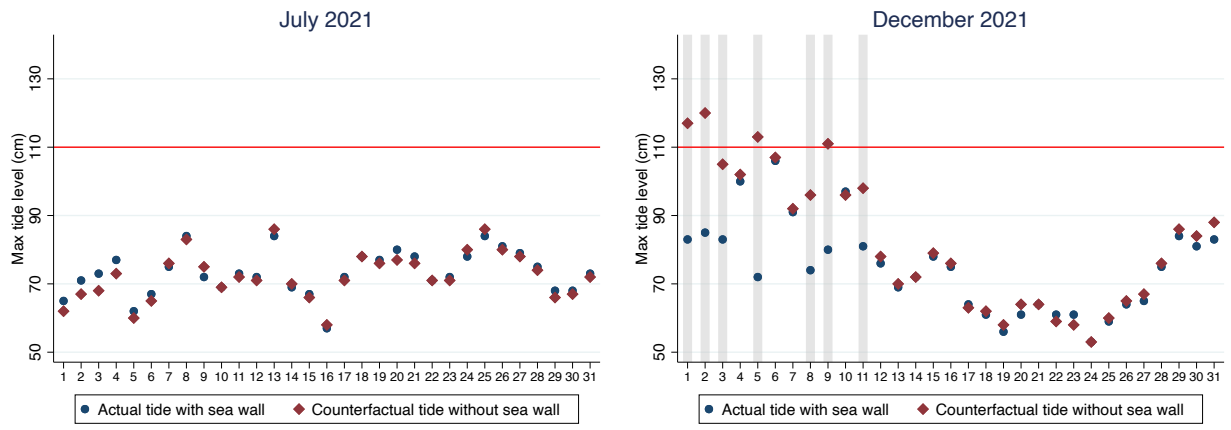
Figure 7: Average actual claim and imputed damage by elevation level

Note: Mean claim is the average flood-related claim for residential and commercial properties after the November 2019 flood by elevation level of the property. Panel (a) shows residential and panel (b) shows commercial properties. Imputed damage is the average damage for residential and commercial properties using the claim data after November 2019 and the number of properties at different elevation levels.

of the water depth. Under a linearity assumption between water depth and damages, we can infer avoided (unobserved) damages from floods prevented by the activation of the sea wall.

We then construct a counterfactual tide level for the city of Venice absent the sea wall, exploiting the availability of contemporaneous measurements of the tide in the city of Venice and an offshore platform. To illustrate the approach to build the counterfactual, Figure 8 shows for the months of July and December 2021 the maximum tide recorded in the city of Venice ("Actual tide with sea wall") and in the offshore platform ("Counterfactual tide without sea wall"). In the month of July 2021 the sea wall is never activated as the predicted tide is always below the activation threshold. As panel (a) of Figure A2 shows, when the sea wall is inactive the tide in the city center of Venice and in the offshore platform is almost identical.[46] Looking at a couple of days in December 2021 provide an example of the activation process. On December 4th 2021, the predicted tide was below the 110 cm activation threshold. The measured tide in the open sea was 102 cm and the recorded tide in the city of Venice was only slightly lower at 100 cm. The day after, December 5th 2021, the expected tide was higher than the activation threshold, hence the barriers were raised. As a result, the measured tide in the open sea was 113 cm, while the city of Venice experienced a tide of

[46] Some gaps might be due to changing meteorological conditions (e.g., winds or rains) and water coming from the river entering the lagoon.



(a) July 2021

(b) December 2021

Figure 8: Observed and Counterfactual Tide Levels

Note: Maximum tide level measured in the Venice city center ("Actual tide with sea wall") and in the offshore platform ("Counterfactual tide without sea wall") in the months of July 2021 and December 2021. The grey vertical bars denote the dates when the sea wall is activated. The red horizontal lines denote the activation thresholds at 110 cm.

less than 75 cm. Therefore, for the days with an active sea wall, we can construct a counterfactual tide level for the city of Venice if the sea wall was not present by leveraging the contemporaneous measurement of the tide in the offshore platform.

Finally, we combine imputed damages with our counterfactual tides to compute the expected benefit from the sea wall in terms of lower damages. Panel A of Table 6 reports our baseline *counterfactual* damages with no sea wall for the years 2021-2022. We find Venice would have experienced a total of 24 high tides, with a very high tide at 170 cm. It is worth noticing that damages are driven by the interaction of flood frequency and severity of the flood. For example, total commercial damages at 120 cm are similar to total commercial damages at 170 cm. The former are due to many tides with relatively limited effects, while the latter come from only one tide with larger impacts. As a result, the activation of the sea wall in 2021-2022 prevented almost €12 millions of damages to residential properties and almost €92 millions of damages to commercial properties. Thus annual avoided damages in the first two years of the activation of the sea wall were about €52 millions.

We compute two additional scenarios. First, Panel B of Table 6 reports the scenario based on observed high tides in the last ten years. The annual number of tides above 110 cm – the activation

Table 6: Flood-related damages in different scenarios

	Elevation								Total
	110	120	130	140	150	160	170	180	
Panel A: Counterfactual no sea wall (2021-2022)									
Number of high tides	16.00	4.00	2.00	1.00	0.00	0.00	1.00	0.00	24
Damages Residential (€M)	2.91	2.00	1.98	1.58	0.00	0.00	3.44	0.00	11.9
Damages Commercial (€M)	24.32	18.63	17.19	11.76	0.00	0.00	19.83	0.00	91.7
Panel B: Historical (last 10 years)									
Number of high tides	5.90	2.70	0.90	0.80	0.30	0.00	0.00	0.10	10.7
Damages Residential (€M)	1.07	1.35	0.89	1.27	0.65	0.00	0.00	0.40	5.6
Damages Commercial (€M)	8.97	12.57	7.74	9.41	4.39	0.00	0.00	2.23	45.3
Panel C: Projection (in 50 years)									
Number of high tides	16.54	7.57	2.52	2.24	0.84	0.00	0.00	0.28	30
Damages Residential (€M)	3.01	3.79	2.50	3.55	1.82	0.00	0.00	1.11	15.8
Damages Commercial (€M)	25.15	35.25	21.69	26.38	12.30	0.00	0.00	6.27	127.0

Note: The Table shows the number of high tides, total damages to residential properties and total damages for commercial properties for three scenarios. Panel A reports the counterfactual scenario with no sea wall in 2021-2022. In this case the probability of high tides at different elevation is based on the tide measured in the offshore platform. Panel B reports the baseline scenario where the probability of high tides at different elevation levels are based on observed tides in Venice in the last ten years. Panel C reports the projection scenario where the number of high tides is based on the estimates 50 years from now by Caporin and Fontini (2014).

threshold of the sea wall – is about 11. The total damages to residential properties amount to €5.6 millions per year, while damages to commercial properties reach about €45 millions. Second, in Panel C we also show *expected* damages using predicted high tides in 50 years by Caporin and Fontini (2014).[47] As a result of sea level rise, the number of annual high tides increases to about 30. Annual damages to residential properties increase to €16 millions and annual damages to commercial properties reach €127 millions. This large increase in expected annual damages in fifty years is consistent with the recent increasing trend in high tides displayed in Figure 2, which is expected to deteriorate over the next several years.

6 Discussion of Costs and Benefits

In this section, we compare the benefits from the sea wall estimated in Sections 4 and 5 with its costs. Table 7 summarizes our calculations assuming a protective lifetime of 100 years.[48] In Panel

[47] We select their central scenario which is based on an annual sea level rise of 5.6mm per year. Caporin and Fontini (2014) only provide the expected number of tides above 110 cm. We allocate them proportionally across levels based on the tides in the last ten years. The results are robust to a proportional allocation based on the last 100 years.

[48] This assumption is in line with recent estimates (https://www.commissariostraordinariomose.it/il-mose-proteggera-venezia-per-i-prossimi-100-anni-positivi-i-risultati-dello-studio-sulla-corrosione/. We find qualitatively

A we report information on the costs associated with the sea wall, which we obtained from official government documents from the Italian court of auditors. The main estimate of overall construction cost of the sea wall is about €6.4 billions.[49] The sea wall will require additional costs in the future to be activated and maintained. The estimates for these future costs are more uncertain, but current estimates place them around €10 millions annually.[50] In Panel A of Table 7 we also report the original planned costs rather than the final costs, which as we discussed have been affected by delays and political scandals. The original project expected cost was 3.2 billions of Italian lira in 1989, which correspond to about €3.4 billions at the time of the first sea wall activation.[51]

Panel B of Table 7 summarizes the benefits coming from our complementary approaches. The benefits directly capitalized in property prices amount to almost €1 billion (see Table 4), with about €460 coming from residential properties and €540 from commercial properties. Using the empirical estimates comparing the Venice city center with the mainland after the flood of November 2019 from Section 5.1, we compute additional indirect capitalized benefits for residential properties by approximately €635 millions.[52]

As we discussed, a key advantage of our capitalization approach is that it provides a present-value measure of benefits that is market-based and does not require assumptions on discount rates. The main concern is that changes in property prices after the first activation of the sea wall (or after the extremely high tide) may not capture all the benefits from the sea wall. Residents might fail to completely internalize the increasingly larger damages from flooding, because they can obtain (partial) compensation from the government after floods or because they underestimate the impact of sea level rise on future floods.[53] Hence, we interpret the capitalized benefits as a lower bound

similar results with a shorter (50 years) and longer (perpetuity) horizon.

[49] See Table 10 here https://www.corteconti.it/Download?id=eb4395cf-a580-4051-b07e-68b2cd6acbb6 for a detailed breakdown of the costs.

[50] The same above-cited report of the Italian court of auditors estimates €9.13 millions of annual maintenance costs (see Table 15) and additional operational costs overcoming €200,000 per year and depending on the number of times the sea wall is activated (see Tables 25 and 26).

[51] We leave the maintenance costs unaffected in our calculations. See https://www.contocorrenteonline.it/2020/12/09/mose-non-funziona-costo-venezia-acqua-alta/ and https://it.wikipedia.org/wiki/MOSE)

[52] We obtain this number by using the total residential area from Panel A of Table 4 and the 4% estimates from column (2) of Table 5. Notice that we do not use the estimates from Table 4 for commercial properties as indirectly capitalized benefits. We made this decision to avoid double counting the benefits, since the analysis of directly capitalized benefits for commercial properties only exploits time-series variation, which already captures overall effects.

[53] While the government has historically acted as an "insurer of last resort" after extreme events, compensations might take a long time. For example, the claims after the November 2019 floods have not yet been distributed (See: https://www.metropolitano.it/acqua-alta-risarcimenti/).

and combine them with the estimated lower expenses for the government to compensate residents after floods. The latter provides a direct measure of benefits, rather than an indirect one through property prices. However, it requires potentially strong assumptions on: (*i*) the future likelihood of floods; and (*ii*) the discount rate to obtain a present value measure. Using the estimates from Section 5.2, we compute the present value of avoided damages both in the counterfactual with no sea wall for the years 2021-2022 (Baseline), as well the expected avoided damages with predicted high tides in 50 years by Caporin and Fontini (2014) (Sea level rise - SLR). In our baseline, we choose a discount rate of 2.5% motivated by the work of Drupp et al. (2018) and Giglio et al. (2021), but we show the results with a wide range of discount rates from the literature in Figure 9.

Panel C of Table 7 reports the ratio between costs and benefits. In our baseline calculation, estimated benefits cover approximately 52% of the actual costs. Accounting for the effect of sea level rise on (higher) government expenses to cover for damages, we estimate that the benefits exceed the costs of the project. When comparing estimated benefits to the originally planned costs (in 2020 euros), the estimated benefit/cost ratio is already about 95% in the baseline and increases to more than 180% when accounting for sea level rise.

Finally, we focus only on the flow benefits from avoided damages covered by the government and higher tourist flow and we study how discount factors affect the cost-benefit analysis of the sea wall at the time of the first activation. The choice of the discount rate has been and still is an important area of debate, since discount rates effectively determine policy choices (Stern, 2007; Nordhaus, 2013; Giglio et al., 2021; Carleton and Greenstone, 2022; Howard et al., 2023; Bauer and Rudebusch, 2023). Figure 9 reports the ratio of the present value of flow benefits over the present value of the costs as a function of different discount rates, ranging from 50 basis points to 8 percentage points. Rather than taking a stance on the "right" discount rate, we compute several break-even discount rates (i.e., the rate that makes the sea wall a zero net-present-value project), under different scenarios for costs (actual vs planned) and benefits (baseline VS sea level rise).

In our baseline scenario, we obtain a break-even interest rate of 1.1%. This low interest rate is within the bounds discussed in the literature that views investment in adaptation to climate change as a hedge against disaster risk, which primarily pays off in the bad states of the world and is thus particularly valuable (Stern, 2007; Weitzman, 2012; Martin, 2012; Carleton and Greenstone, 2022;

Table 7: Costs and Benefits Analysis of the Sea Wall

	Annual flows		Present Value	
	Baseline	Sea Level Rise	Baseline	Sea Level Rise
Panel A: Costs				
Construction (Actual)			6400	6400
Maintenance	10	10	366	366
Total Costs (Actual)			6766	6766
Construction (Planned)			3400	3400
Maintenance	10	10	366	366
Total Costs (Planned)			3766	3766
Panel B: Benefits				
Capitalized direct			990	990
Capitalized indirect			636	636
Lower government bailouts	52	143	1904	5236
Total Benefits			3530	6862
Panel C: Ratios				
Benefits / Costs (Actual)			0.52	1.01
Benefits / Costs (Planned)			0.94	1.82

Note: The Table shows the costs and benefits of the sea wall. Panel A shows the construction and maintenance costs coming from the Italian court of auditors. Panel B shows the benefits based on the capitalization analysis of Section 4 – the numbers are from Table 4 – and based on the additional analyses of Section 5. Panel C reports the ratio of benefits over costs. In Panels A and B the value are in €millions.

Hahn et al., 2024).[54] Accounting for the effect of sea level rise on damages increases the break-even rate to about 2.5%, which is almost identical to the one we use in the calculations in Table 7. Finally, if the overall cost were kept at the level originally planned, the break-even discount rate without sea level rise is about 2.1% and the break-even discount rate with sea level rise reaches 4.8%.

7 Conclusions

This paper exploits the unexpected successful activation of a sea wall to protect the city of Venice to provide new quasi-experimental evidence on the capitalization of infrastructure investment reducing flood risk into housing values. Our results show that forward-looking property prices capture the benefits of public investment to reduce the damage from climate change, albeit imperfectly if ex-post government interventions compensate residents in the case of extreme events. While the magnitudes

[54] Related, the US Office of Management and Budget's (OMB's) decided in April 2023 to decrease the risk-adjusted discount rate for public projects from 3% or 7% to 1.7%. See https://www.whitehouse.gov/wp-content/uploads/2023/02/M-23-12-Appendix-C-Update_Discount-Rates.pdf.

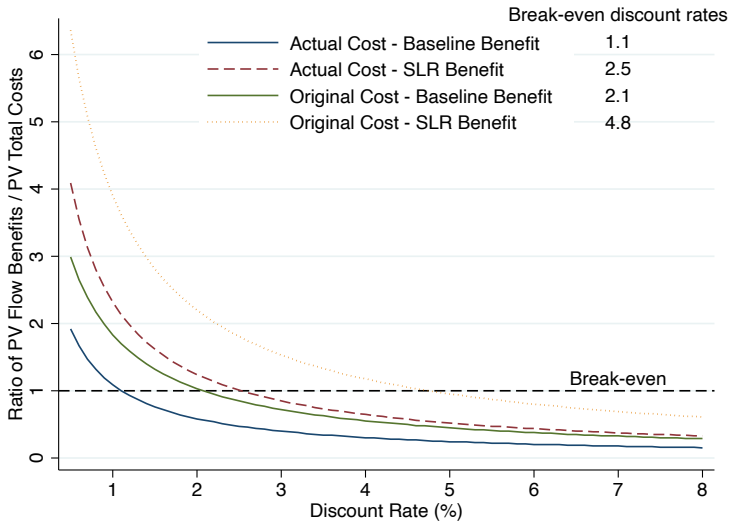


Figure 9: Break-even Discount Rates

Note: The figure shows the ratio of the present value of flow benefits over the present value of the costs as a function of different discount rates. The flow benefits are estimated in Section 5.2 and Appendix D. We present four scenarios: (i) actual cost and baseline benefits; (ii) actual cost and benefits accounting for sea level rise; (iii) original planned costs and baseline benefits; and (iv) original planned costs and benefits account for sea level rise. For each scenario we report the break-even discount rate that makes the present value of the benefits equal to the present value of the costs.

are specific to the context, our analyses of capitalized benefits across heterogeneous properties and counterfactual government savings could inform the discussion about public investment in resilience infrastructure that is taking place in major coastal cities around the world facing increasing risks from sea level rise.

The large initial fixed costs and decades-long lifespan of public investment in resilience infrastructure open an array of long-run issues that demand further research. Recent papers have explored endogenous responses in construction activity that lead to a spiral of over-development and ex-post costly protection (Hsiao, 2022), and a potential vicious cycle of lack of maintenance, low property values, and lower property taxes which further hinder maintenance (Fan, 2024). Political economy issues related to the financing of adaptation policies – for example via targeted property tax increases – and the distribution of their benefits as well as the interaction between public and private adaptation are interesting areas for future research that could yield additional insights for policymakers.

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Internet Appendix

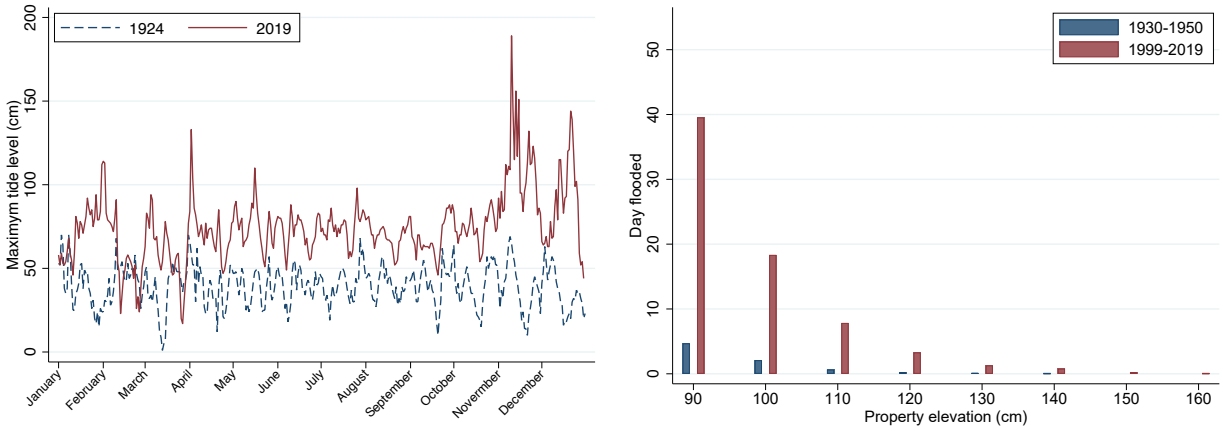
Appendix A provides supplementary figures and tables for the data and setting. Appendix B discusses data sources, variables and the construction steps for the final dataset. Appendix C provides supplementary figures and tables for the empirical analysis of residential and commercial properties, as well as the capitalization exercise. Appendix D provides supplementary analysis of the effect of high tides on tourist revenues. Appendix E provides supplementary analysis of the flow benefits and the comparison with costs.

A Additional Tables and Figures for Data and Setting

Table A1: Effect of flood risk on property values

	Price (level)			Price (log)		
	(1)	(2)	(3)	(4)	(5)	(6)
Flood probability	-134.33***		-87.22*	-0.03***		-0.02**
	(39.93)		(44.48)	(0.01)		(0.01)
Ground floor		-303.75*	-261.43**		-0.07**	-0.05**
		(146.71)	(111.54)		(0.03)	(0.02)
Flood probability × Ground floor			-301.88			-0.06*
			(173.41)			(0.03)
FE location-type	Yes	Yes	Yes	Yes	Yes	Yes
FE year-month	Yes	Yes	Yes	Yes	Yes	Yes
Controls	Yes	Yes	Yes	Yes	Yes	Yes
Mean Y	4999.49	5006.58	4999.49	8.49	8.49	8.49
SD Y	1200.56	1192.09	1200.56	0.24	0.23	0.24
R2	0.38	0.38	0.40	0.40	0.39	0.41
Obs.	6996	7596	6996	6996	7596	6996

Note: The Table shows the estimates of the effect of flood risk on house prices in the year before the activation of the sea wall. In columns (1) to (3) the dependent variable is the asking price in euro per square meter; in columns (4) to (6) the dependent variable is the log of the asking price in euro per square meter. Flood probability is the daily probability that the building is flooded based on the elevation and the daily level of tides since 1923. Ground floor is a dummy equal to one for properties located on the ground floor. Location-type fixed effects are interacted fixed effect for location and property type. Controls include floor surface, number of bathrooms, a dummy for garage and garden type, a dummy for the presence of an elevator, and several measures of distance of the property from tourist attractions (San Marco Cathedral, Rialto Bridge, Canal Grande), bridges and public boat stations. Standard errors are double clustered at the location-type and year-month level. *, **, and *** denote significance at the 10%, 5% and 1% levels, respectively.



(a) Max tide level in 1924 and 2019 (b) Days flooded by year and elevation

Figure A1: Venice tide level and flooding in the last century

Note: The left figure shows the maximum tide level in 1924 and 2019. The right figure shows the days property at different elevation levels were flooded in 1930-1950 and 1999-2019.

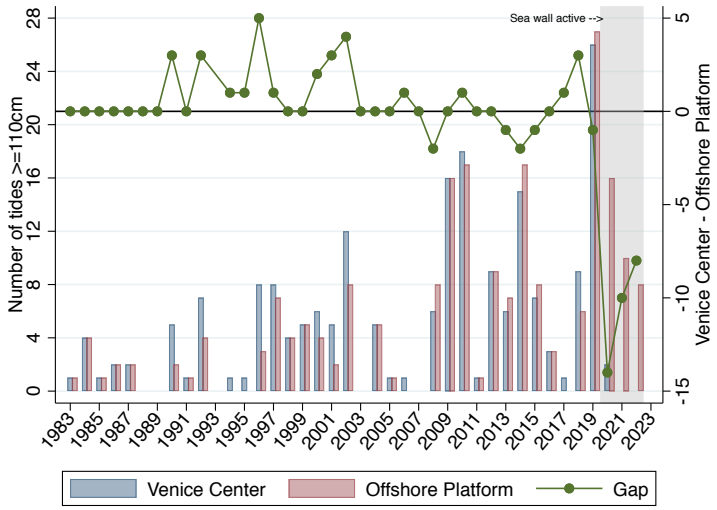


Figure A2: Venice Sea Wall Operations

Note: The figure shows the number of high tides (>=110 cm) registered in the city of Venice and the offshore platform and the gap between the two.

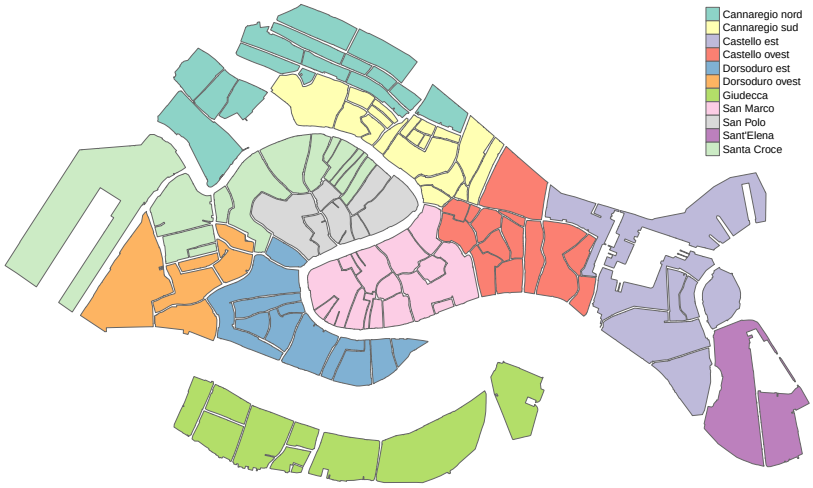
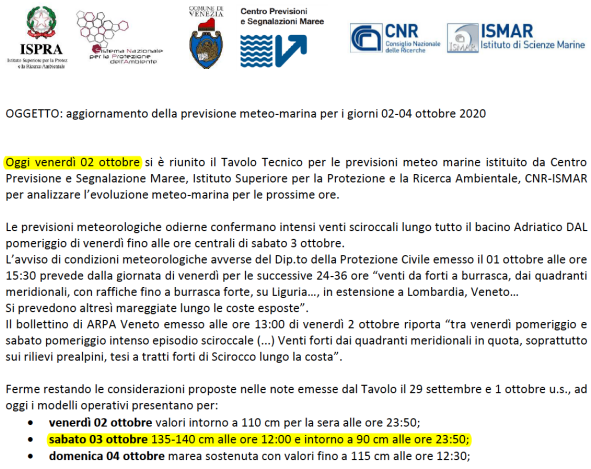


Figure A3: Venice Neighborhoods

Note: The figure shows the name and areas of the different neighborhoods in Venice main island.



OGGETTO: aggiornamento della previsione meteo-marina per i giorni 02-04 ottobre 2020

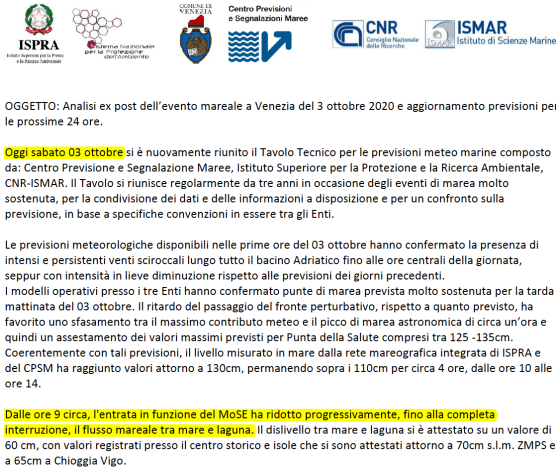
Oggi venerdì 02 ottobre si è riunito il Tavolo Tecnico per le previsioni meteo marine istituito da Centro Previsione e Segnalazione Maree, Istituto Superiore per la Protezione e la Ricerca Ambientale, CNR-ISMAR per analizzare l'evoluzione meteo-marina per le prossime ore.

Le previsioni meteorologiche odierne confermano intensi venti sciroccali lungo tutto il bacino Adriatico DAL pomeriggio di venerdì fino alle ore centrali di sabato 3 ottobre.
L'avviso di condizioni meteorologiche avverse del Dip.to della Protezione Civile emesso il 01 ottobre alle ore 15:30 prevede dalla giornata di venerdì per le successive 24-36 ore "venti da forti a burrasca, dai quadranti meridionali, con raffiche fino a burrasca forte, su Liguria..., in estensione a Lombardia, Veneto...
Si prevedono altresì mareggiate lungo le coste esposte".
Il bollettino di ARPA Veneto emesso alle ore 13:00 di venerdì 2 ottobre riporta "tra venerdì pomeriggio e sabato pomeriggio intenso episodio sciroccale (...) Venti forti dai quadranti meridionali in quota, soprattutto sui rilievi prealpini, tesi a tratti forti di Scirocco lungo la costa".

Ferme restando le considerazioni proposte nelle note emesse dal Tavolo il 29 settembre e 1 ottobre u.s., ad oggi i modelli operativi presentano per:

- **venerdì 02 ottobre** valori intorno a 110 cm per la sera alle ore 23:50;
- **sabato 03 ottobre** 135-140 cm alle ore 12:00 e intorno a 90 cm alle ore 23:50;
- **domenica 04 ottobre** marea sostenuta con valori fino a 115 cm alle ore 12:30;

(a) October 2nd 2020



OGGETTO: Analisi ex post dell'evento mareale a Venezia del 3 ottobre 2020 e aggiornamento previsioni per le prossime 24 ore.

Oggi sabato 03 ottobre si è nuovamente riunito il Tavolo Tecnico per le previsioni meteo marine composto da: Centro Previsione e Segnalazione Maree, Istituto Superiore per la Protezione e la Ricerca Ambientale, CNR-ISMAR. Il Tavolo si riunisce regolarmente da tre anni in occasione degli eventi di marea molto sostenuta, per la condivisione dei dati e delle informazioni a disposizione e per un confronto sulla previsione, in base a specifiche convenzioni in essere tra gli Enti.

Le previsioni meteorologiche disponibili nelle prime ore del 03 ottobre hanno confermato la presenza di intensi e persistenti venti sciroccali lungo tutto il bacino Adriatico fino alle ore centrali della giornata, seppur con intensità in lieve diminuzione rispetto alle previsioni dei giorni precedenti.
I modelli operativi presso i tre Enti hanno confermato punte di marea prevista molto sostenuta per la tarda mattinata del 03 ottobre. Il ritardo del passaggio del fronte perturbativo, rispetto a quanto previsto, ha favorito uno sfasamento tra il massimo contributo meteo e il picco di marea astronomica di circa un'ora e quindi un assestamento dei valori massimi previsti per Punta della Salute compresi tra 125 -135cm.
Coerentemente con tali previsioni, il livello misurato in mare dalla rete mareografica integrata di ISPRA e del CPSM ha raggiunto valori attorno a 130cm, permanendo sopra i 110cm per circa 4 ore, dalle ore 10 alle ore 14.

Dalle ore 9 circa, l'entrata in funzione del MoSE ha ridotto progressivamente, fino alla completa interruzione, il flusso mareale tra mare e laguna. Il dislivello tra mare e laguna si è attestato su un valore di 60 cm, con valori registrati presso il centro storico e isole che si sono attestati attorno a 70cm s.l.m. ZMPS e a 65cm a Chioggia Vigo.

(b) October 3rd 2020

Figure A4: Venice high-tide briefings around first sea wall activation

Note: The left figure shows the briefing the day before the first activation of the sea wall (Friday October 2 2020). The right figure shows the briefing the day of the first activation of the sea wall (Saturday October 3 2020). The translation for the text in yellow on the left panel is "Today Friday October 2nd" and "Saturday October 3rd [the expected tide is] 135-140 cm around noon and about 90 cm around 11.30pm". The translation for the text in yellow of the right panel is "Today Saturday October 3rd" and "From about 9am, the activation of MOSE has gradually reduced, until the complete interruption, the tide flow between the open sea and the lagoon".

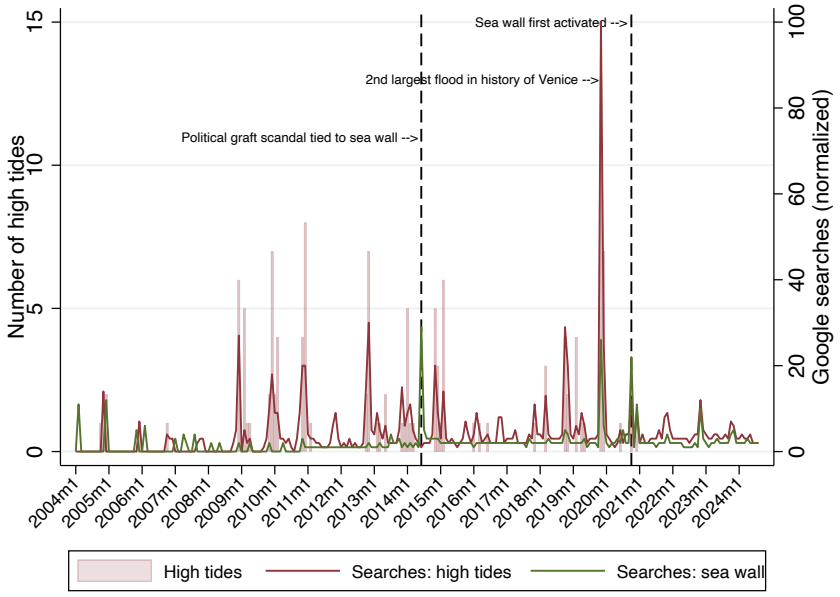


Figure A5: Google Trends

Note: The figure shows searches reported in google trends for the words high tide (acqua alta) and sea wall (MOSE) in the Veneto region, where Venice is located, from 2004 to 2024. The red vertical bars show the number of times the sea level in Venice was higher than 110 cm.

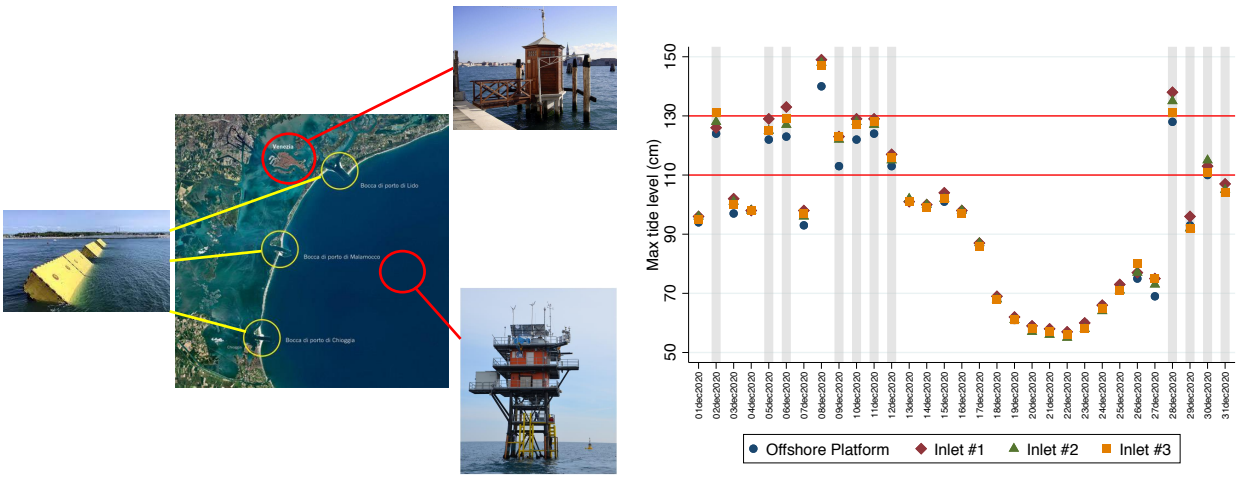


Figure A6: Offshore platform and inlets

Note: The left figure shows the location of the offshore platform, the three inlets, and the city of Venice. The right figure shows the highest measured tide offshore and in the three inlets in December 2020.

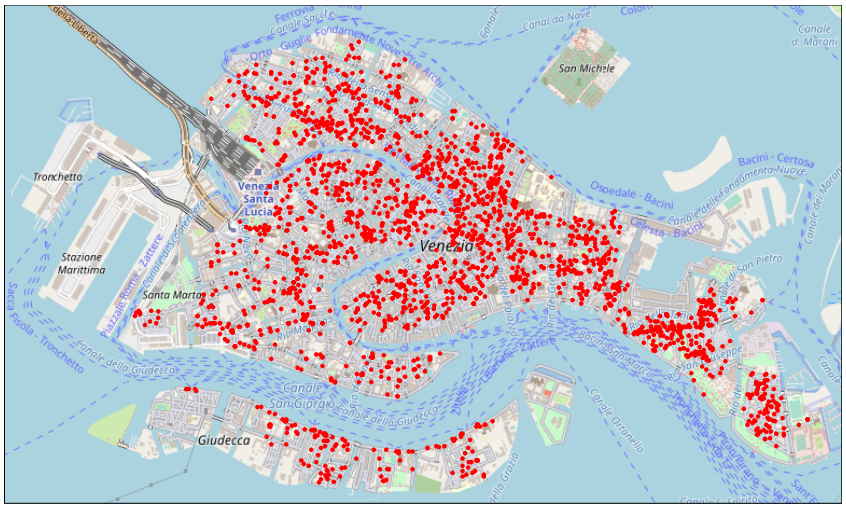


Figure A7: Properties across location

Note: The figure shows the location of houses in our dataset in Venice main island. Each dot corresponds to one house.

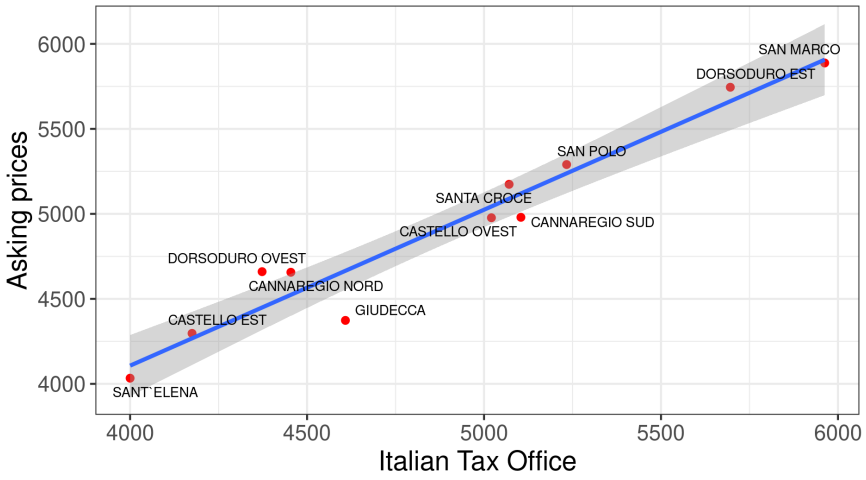


Figure A8: Listing and Transaction Prices by Area

Note: The figure shows the average price per square meter in different areas of Venice. The vertical axis shows average listing prices across observations in the area in our main dataset; the horizontal axis shows average transaction prices published by the Italian tax office.

B Data Discussion

Listings. Immobiliare.it (www.immobiliare.it) provided us with a list of weekly files including all listed residential properties in Venice on their website between January 1, 2018 and December 31, 2022. Each file includes all listings visible on their website on Monday. Listings are both for sale and for rental. We observe the asking price but we do not know if the house is sold (or rented) and the transaction price.

The original data are processed to eliminate duplicate ads (i.e., multiple ads referring to the same house) and those missing crucial information (i.e., the ads without the exact location or with the asking price missing). We also eliminate ads that are related to foreclosure sales. This procedure is described in Loberto et al. (2022). We end up with a sample of 4,500 unique homes in the city center of Venice. For comparison, during the period 2018-2022 there were about 3,500 house sales in the same area.

In the final sample used in the regressions, we remove listings with extreme values for price per square meter. We compute the 2.5 and 97.5 percentiles of the distribution of the price per square meter for each year, elevation range (considering bands of 10 cm), and exposure (upper floors vs. ground floors). We drop the listings with a price per square meter below the 2.5 percentile or above the 97.5 percentile.

Neighborhoods. We identify neighborhoods based on the urban partition developed by the Italian Tax Office. The city center of Venice is divided into 11 zones. These zones are contiguous areas of the city territory that satisfy strict requirements regarding the homogeneity of house prices, urban characteristics, and the endowment of services and urban infrastructures. OMI microzones are periodically revised to satisfy these criteria and to better approximate local housing markets. The last revision dates back to 2014.

The Italian Tax Office disseminates estimates of minimum and maximum home values in euros per square meter in each zone. These are estimated based on a limited sample of home sales and valuations by real estate experts. We use these data to check the consistency between asking and transaction prices (see Figure A8). Figure B1 shows the distribution of listing prices by neighborhoods. Further information is available at https://www.agenziaentrate.gov.it/wps/content/Nsilib/Nsi/Schede/FabbricatiTerreni/omi.

Commercial properties. We downloaded detailed data on all commercial activities in the city center of Venice in 2017 at https://dati.venezia.it/?q=content/open-data-del-commercio. For shops and restaurants, we can extract information on the neighborhood where the commercial property is located and the surface area. These commercial properties are usually at the street level.

We compute the value of the stock of shops and restaurants by multiplying the total floor area with the average price per square meter of a retail property (provided by the Italian Tax Office) in each neighborhood. We assume that the spatial distribution of shops and restaurants in each neighborhood is the same as residential properties.

Census data. We retrieve detailed information on the socio-economic characteristics and the housing stock from the 2011 Census by Istat. Census tracts are much smaller than neighborhoods: the city center of Venice is divided in about 1,300 census tracts. We perform spatial interpolation of the zones representing the census tracts and the neighborhoods to compute some statistics for each neighborhood (Table B1). When census tracts belong to more than one neighborhood, we split the census tract among the neighborhoods based on the extent of the overlapping area.

Altimetry. GIS data layers reporting the elevation of the paving in the city center of Venice were produced by the Municipality of Venice and are available at https://smu.insula.it. Elevation measurement was done in 2011 and is defined in centimeters using as a reference point Punta della Salute.

We associate to each house a measure of elevation by computing the average elevation of the paving in a 10-meters radius around the house. Figure B2 shows the distribution of houses' elevation by neighborhoods.

Tides. To compute the flooding probability we use daily data on the maximum tide – using as a reference point Punta della Salute – since 1924. Data are available at https://www.venezia.isprambiente.it/rete-meteo-mareografica. Then, we compute the empirical distribution of the daily maximum tide. For each level of elevation $\bar{x}$, we define the flooding probability as the relative frequency that the daily maximum tide was higher than $\bar{x}$.

Data on high tides at the off-shore platform are available at https://www.comune.venezia.it/it/content/3-piattaforma-ismar-cnr, while all information about sea wall activations are

Table B1: Descriptive statistics - Neighborhoods

Neighborhoods	(1) Population	(2) Housing stock	(3) Before 1945	(4) Land	(5) Listings	(6) Asking prices
Cannaregio sud	8,615	5,256	89.3	0.54	122	4,965
San Polo	4,507	3,044	98.7	0.27	52	5,204
Castello ovest	7,038	4,555	99.2	0.49	100	4,939
Cannaregio nord	7,916	4,321	57.7	0.67	62	4,626
Dorsoduro ovest	3,003	1,900	75.7	0.42	22	4,691
Castello est	5,220	2,813	95.8	0.74	75	4,287
Sant'Elena	1,864	936	94.3	0.31	22	4,011
Dorsoduro est	3,834	3,011	96.2	0.43	55	5,697
San Marco	4,205	3,875	98.9	0.49	84	5,983
Santa Croce	5,017	3,337	96.2	1.04	61	5,151
Giudecca	6,060	3,526	65.3	0.81	51	4,381

Note: The Table shows the relevant statistics for each neighborhood. Columns (1) and (2) report the number of residents and houses according to the 2011 Census. Column (3) shows the share of buildings built before 1945. Column (4) reports the land area (km^2). Column (5) and (6) show the average number of monthly listings and the average asking prices.

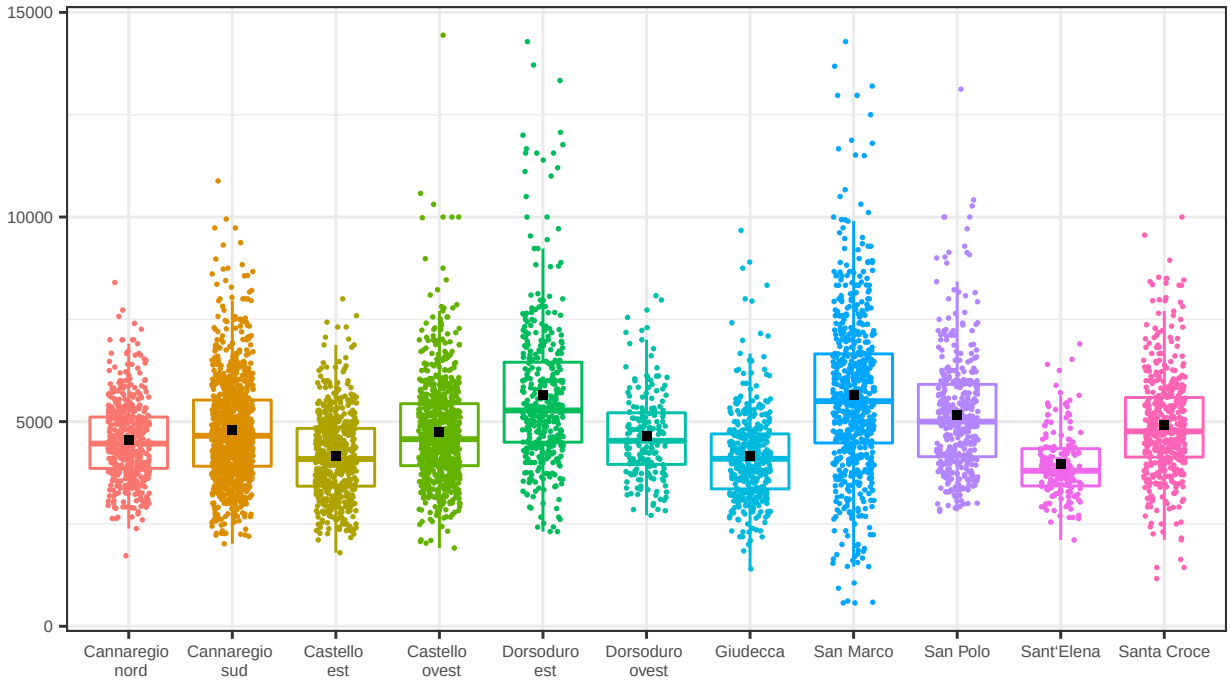


Figure B1: Listing prices by Neighborhood

Note: The figure shows the distribution of the asking prices per square meter in different areas of Venice. For each listing the average asking prices is reported.

available at https://www.mosevenezia.eu/il-mose-in-funzione/.

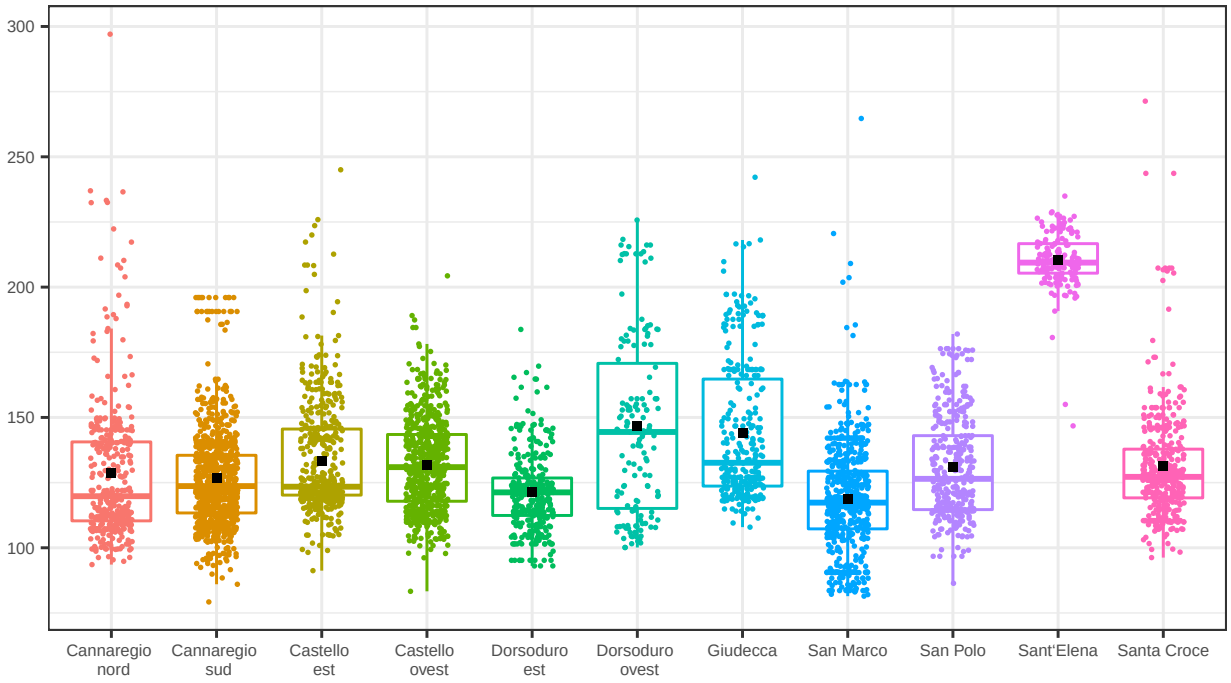


Figure B2: Houses' elevation by Neighborhood

Note: The figure shows the distribution of the elevation of houses in different areas of Venice.

C Additional Results on Capitalization Analysis

In this section we report additional figures and tables in relation to the capitalization analysis.

Figure C1 shows the average price per square meter in a two-year window around the first activation of the sea wall for ground floor and higher floor properties, similarly to panel (a) of Figure 4, but splitting the sample by the elevation of the property. We find that the differential increase after the first activation of the sea wall in ground floor property prices is driven by properties at lower elevation levels, as expected.

Table C1 shows the results of a placebo test in which we estimate a version of equations (4) and (5) interacting the exposure dummies with a dummy equal to one all months after October 2019, which is one year *before* the sea wall was first activated. We restrict our sample to a one-year interval around October 2019 to avoid including periods after the first activation of the sea wall. We find again that ground floor property prices are lower than comparable houses located at higher floors. Interestingly we find that the discount is present for both low and high elevation areas, even if the magnitude is still larger for properties in low elevation areas. The discount for high elevation ground-floor properties could be driven by the extremely high-tide of November 2019, which reached almost 190 cm impacting areas of the city which have not been subject to flooding since the highest tide of 1966. Importantly for our analysis, we do not find any differential effect on ground floor properties after October 2019, neither in the full sample nor for properties above or below 140 cm. Additionally, we do not find any differential positive effect on properties located 110-140 cm after October 2019, confirming that the main results in Table 2 are driven by the sea wall activation, rather than by seasonal or anticipation effects.

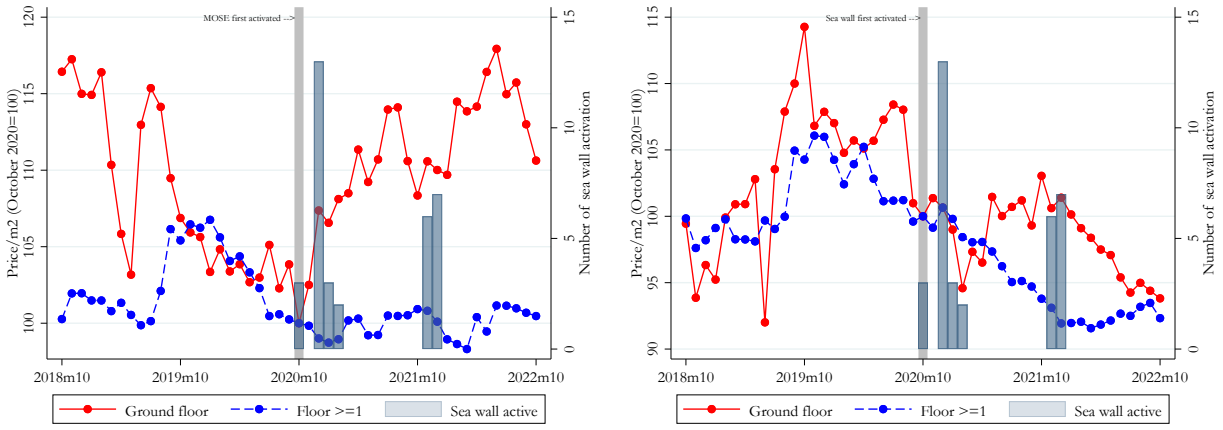
Table C2 shows the results using the same equations (4) and (5) from the main text and rent prices per square meter as dependent variable. Ground floor properties have on average lower rent prices per square meter than similar higher floor properties, but the difference is only marginally significant. We find that after the activation of the sea wall rent prices of ground floor properties do not increase relative to higher floor properties. The lack of significant results on rent price indicates that the activation of the sea wall affects ground floors mainly through the present discounted benefit from lower high-tide risk and related damage expenses, rather than by increasing flow utility of housing services, which is common to both rented and owner-occupied properties.

However, we acknowledge that few properties on the ground floor are rented, which limit the power of our analysis. Indeed when we look at higher floors and exploit variation based on elevation we find that after the activation of the sea wall rent prices of low-elevation properties increase relative to rents of higher-elevation properties. Most notably, columns (7) and (8) of Table C2 show a statistically significant increase by about 6%. This effect is consistent with renters benefiting from less flooding in the area where they live, which can impair the quality of living in an area. Hence, while landlords capture the majority of the benefits from both current and expected flooding, they can increase rent prices in areas which become more attractive after the activation of the sea wall.

Finally, we explore if property characteristics change as a result of the activation of the sea wall. Most notably, we use some of the characteristics X_i used in equation (4) as controls, now as dependent variables. We estimate the following specification:

$$y_{ilkt} = \beta Sea\ \ Wall_t + \theta X_i + \gamma_{lk} + \epsilon_{ilkt}, \tag{8}$$

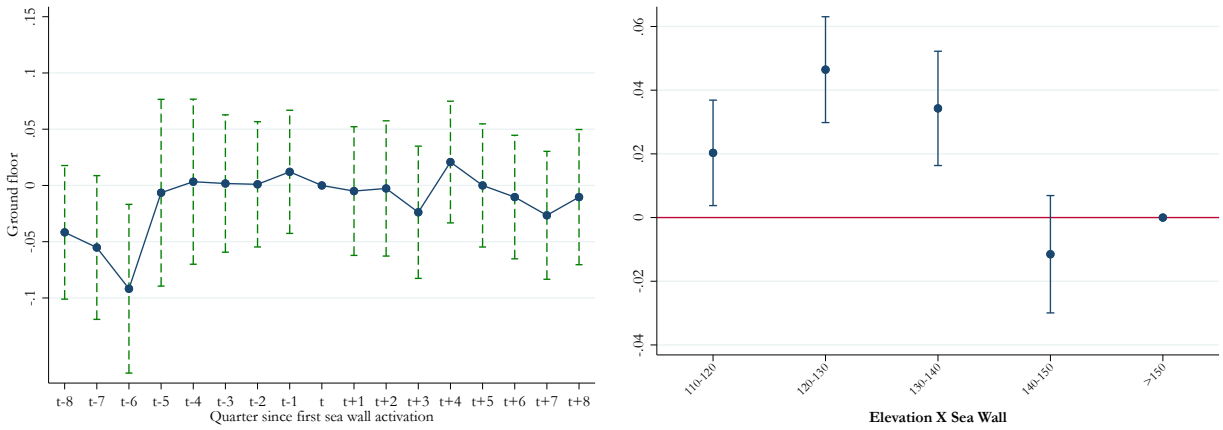
where y_{ilkt} is a characteristic of property i at time t (e.g, ground floor), X_i are other property characteristics, and γ_{lk} are location-type fixed effects. As a dependent variable we use a dummy for ground floor properties, the size of the property in square meters, and a dummy for properties in new conditions/just renovated. Table C3 shows the results. We cannot reject the null hypothesis that properties after the activation of the sea wall are similar to before in terms of fraction of ground floors, maintenance status and size. The point estimates are never significant and also small in magnitude.



(a) Elevation $\leq$ 140 cm (b) Elevation $>$ 140 cm

Figure C1: Prices per m^2 around the first activation of the sea wall

Note: The figure shows the average price per square meter in a four-year window around around October 2020, which is the month when the sea wall was first activated. The price is normalized to 100 in October 2020. The left figure focuses on properties with an elevation up to 140 cm relative to the reference point. The right figure focuses on properties with an elevation higher than 140 cm relative to the reference point. The blue vertical bars show the number of times the sea wall has been activated in the respective month.



(a) Ground Floor At High Elevation (b) Across elevation

Figure C2: Higher floors: Log prices per m^2

Note: Panel (a) shows the coefficients on the interaction terms between ground floor and quarter for properties with an elevation higher than 140 cm relative to the reference point. The estimated coefficients are based on equation (4) replacing the interaction term between ground floor and sea wall with interaction dummies of ground floors with time for quarters before and after the quarter of the first activation of the sea wall. Panel (b) shows the coefficient on 10 cm elevation bins and their interaction with the post-sea wall period. The estimated coefficients are based on equation (5) replacing the interaction term between elevation 110-140 cm and sea wall with interaction dummies of elevation: 110-120 cm, 120-130 cm, 130-140 cm, and 140-150 cm. The vertical bars are 95% confidence intervals.

Table C1: Effect of sea wall on residential properties: Placebo

	All properties		Elevation<=140		Elevation>140		Higher floors	
	(1) Level	(2) Log	(3) Level	(4) Log	(5) Level	(6) Log	(7) Level	(8) Log
Ground floor	-436.74***	-0.09***	-485.90**	-0.11**	-336.47**	-0.07**		
	(151.01)	(0.03)	(178.36)	(0.04)	(126.93)	(0.03)		
Ground floor × Sea wall placebo	71.90	0.01	-94.17	-0.02	198.11	0.05		
	(117.50)	(0.03)	(167.20)	(0.04)	(186.81)	(0.04)		
Elevation: 110-140							-49.33	-0.01
							(100.79)	(0.02)
Elevation: 110-140 × Sea wall placebo							-2.95	0.00
							(82.90)	(0.02)
FE location-type	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
FE year-month	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Controls	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Mean Y	4973.49	8.49	5012.48	8.49	4895.32	8.47	5091.32	8.51
SD Y	1137.27	0.23	1159.97	0.23	1086.30	0.22	1123.85	0.22
R2	0.38	0.40	0.38	0.41	0.51	0.52	0.33	0.34
Obs.	10109	10109	6745	6745	3364	3364	8053	8053

Note: The Table shows the estimates from equations (4) and (5) for the period October 2018 - October 2020. In columns (1), (3), (5) and (7) the dependent variable is the asking price in euro per square meter; in columns (2), (4), (6) and (8) the dependent variable is the log of the asking price in euro per square meter. Ground floor is a dummy equal to one for properties located on the ground floor. Sea wall placebo is a dummy equal to one in all months after October 2019, one year before the sea wall was first activated. Location-type fixed effects are interacted fixed effects for location and property type. Controls include floor surface, number of bathrooms, a dummy for garage and garden type, a dummy for the presence of an elevator, and several measures of distance of the property from tourist attractions (San Marco Cathedral, Rialto Bridge, Canal Grande), bridges and public boat stations. Standard errors are double clustered at the location-type and year-month level. *, **, and *** denote significance at the 10%, 5% and 1% levels, respectively.

Table C2: Effect of sea wall on residential properties: Rents

	All properties		Elevation<=140		Elevation>140		Higher floors	
	(1) Level	(2) Log	(3) Level	(4) Log	(5) Level	(6) Log	(7) Level	(8) Log
Ground floor	-0.89*	-0.05	-0.57	-0.03	-1.10*	-0.06*		
	(0.49)	(0.03)	(0.75)	(0.04)	(0.58)	(0.03)		
Ground floor × Sea wall	-0.05	0.01	-0.10	0.00	-0.33	-0.02		
	(0.40)	(0.03)	(0.53)	(0.03)	(0.88)	(0.04)		
Elevation: 110-140							0.03	-0.01
							(0.39)	(0.02)
Elevation: 110-140 × Sea wall							0.72	0.06**
							(0.43)	(0.02)
FE location-type	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
FE year-month	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Controls	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Mean Y	16.06	2.74	16.18	2.75	15.78	2.72	16.10	2.74
SD Y	4.59	0.27	4.73	0.27	4.20	0.28	4.66	0.28
R2	0.31	0.33	0.30	0.34	0.45	0.45	0.31	0.34
Obs.	27962	27962	19868	19868	8094	8094	24225	24225

Note: The Table shows the estimates from equations (4) and (5) for the period October 2018 - December 2022. In columns (1), (3), (5) and (7) the dependent variable is the asking rent price in euro per square meter; in columns (2), (4), (6) and (8) the dependent variable is the log of the rent price in euro per square meter. Ground floor is a dummy equal to one for properties located on the ground floor. Sea wall is a dummy equal to one in all months after October 2020, when the sea wall was first activated. Location-type fixed effects are interacted fixed effects for location and property type. Controls include floor surface, number of bathrooms, a dummy for garage and garden type, a dummy for the presence of an elevator, and several measures of distance of the property from tourist attractions (San Marco Cathedral, Rialto Bridge, Canal Grande), bridges and public boat stations. Standard errors are double clustered at the location-type and year-month level. *, **, and *** denote significance at the 10%, 5% and 1% levels, respectively.

Table C3: Effect of sea wall on residential properties: Selection

	All properties			Elevation<=140			Elevation>140		
	(1) Ground floor	(2) Floor area	(3) Status	(4) Ground floor	(5) Floor area	(6) Status	(7) Ground floor	(8) Floor area	(9) Status
Sea wall	0.01	0.17	0.00	0.00	-1.67	0.02	0.00	3.17	-0.04
	(0.01)	(1.87)	(0.03)	(0.01)	(2.11)	(0.03)	(0.01)	(4.22)	(0.04)
FE location-type	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
FE year-month	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Controls	0.11	109.80	0.54	0.10	112.23	0.53	0.13	104.85	0.55
Mean Y	0.32	65.64	0.50	0.31	67.13	0.50	0.33	62.21	0.50
SD Y	0.15	0.45	0.05	0.13	0.47	0.05	0.29	0.48	0.09
R2	26342	26342	26342	17670	17670	17670	8670	8670	8672

Note: The Table shows the estimates from equation (8). Ground floor is a dummy equal to one for properties located on the ground floor. Renovation status is a dummy equal to one for properties in new conditions/just renovated. Location-type fixed effects are interacted fixed effects for location and property type. Controls include floor surface, number of bathrooms, a dummy for garage and garden type, a dummy for the presence of an elevator, and several measures of distance of the property from tourist attractions (San Marco Cathedral, Rialto Bridge, Canal Grande), bridges and public boat stations. Standard errors are double clustered at the location-type and year-month level. *, **, and *** denote significance at the 10%, 5% and 1% levels, respectively.

Table C4: Effect of sea wall on residential properties: Spillovers

	By floor		By elevation	
	(1) Level	(2) Log	(3) Level	(4) Log
Comparable ground floor properties	-5282.08	-0.80		
	(5218.11)	(1.01)		
Comparable ground floor properties × Sea wall	1075.45	-0.41		
	(5447.24)	(1.02)		
Comparable low-elevation properties			-662.55	-0.05
			(2348.72)	(0.43)
Comparable low-elevation properties × Sea wall			846.51	0.19
			(1412.34)	(0.33)
FE location-type	Yes	Yes	Yes	Yes
FE year-month	Yes	Yes	Yes	Yes
Controls	Yes	Yes	Yes	Yes
Mean Y	5090.32	8.50	4791.72	8.44
SD Y	1468.91	0.28	1369.30	0.27
R2	0.31	0.35	0.45	0.47
Obs.	18690	18690	8725	8725

Note: The dependent variable of columns (1) and (2) is the (log) price/mq of upper floor properties located at an elevation of 110-140 cm, which represent the control group of specification (4) For these properties, we assess the spillovers potentially deriving from treated properties ('Comparable ground floor properties'), that is the share of ground floor properties located in the same neighborhood, with roughly the same size (±15%) and roughly at the same elevation (±15%) over the total number of properties put on sale in the same neighborhood during the same period (Oct. 2018 - Oct. 2020). The dependent variable of columns (3) and (4) is the (log) price/mq of upper floor properties located at high elevation (> 140 cm), which represent the control group of specification (5). For these properties, we assess the spillovers potentially deriving from treated properties ('Comparable low-elevation properties'), that is the share of upper floor properties located in the same neighborhood at an elevation between 110 and 140 cm, with roughly the same size (±15%) over the total number of properties put on sale in the same neighborhood during the same period (Oct. 2018 - Oct. 2020). Location-type fixed effects are interacted fixed effects for location and property type. Controls include floor surface, number of bathrooms, a dummy for garage and garden type, a dummy for the presence of an elevator, and several measures of distance of the property from tourist attractions (San Marco Cathedral, Rialto Bridge, Canal Grande), bridges and public boat stations. Standard errors are double clustered at the location-type and year-month level. *, **, and *** denote significance at the 10%, 5% and 1% levels, respectively.

D Tourist Revenues Losses Due to High Tides

High tides – in particular the most severe, that are becoming increasingly frequent – may discourage tourists from visiting the center of Venice, as they make the experience less enjoyable if not entirely wasteful. Interestingly, tourist flows in Venice exhibited a much more marked seasonal pattern compared to other Italian cities of art like Florence and Rome: tourist arrivals were concentrated in the summer months, when the risk of high tides is at its minimum. The activation of the sea wall can make the city more attractive to tourists, thereby generating additional revenues from accommodation, recreational and commercial activities. To roughly quantify these benefits, we proceed in three steps.

First, we exploit historical variation in high tides and tourist flows in Venice to estimate if and to what extent the occurrence of high tides used to influence tourist flows.[55] To this end, we run the following specification:

$$y_t = \beta \mathit{High\ tide}_{t-1} + \delta \mathit{Carnival}_t + \gamma_m + \epsilon_t, \tag{9}$$

where y_t is the log of the number of nights spent by tourists in the city – provided by the Italian National Statistical Institute (ISTAT) at monthly frequency since January 2008 – and $\mathit{High\ tide}_{t-1}$ is a dummy variable that takes a value of one if a tide higher than 110 cm occurred in the previous calendar month. We control for common seasonal patterns through calendar month fixed effects (γ_m) and by including a dummy ($\mathit{Carnival}_t$) for the Carnival days, when a lot of tourists reach the city for its peculiar and renowned celebrations. The coefficient on interest is β which captures the effect of floods on the number of tourists in Venice. We obtain a negative β of -0.052, statistically significant at the 5% level. This implies that high tides discourage tourist flows in the following days, reducing the number of tourist nights by about 5%.

The second step uses these estimates to simulate the number of tourist nights in Venice under two scenarios: (i) a baseline scenario based on the historical series of floods used in the estimation, and (ii) a counterfactual scenario that hypothesizes that no high tide had occurred over the sample period, which roughly mimics the situation after the activation of the sea wall. Figure D1 shows the results. Under the counterfactual scenario, the number of tourists is considerably higher, especially

[55] We use data up to December 2019 to exclude the major shifts induced by the pandemic.

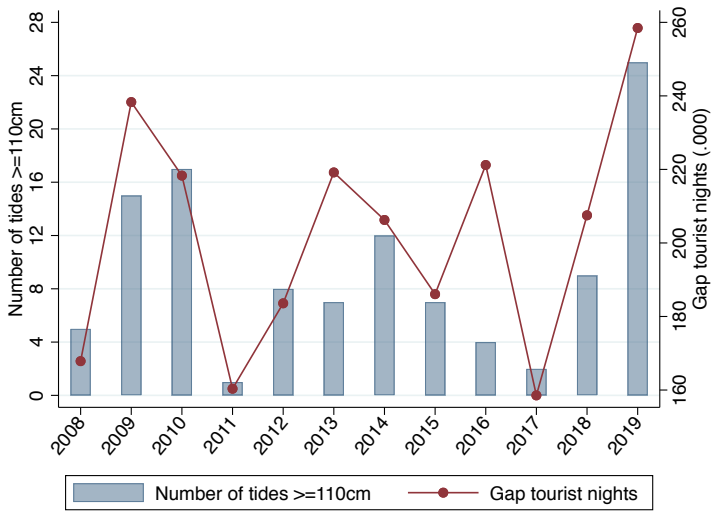


Figure D1: High tides and Lost tourist revenues

Note: The figure shows the number of high tides – defined as tides higher than 110 cm – from 2008 to 2019. The solid line shows the gap in the number of nights spent by tourist each year between a baseline scenario based on the historical series of floods used in the estimation of equation (9) and a counterfactual scenario that hypothesize that no high tide had occurred over the sample period, which roughly mimics the situation after the activation of the sea wall.

during the years that were affected by several floods. On average, our estimates imply that the sea wall could have increased the number of nights tourists spend in the city each year by 220,000 (about 0.7% of the total annual nights).

Finally, we convert the estimates on additional tourist nights into monetary values by considering external estimates on the average expenditure by tourists in Venice. According to conservative estimates, each tourist in Venice spends about €130 per day.[56] This leads to an estimate of 220,000*130 = €28,6 millions of additional revenues that may be generated annually by the sea wall via increased tourist flows.

[56] See Città di Venezia (2019).

E Additional Results on Cost-Benefit Analysis

In this section we report additional figures and tables in relation to the flow benefit and the cost/benefit analyses.

Our claim data come from almost 5,000 properties – 37% are residential and 63% commercial – which used a government-sponsored fund to help residents cover the expenses due to the flood. The average claim for residential properties is almost €2,500, while the average claim for commercial properties is higher at about €8,000. This difference is in line with the maximum amount that residents and businesses could demand: €5,000 for residential and €20,000 for commercial properties. Figure E2 shows that about 20% (7%) of residential (commercial) properties claimed the highest possible amount, but there is quite a lot of variation across properties. The standard deviation is €1,700 for residential properties and €6,300 for commercial properties. Most importantly, Figure E3 shows the binscatter of claims relative to elevation. Claims are negatively correlated with higher elevation levels, as we expected. For example, the average claim at an elevation of 110 – the threshold at which the sea wall is activated – is almost €2,600 for residential properties and €9,500 for commercial properties, while the average claim at an elevation of 150 – which was also flooded on November 12th 2019 – is approximately €2100 for residential properties and €8,100 for commercial properties.

We build our measure of imputed damages from the observed claim data in the following steps. First, we construct 10-cm elevation bins starting from 100 cm. Second, we divide total damages at each elevation bin by the number of properties in the historical center of Venice at the corresponding elevation level. For residential properties we restrict to ground floor properties by considering 10% of the properties, consistent with our analysis in Section 4.1 that damages are more likely for ground floor properties. On the other hand, commercial properties are most likely on the ground floor. Indeed, the ratio of commercial properties with claims over total properties is on average 40% and above 50% with elevation below 120 cm. Third, as the level of the November 2019 high tide was 187 cm, we can estimate for each elevation bin an approximate level of water depth. For example, for homes in the 130-140 cm elevation bin the water depth was about 50 cm. Therefore, the average damage computed in the previous step can be interpreted as a function of the water depth. Finally, we assume that damages are linear across levels of water depth to infer damages for other floods.

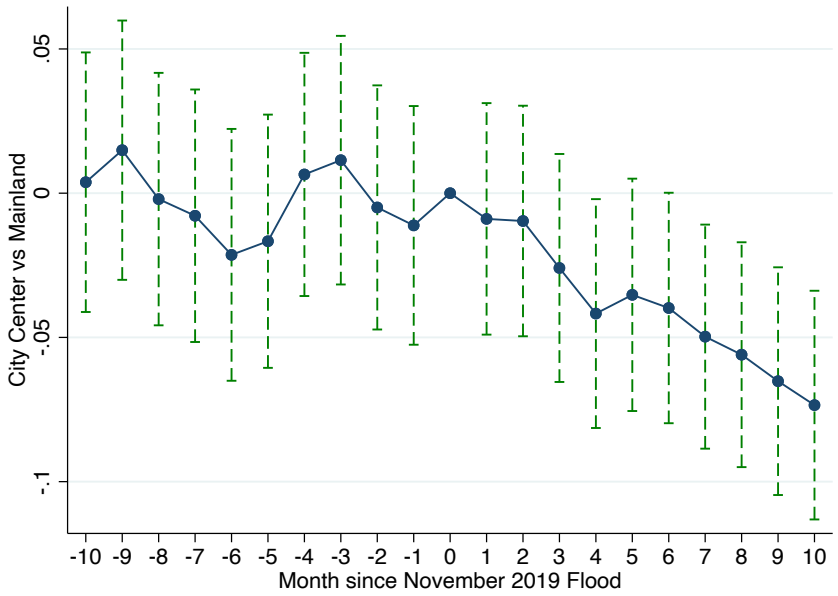


Figure E1: City center vs mainland: Log prices per m^2

Note: The figure shows the coefficients on the interaction terms between city center floor and month. The estimated coefficients are based on equation (7) replacing the interaction term between city center and post flood with interaction dummies of city center with time for months before and after the month of the extremely high tide. The vertical bars are 95% confidence intervals.

For example, we impute the damages of a 165 cm high tide on homes in the 110-140 cm elevation bin by exploiting the average damage of the November 2019 high tide on homes in the 130-140 cm elevation bin because the level of the water depth is similar.

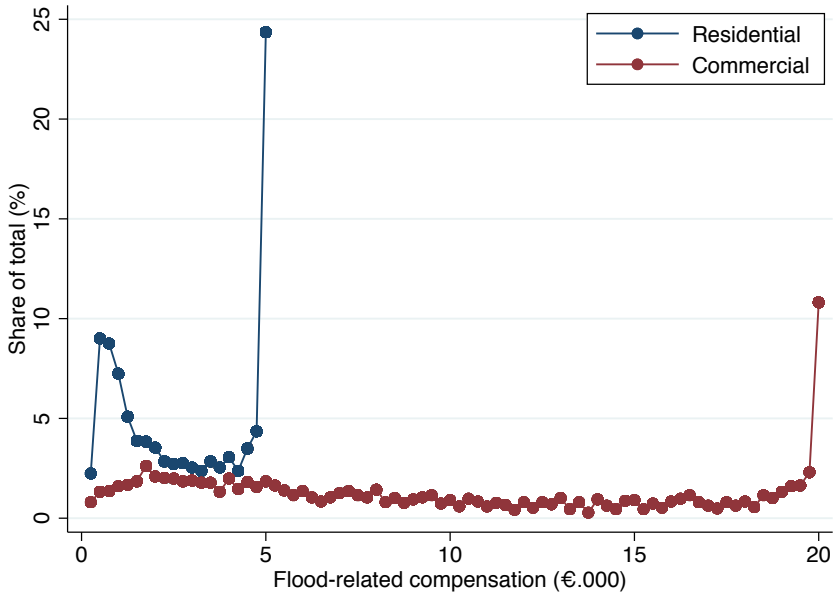
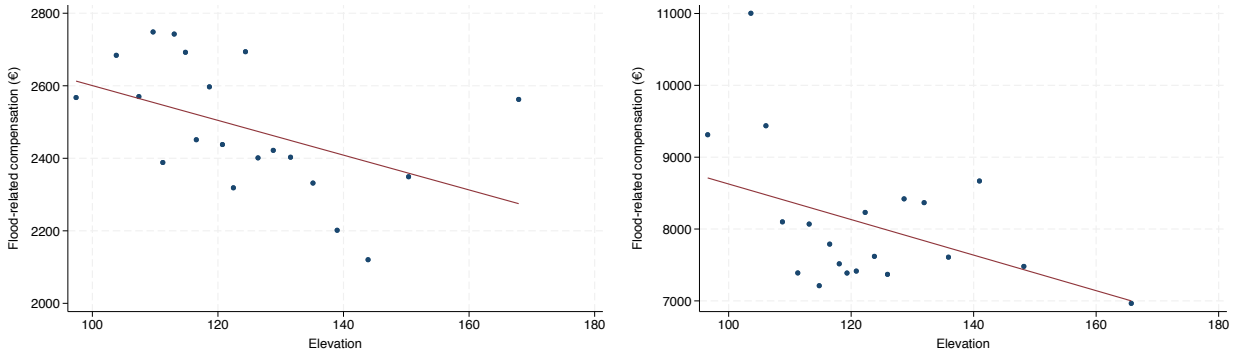


Figure E2: Residential and Commercial Claims after November 2019 Flood

Note: The figure shows the distribution of claims for residential and commercial properties after the November 2019 flood.



(a) Residential (b) Commercial

Figure E3: Claims and Elevation level

Note: Binscatter of flood-related claim for residential and commercial properties after the November 2019 flood by elevation level of the property. Panel (a) shows residential and panel (b) shows commercial properties.