Does Climate Change *Adaptation* Matter?

Evidence from the City on the Water [*]

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Abstract

This paper exploits the unexpected activation of a sea wall built to protect the city of Venice from increasingly high tides to estimate the capitalization of public investment in resilience infrastructure. A difference-in-differences hedonic design shows that properties above the sea wall activation threshold experience a permanent reduction in flood risk and expected damages, which are reflected in higher prices. Combining microdata on both residential and commercial properties, tourist flows, and damage claims, we estimate a lower bound at about €1 billion for capitalized benefits, which accounts for approximately 15% of the costs of the sea wall. Finally, we compute a break-even discount rate of 1.1%, which increases to 2.5% with sea level rise.

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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). 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] We leverage the recent unexpected activation of a sea wall to protect the city of Venice to provide new evidence on the capitalization into property values of infrastructure investment reducing flood risk. The sea wall activation in 2020 was a milestone in a multi-decades effort to make the city of Venice more resilient to increasing high tides and related flooding events.[3]

Our main empirical analysis exploits the quasi-experimental temporal discontinuity in the exposure to sea floods from the first unexpected activation of the sea wall to identify the causal effect

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[1] In the related literature, we discuss recent papers showing that not accounting for adaptation can have a large impact on the expected damages from climate change. Recent proposals in the US include building an 8-mile seawall around Charleston with an estimated cost of $2 billion, and a 1-mile wall for Miami-Dade with an estimated cost of $4.6 billion. The city of New York has recently started building a system of walls and floodgates, which is expected to cost $1.45-billion and be completed in 2026.

[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). In Section 2 we look at both high and low tides going back to 1870.

[3] The Major of Venice described the first activation of the sea wall as an "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`).

of a permanent shock to amenities (a reduction in flood risk) on both residential and commercial property prices. Combining time-series variation from the event with granular cross-sectional variation in properties stilts elevation and high-frequency data on prices, 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).[4]

We begin our empirical analysis by focusing on residential properties and leveraging a rich high-frequency dataset on house listings from the largest online portal for real estate services in Italy (Immobiliare.it). 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. One year after the first activation of the sea wall, the fraction of house listings mentioning high-tide and flood risk has decreased from 16% to slightly above 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 (DD) 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. Our second strategy focuses on higher floors and exploits variation in properties stilts elevation, as a measure of differential exposure to the sea wall.

First, we find that after the activation of the sea wall ground floor properties experience an in-

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

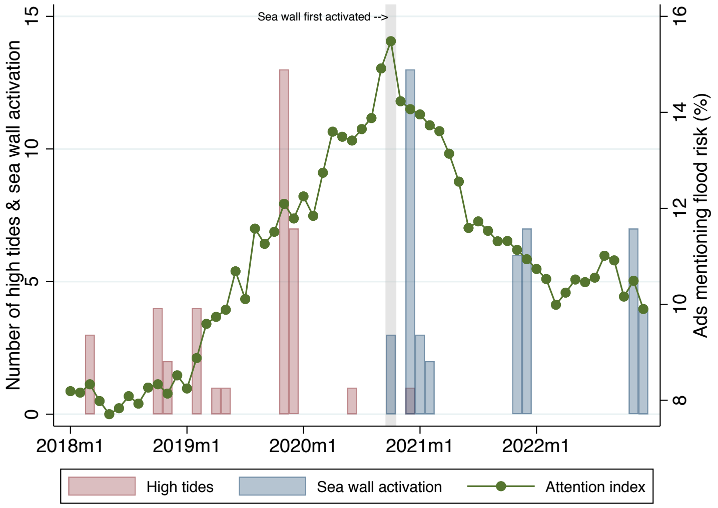

Figure 1: High tides, adaptation and attention to flood risk
Note: The green line shows a measure of climate attention which is a dummy equal to one if the property description mentions flooding, high tide or the sea wall. The Italian words used to compute the attention index are: "marea", "maree", "MOSE"and "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.

crease 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 properties. 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 test the robustness of our results. We rule out possible anticipation effects showing that sale prices of properties more or less exposed to flooding exhibited parallel trends before the activation of the sea wall. Moreover, 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 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.

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. The largest city-wide gains come from upper floors with an elevation of 110-140 cm that contribute for almost €370 millions, and from shops, that appreciate by €380 millions. Combining residential and commercial gains, 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.

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, changes in property prices around the first activation of the sea wall may not capture all the benefits from the public investment. First, while the first activation of the sea wall and its success was a surprise, its construction has been a decade-long process. Property prices might then have already incorporated some of the benefits from expected future adaptation. Second, 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.[6] Third, our econometric strategy measures only the

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[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.

[6] While we think this is a legitimate concern, we discuss more in the paper how government bailouts are both

relative benefits of sea wall activation for about two-thirds of properties that experienced a sharp reduction in flooding risk. Therefore, we also implement a complementary approach and construct two flow-based measures of the impact of floods.

First, we study the impact of high tides on annual tourist revenues. We find that high tides discourage tourist flows in the following days, reducing the number of tourists by about 5%. We then simulate the counterfactual number of tourists with an active sea wall and find that the number of nights tourists spend in the city each year would have been higher by 220,000, generating additional revenues of about €29 millions.

Second, we exploit detailed individual level data on claims by approximately five thousands households and businesses following the November 12th 2019 flood – the second highest level ever recorded in the history of Venice – to construct a measure of imputed damages. We assume for simplicity that damages are linear across elevation levels to infer the damages of other floods and construct three scenarios based on: (i) historical tides in the last 10 years; (ii) counterfactual tides in the first two years after the activation of the sea wall; and (iii) expected tides in 50 years due to sea level rise. In our preferred counterfactual scenario that exploits the availability of two different tide measurements for each event – one in the city center of Venice and one in the offshore platform – we estimate that the active sea wall prevented about €52 millions in annual damages during the first two years.

In the last part of the paper we compare the benefits capitalized in house prices and measured by annual flows to the costs of the sea wall.[7] Official documents from the Italian court of auditors estimate the construction cost of the sea wall at about €6.4 billions and expected annual maintenance-activation costs of €10 million. To compare the present value of total benefits from the sea wall to its cost, we need to make an assumption on the discount rate. The choice of the latter has been and still is an important area of debate, since discount rates effectively determine policy choices (Stern, 2007; Martin, 2012; Nordhaus, 2013; Giglio et al., 2021; Carleton and Greenstone, 2022; Bauer and Rudebusch, 2023; Howard et al., 2023). Using the capitalization approach, we find that the benefits reflected in residential and commercial properties cover approximately 15% of the costs. This estimate is not very sensitive to the choice of the discount rate, since the

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partial and delayed. For example the claims after a large flood in Venice in 2019 have not yet been paid almost five years after the event.

[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.

latter only affects the present value of the maintenance costs, and represents a lower bound on the benefits from the sea wall. We explore the sensitivity of the cost-benefit analysis based on flows to assumptions on discount rates and sea level rise. Motivated by the work of Drupp et al. (2018) and Giglio et al. (2021) we adopt a 2.5% discount rate as the baseline. In this case the present value of flow benefits cover almost 50% of the present value of the costs. Finally 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%.

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 on the choice of the discount rate for assessing public investments in adaptation.[8] While we cannot 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.

Related Literature. 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; Desmet et al., 2021; Fried, 2021; Carleton et al., 2022; Hsiao, 2022). Our work is most closely related to Kocornik-Mina et al. (2020), who find little permanent movement of economic activity in response to floods, and Gandhi et al. (2022), who show that cities protected by dams suffer more floods, but the effect of each flood is mitigated substantially. We complement these works based on a large cross-section of cities, by exploiting granular *within-city* data and quasi-experimental variation to identify the effect of adap-

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[8] 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.

tation, overcoming potential issues with local idiosyncratic shocks or heterogeneous trends across different cities. Given the sensitivity of models' estimates to adaptation strategies, empirically grounded estimates of the impact of *observed* investment in adaptation to sea level rise could be valuable.

Our work is also related to the large literature that exploits house prices to infer the local benefits from 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., 2022; Tsivanidis, 2018; Severen, 2019). Our paper is 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. We apply quasi-experimental techniques to retrieve a consistent estimation of the hedonic price schedule and study both residential and commercial properties. Additionally, by comparing the capitalization results with estimates of the (avoided) damages as a result of the sea wall, we show that our capitalized benefits represent a likely lower bound on the gain from the sea wall.

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., 2021). Other recent works have instead combined granular 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.[9] Second, all the aforementioned papers study an *increase* in actual or expected risk of flooding. Our work provides a new angle by looking into the effect on property values of a *decrease* in flood risk, as a result of infrastructure investment. Thus, our results provide an additional explanation for the wide range of estimates of capitalization of future flood risk in house prices: unobserved differences in adaptation investments.

Overview. The rest of the paper is organized as follows. 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 flow benefits from the sea wall. Section 6 presents a cost-benefit analysis and Section 7 concludes.

2 Setting

2.1 High Tides 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.

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[9] 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.

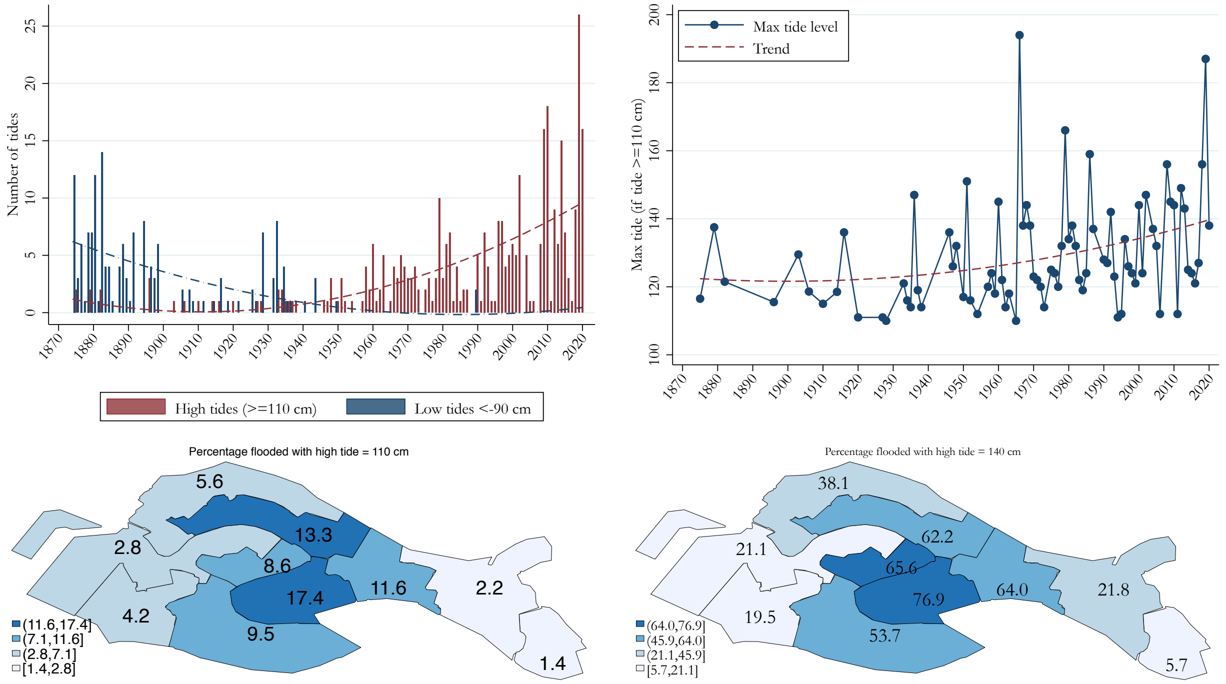

Figure 2: High Tides and Flooding in Venice

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.

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. In the last 50 years of the 20th century, tides higher than 150 cm occurred four times, 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).[10]

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. In November 12th 2019 the sea level reached almost 190 cm, which is the second highest level ever recorded in the history of Venice, causing about 90% of the city center to be flooded.[11] The bottom

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[10] 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.

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

panel of Figure 2 shows significant heterogeneity in flooding across different areas of Venice for two different levels of high tides.[12] For example, the San Marco area is about 17% flooded with a high tide of 110 cm and almost 90% with a high tide of 150 cm. The area of Castello to the far right is barely affected by a high tide of 110 cm, and is about 10% flooded when the sea level reaches 150 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 local 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 for residents and local governments, in line with the recent trend observed for other environmental risk in other parts of the world.[13]

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. Figure A3 shows the briefing from the official municipality of Venice website about the tide level on the day before and the day of the first activation of the sea wall. On October 2nd, the expected tide for the following

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alte-eccezionali).

[12] Figure A2 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.

[13] 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.

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 created a gap in the tide level between the open sea and the lagoon.[14]

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.[15] In normal times, the barriers are not visible because they are placed on the seafloor. When high tides are expected, the gates are temporarily raised and block the tide. 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 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. Panel (a) of Figure 3 shows the number of high tides measured in the city center of Venice and in the offshore platform.[16] From 1983 until 2019 the number of high tides registered in the city of Venice and the offshore platform closely track each other.[17] Hence the gap in high tides between the city of Venice and the offshore platform is close to zero in most years up until 2020 when the sea wall was first activated. For example, in 2021 ten high tides events were measured in the offshore platform and none of them affected the city of Venice.

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] To illustrate the activation process, panel (b) of Figure 3 shows the highest tide for each day for the month of December 2020. We show the highest tide recorded in the city of Venice and the highest tide among the offshore

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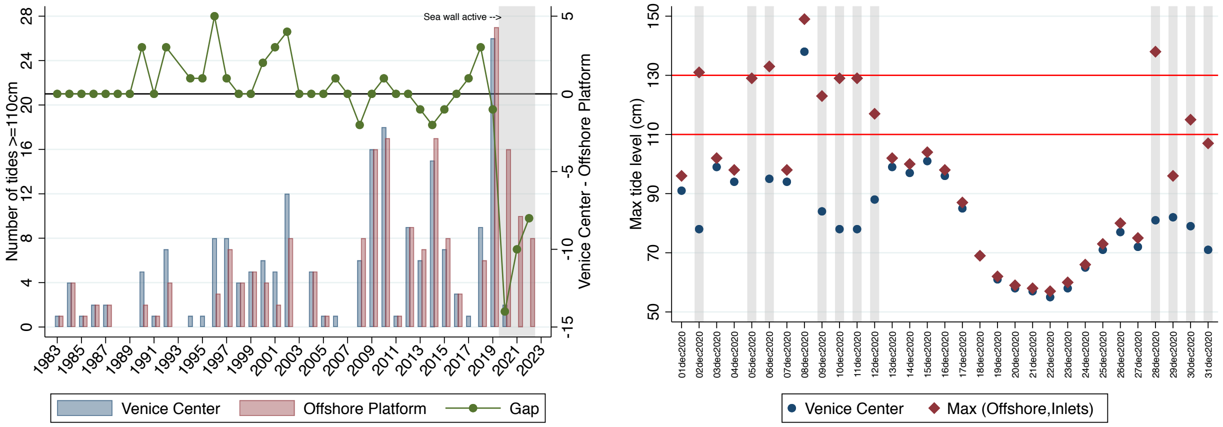
[14] In our empirical strategy we will exploit the high frequency nature of listing data to test for pre-trends and anticipation effects.

[15] The left panel of Figure A4 in the Appendix shows the location of the barriers at the three inlets relative to the city of Venice.

[16] The platform was installed in 1970 following the high tide of 1966 and since 1983 it is used to measure the tide levels (see: `https://www.comune.venezia.it/it/content/3-piattaforma-ismar-cnr`).

[17] Some differences can be due to changing meteorological conditions (e.g., winds) which can affect the tides between the two locations.

[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.



(a) Venice center VS Offshore Platform

(b) Tides in December 2020

Figure 3: Venice Sea Wall Operations

Note: Panel (a) shows the number of high tides (>=110 cm) registered in the city of Venice and the offshore platform and the gap between the two. Panel (b) shows the highest tide for each day for the month of December 2020. We show the highest tide recorded in the city of Venice and the highest tide among the offshore platform and the three inlets. The grey vertical bars denote the dates when the sea wall is activated. The red horizontal lines denote the activation thresholds at 130 cm and 110 cm.

platform and the three inlets.[19] The first two days of December 2020 provide an example of the activation process. On December 1st 2020, the measured tide in the open sea was 98cm, the sea wall was not activated and the recorded tide in the city of Venice was slightly lower at 92cm. On December 2nd 2020, the measured tide in the open sea was 132cm, the sea wall was activated protecting the city of Venice, which experienced a tide of less than 80 cm. Our empirical strategy will thus exploit that the sea wall reduced the risk of flooding for properties with an elevation above 110 cm.

Finally, we mention two additional insights into the operations of the sea wall. First, on December 8th the sea wall was not activated, as the predicted tide was below the experimental threshold. Panel (b) of Figure 3 shows that the measured tide in the open sea reached almost 150 cm, and the center of Venice was flooded with a recorded high tide of 138cm. The failure to raise the barrier on December 8th reflects the uncertainty around the estimates on predicted tide levels which depend on the measured sea level, as well as on wind, rain and river water. Second, and perhaps related to the failed activation of December 8th, the sea wall was activated toward the

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[19] The predictions are based on the sea level measured on the offshore platform and the three inlets, as well on other factors such as wind and rain. In the right panel of Figure A4 we show the tide measured in the offshore platform and each of the inlets separately.

end of 2020 for lower levels of the tide measured in the open sea. For example, Panel (b) of Figure 3 shows that on December 29th and 31st 2020 the tide measured in the open sea was below 110 cm but the sea wall was activated, protecting the city of Venice, which experienced tides around 80 cm. In the more recent period, the sea wall was activated even when the measured tide in the open sea was not more than 20 cm below the 110 cm threshold.[20] This behavior is consistent with a more conservative approach. Since December 8th 2020 the city of Venice has never experienced a tide greater than 110 cm.

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).[21]

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

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[20] Figure A5 in the Appendix shows the measured tide offshore and in the center of Venice for all dates in which the sea wall was activated in 2020-2021.

[21] Figure A7 in the Appendix shows that average transaction and listing prices for different areas are close to the 45 degree line.

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 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.[22] The vast majority of properties have no garage (99%) or garden (80%), while about 10% are in buildings with an elevator.[23]

The average elevation of properties relative to the reference point is about 130 cm, with a wide range of variation.[24] The lowest elevation is just above 80 cm, while the highest is almost 290 cm. Depending on historical observations of the sea levels and their elevation, properties have different flood probabilities. 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.

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[22] 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.

[23] 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.

[24] Since 1897 the measurement of the sea level and paving elevation is relative to the zero tide of Punta della Salute. Figure A6 in the Appendix shows the location of houses in our dataset in Venice main island.

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.

3.2 Descriptive Evidence

Do house prices in Venice reflect high tide risk? In this Section we investigate the relation between flood risk and house prices using variation across properties based on their elevation and floor. Figure 4 shows the cumulative distribution of houses in our dataset 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.

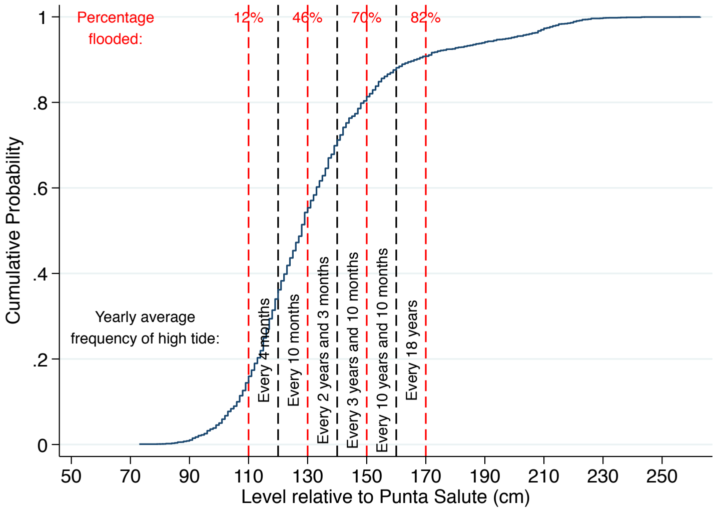

Figure 4: Distribution of properties across elevation levels

Note: The figure 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.

We study the relationship between elevation and house prices per square meter controlling for other determinants of house prices with the following empirical specification:

$$y_{ilkt} = \alpha Exposure_i + \theta X_i + \gamma_{lk} + \gamma_t + \epsilon_{ilkt}, \tag{1}$$

where y_{ilkt} is the house price per square meter for house i in location l of type k in period t; $Exposure_i$ is a measure of house i exposure to high-tide risk; X_i are other house characteristics; 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.[25] We define property type as the interaction of a house 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. Our measures of exposure are: (i) the daily probability that the building is flooded based on its elevation and the historical measurements

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[25] 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.

of daily sea level; (ii) a dummy for the property being on the ground floor; and (iii) the interaction of the previous two measures.

Table A1 in the Appendix shows the estimates from equation (1) in the year before the activation of the sea wall. Given the limited 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 housing prices through the lens of an asset pricing equation (Poterba, 1984). Assume that a representative household is indifferent between owning and renting a house of type h. We can then write the housing sale price in year t ($P_{h,t}$) as the present discounted value of expected future rents $R_{h,t}$ net of maintenance costs $C_{h,t}$:

$$P_{h,t} = \mathbb{E}_t \left[\sum_{j=0}^{\infty} \xi^{j}_{h,t+j} (R_{h,t+j} - C_{h,t+j}) \right], \tag{2}$$

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 (2) simplifies to:

$$P_{h,t} = \frac{\bar{R}_{h|t} - \bar{C}_{h|t}}{\bar{i}_{h|t}}, \tag{3}$$

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 house of type h can be expressed as:

$$\Delta P_h = \overbrace{\frac{\bar{R}_{h|after} - \bar{C}_{h|after}}{\bar{i}_{h|after}}}^{P_{h,after}} - \overbrace{\frac{\bar{R}_{h|before} - \bar{C}_{h|before}}{\bar{i}_{h|before}}}^{P_{h,before}} = \frac{1}{\bar{i}_{h|before}}\left[\Delta\bar{R}_h - \Delta\bar{C}_h\right] - \frac{\Delta\bar{i}}{\bar{i}_{h|before}} P_{h,after}. \tag{4}$$

Equation (4) shows that the revaluation of houses 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 ($\frac{\Delta\bar{i}}{\bar{i}_{h|t}} < 0$).

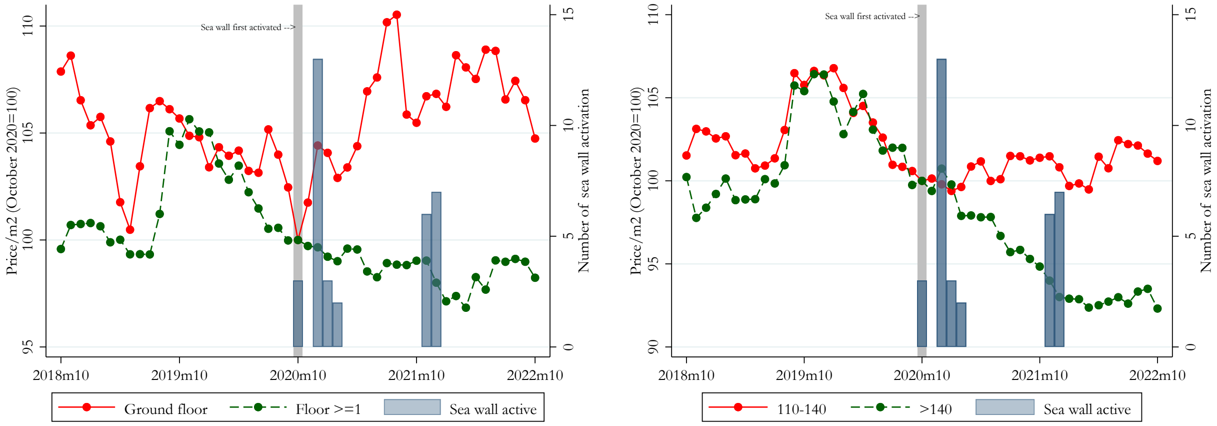
Our main analysis in Section 4 will focus on variation in house prices (ΔP_h) to capture the benefits from the sea wall that are capitalized. This approach lies in the tradition of hedonic models, which aim at estimating the (unobserved) implicit value of amenities through (observable) variations in housing prices. The key advantage is that we obtain a market-based present-value measure that does not require assumptions on discount rates. Furthermore, this approach exploits high-frequency data on property values and observable variation from the actual activation of the sea wall. In Section 5 we present additional complementary analyses that proxy factors on the right side of equation (4). Most notably, we study the impact of past floods on tourist flows, which could affect expected future rents ($\Delta\bar{R}_h$), and damages to properties, which are related to expected maintenance costs ($\Delta\bar{C}_h$). 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

4.1 The Effects of the Sea Wall on Residential Properties

4.1.1 Empirical Strategy

Our first identification strategy exploits the activation of the sea wall and its differential effect on ground-floor properties. Panel (a) of Figure 5 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. The price is normalized to 100 in October 2020, which is the month when the sea wall was first activated. The prices of higher floor properties experienced an increase toward the end of 2019,



(a) By Floor

(b) By Elevation

Figure 5: 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.

started to decrease in January 2020 and have been on a declining trend since then. This pattern is consistent with the aggregate trends in several Italian cities following the Covid-19 pandemic. The prices of ground floor properties tend to be more volatile, but the overall trend is similar to that of other properties until about the end of 2020 (in what follows we will test the parallel trend assumption more formally). From the beginning of 2021, after the sea wall successfully operated several times, ground floor properties have experienced an increase in values relative to October 2020, in sharp contrast to the declining trend observed for other properties.

To isolate the differential effect of the sea wall on ground-floor properties, we estimate the following difference-in-difference specification:

$$y_{ilkt} = \alpha \mathit{Ground\ Floor}_i + \beta \mathit{Ground\ Floor}_i \times \mathit{Sea\ Wall}_t + \theta X_i + \gamma_{lk} + \gamma_t + \epsilon_{ilkt}, \tag{5}$$

where $\mathit{Ground\ Floor}_i$ is a dummy equal to one if property i is on the ground floor; $\mathit{Sea\ Wall}_t$ is a dummy equal to one in all months after October 2020, when the sea wall was first activated; and other control variables and fixed effects are as in equation (1). The main coefficient of interest is β which captures the differential effect of the sea wall on ground floor properties.

We show in Section 3 that the discount for ground floor properties is higher in areas more exposed to flood risk. For the same reason, we might expect higher house price gains from the sea wall for ground floor properties in locations more exposed to flood risk.[26] To allow for heterogeneity across locations we estimate equation (5) both in the full sample and separately for properties with different elevation levels.

Our second identification strategy exploits variation to identify the effect of the sea wall on property values. Most notably, we exploit 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. Panel (b) of Figure 5 shows the average price per square meter in a two-year window around the first activation of the sea wall for properties with an elevation between 110 and 140 cm and for properties at higher elevation levels.[27] Properties with an elevation of 140 cm or higher have been on a declining trend since the start of the pandemic. Properties with an elevation level below 140 cm closely follow the declining pattern of higher elevation properties up until the end of 2020. From the beginning of 2021, after several successful activations of the sea wall, prices for properties with an elevation between 110 and 140 cm remain fairly stable (and even increase slightly), in sharp contrast to the large decrease observed for higher elevation properties.

Similarly to our first identification strategy, we estimate the following difference-in-difference specification:

$$y_{ilkt} = \alpha Low\ Elevation_i + \beta Low\ Elevation_i \times Sea\ Wall_t + \theta X_i + \gamma_{lk} + \gamma_t + \epsilon_{ilkt}, \tag{6}$$

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 (5). 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 (5) and (6) 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

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[26] Figure C1 in the Appendix 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 5, 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.

[27] We later estimate a more granular split by elevation and confirm that the effect of the sea wall is significant for properties with an elevation up to about 140 cm.

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.[28]

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%, relative to a discount pre-sea wall of 8%.

Columns (3)-(4) and (5)-(6) of Table 2 report the estimates of equation (5) 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.[29]

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

[29] 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, albeit imperfectly, renovation work that has been done to the property before listing. We also estimate specification (5) separately for properties in good conditions and property 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 (5) and (6) 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.

Ground floor properties with an elevation up to 140 cm experience an increase in price per square meter of about 500€. Similarly when we look at the log of the price per square meter, we find that ground floor properties in low elevation areas have an average 11% discount on the price, but this discount is more than halved by the activation of the sea wall, with ground floor properties prices per square meter increasing by 9%. 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. Consistent with the descriptive evidence from Table A1, we find that low elevation properties are listed at a discount relative to otherwise similar properties. However, the activation of the sea wall led to an increase in the price of properties 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.

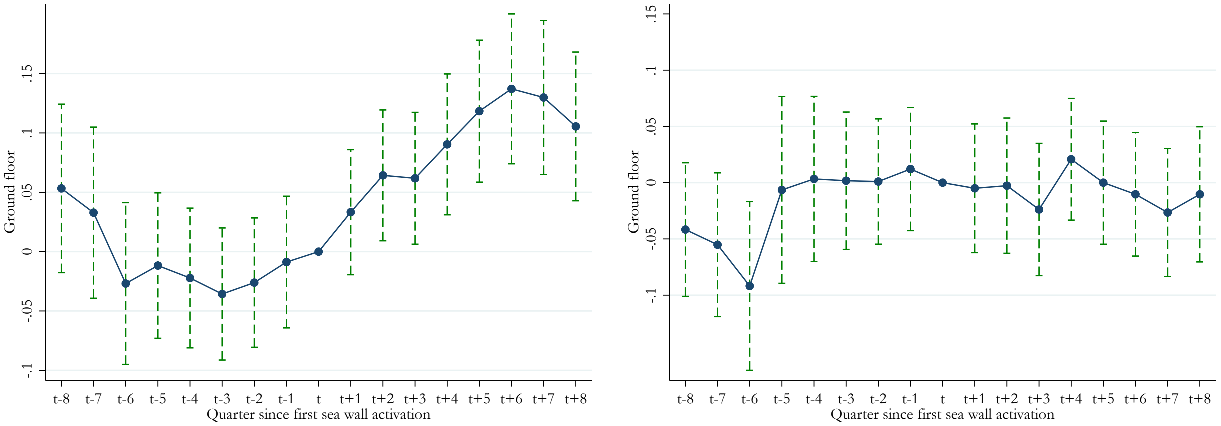
4.1.3 Additional Analyses and Robustness

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. This could have been the case because of *expectation* of future activation – even if we discussed in Section 2 the reason why we think the activation was a surprise – or other events (such as floods). We estimate a version of equations (5) and (6) in which we interact the dummy 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.

Figure 6 shows the coefficients on the interaction term between ground floor and quarter for properties with low and high elevation. Panel (a) of Figure 7 shows the coefficients on the interaction term between elevation 110-140 cm and quarter. The interaction term is 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; (ii) none of the interaction terms is significant for ground-floor properties in high elevation areas after the activation of the sea wall; and (iii) higher floors properties with an elevation between 110 cm and 140 cm experience a significant increase in prices per square meter.

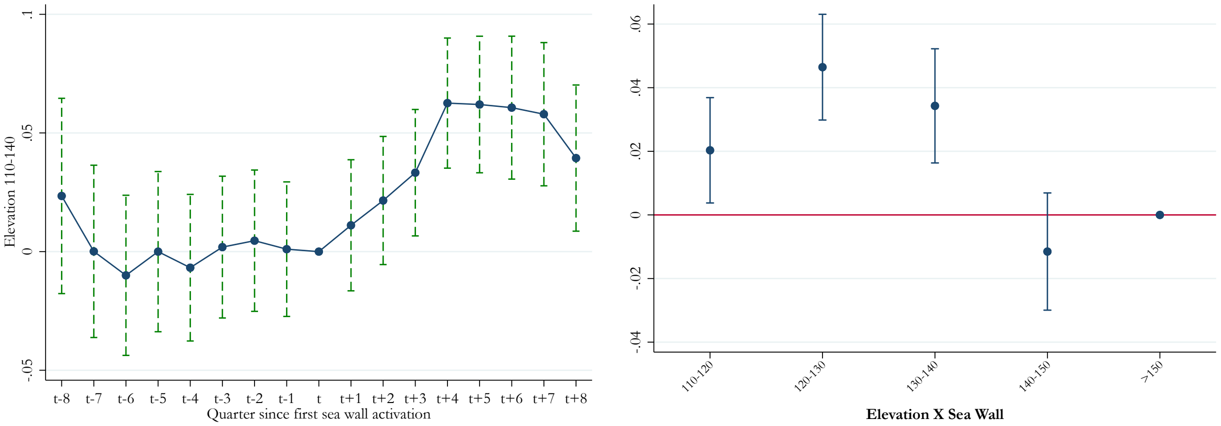
Elevation bins. We also estimate a version of equation (6) with 10 cm-bins for elevation levels. Panel (b) of Figure 7 reports the coefficients on the interactions of elevation bins with the post sea wall period. Relative to properties with an elevation higher than 150 cm, houses with an elevation 120-130 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



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

Figure 6: Ground 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 up to 140 cm relative to the reference point. Panel (b) 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 (5) 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. The vertical bars are 95% confidence intervals.



(a) Over time (b) Across elevation

Figure 7: Higher Floors: Log prices per m^2

Note: Panel (a) shows the coefficients on the interaction terms between elevation 110-140 cm and quarter. The estimated coefficients are based on equation (6) 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. 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 (6) 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.

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 (5) and (6) 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 part 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 (5) and (6) 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.

4.1.4 Interpretation of the Results

Combining the framework from Section 3.3 with the estimates based on the different measures of exposure we discuss possible economic channels for our results. First, higher-floor properties are less exposed to flood-related physical damages: $\Delta\bar{C}_h \approx 0$ in equation (4). Hence, the price change for these properties after the activation of the sea wall is mainly informative about the contributions of changes in expected rents and the discount factor. If we assume a rate of 2.5% to discount rental flows, we obtain that higher future rents contribute by about 14% to the appreciation of residential properties after the activation of the sea wall, while the remaining impact can be attributed to a reduction in the discount factor.[30]

Second, the differential impact of the sea wall on ground floor properties can plausibly be interpreted as a reduction in the expected discounted flow of maintenance expenditures due to physical damages. By plugging our estimates in equation (4) and assuming a discount rate of 2.5% and a reduction in the risk premium equal for ground and upper floor properties, we obtain $\Delta\bar{C}_h$ = -€8.6/m2 or roughly -€970 for an average apartment of 112.5 square meters.[31] This number represents the average annual expected damage that ground floor properties would have suffered absent the sea wall. Unfortunately precise estimates of maintenance costs to repair damages from floods are not available. However, these estimates of expected maintenance expenses backed out from the asset price equation are in the same order of magnitude of the expected damage estimates inferred from claim data that we present in Section 5.

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[30] A discount rate of 2.5% is an intermediate value between the near-zero time discount rate advocated by Stern (2007) on ethical grounds and the 6% discount rate proposed by Nordhaus (2007) for consistency with today's marketplace real interest rates. This value is also consistent with the long-run discount rates estimated by Giglio et al. (2014). We obtain this results by plugging our estimates of Tables 2 and C2 in equation (4), assuming $\Delta\bar{C}_h = 0$ and $\bar{i}_{h|t} = 0.025$. By further observing that the average price of an upper-floor apartment at elevation 110-140 is around €5000 we can solve for $\Delta\bar{i}$: $200 = \frac{1}{0.025} * 0.72 - \frac{\Delta\bar{i}}{0.025} * 5000$. We obtain $\Delta\bar{i} = -0.00856$. The rental component of the price appreciation is simply calculated as $\frac{1}{0.025} * 0.72$ (the first term on the r.h.s) over 200 (the l.h.s), which yields 0.144.

[31] We can plug our estimates of Tables 2 and C2 for ground floor properties (implying no effects on rental prices, $\Delta\bar{R} = 0$) in equation (4), assuming $\bar{i}_{h|t} = 0.025$ and $\Delta\bar{i} = -0.00856$ as found for upper floor properties. By further observing that the average price for a ground-floor apartment at elevation 110-140 is around €4600 we have: $500 = \frac{1}{0.025} * (-\Delta\bar{C}) + \frac{0.00856}{0.025} * 4600$. By solving for $\Delta\bar{C}$ we obtain: $\Delta\bar{C} = -8.6$.

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 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.[32]

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:

$$y_{ilkt} = \alpha Sea\ Wall_t + \beta_1 Covid_t + \beta_2 Reopening_t + \theta X_i + \gamma_{lk} + \epsilon_{ikt} \tag{7}$$

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

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[32] We return to these effects on tourist flows and revenues in Section 5.

sea wall on commercial properties.

The main difference of the empirical specification (7) relative to our identification strategy for residential properties (given by equations (5) and (6)) 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] 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. 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.

Columns (5)-(8) of Table 3 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 25% 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. Finally, we find that during the Covid shutdown in March-May 2020 commercial property prices experienced a significant decline.

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

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[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.

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	2,115.6***	0.14***	2,284.4**	0.15***	3,596.2**	0.24**	3,741.6**	0.25***
	(348.0)	(0.01)	(397.9)	(0.02)	(693.5)	(0.04)	(665.6)	(0.03)
Covid (March-May 2020)	-1,446.5**	-0.21**	-978.1	-0.15	-2,117.6***	-0.33***	-1,950.9*	-0.35***
	(414.4)	(0.05)	(667.8)	(0.09)	(347.2)	(0.04)	(648.8)	(0.05)
Covid (June-August 2020)	-2,098.5***	-0.13*	-1,797.8**	-0.11	-4,709.0**	-0.35***	-4,157.2**	-0.33***
	(289.5)	(0.05)	(367.9)	(0.06)	(819.4)	(0.05)	(917.3)	(0.03)
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	7,667.0	8.52	7,667.0	8.52	6,719.1	8.43	6,719.1	8.43
SD Y	15,989.2	0.93	15,989.2	0.93	15,989.2	0.93	15,989.2	0.93
R^2	0.22	0.33	0.22	0.35	0.16	0.13	0.17	0.16
Observations	1,079	1,079	1,079	1,079	583	583	583	583

Note: The Table shows the estimates from equation (7) 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.

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.

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). 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. The overall area of shops located in the historical city center is taken from the municipality of

Venice.[34] Panel A of Table 4 reports some descriptive statistics: the total residential area is about 3.3 millions of square meters. In terms of elevation, residential area with an elevation between 110 cm and 140 cm accounts for almost 60% of the total, consistent with the distribution of properties in our listing data from Figure 4. 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.[35] 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.[36] 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, for each of the six residential categories and for shops we compute the percentage gain from the sea wall, combining the estimates from Tables 2 and 3. Based on our estimates, 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. 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. Upper floors with an elevation between 110 cm and 140 cm gain 4%. We assume there is no gain for all properties with an elevation below 110 cm and discuss below the implications for our estimates. As we discussed in Section 4, the gains for commercial properties are much larger, reaching 25%

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

[35] 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 A7 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.

[36] 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.

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.

for shops (column (8) of Table 3).

Fourth, we multiply the average area in square meters by the average price per square meter and 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 shops we obtain an overall gain of about €825 millions or almost €1 billion considering all commercial properties.

We discuss further the magnitudes of our capitalization results relative to the cost of the sea wall and to expected damages from future floods, as well as some limitations of our analysis in Section 6.

5 Additional Analyses of Flow Benefits

In this Section we adopt a complementary approach to the one in Section 4 to gauge the benefit of the sea wall. Most notably, we construct two flow-based measures of the impact of floods: (i) tourist revenues, which proxy for the temporary loss of economic activity in a city where tourism plays a vital role; and (ii) claims data for flood-related damages, which capture the cost of restoring the infrastructure.[37] In the main text we discuss briefly our measures and the main results. Additional details are provided in Appendix D.

5.1 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.[38] To this end, we run the following specification:

$$y_t = \beta High\ tide_{t-1} + \delta Carnival_t + \gamma_m + \epsilon_t, \tag{8}$$

where y_t is the log of the number of nights spent by tourists in the city – provided by the Italian

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

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

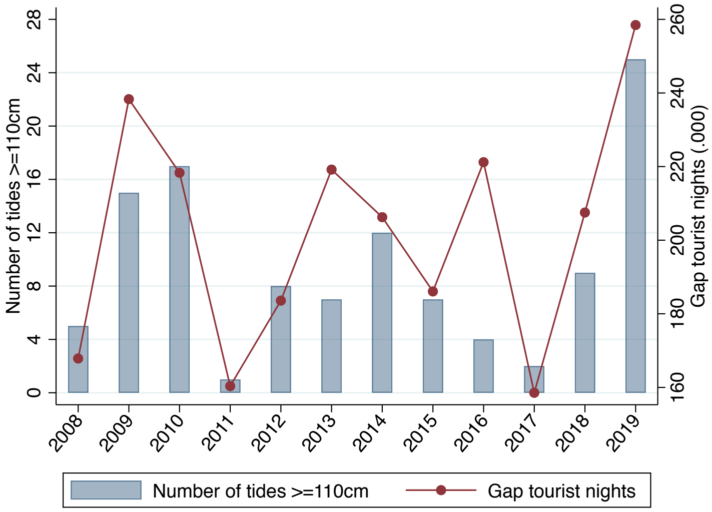

Figure 8: High tides and Lost tourist revenues

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 (8) 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.

National Statistical Institute (ISTAT) at monthly frequency since January 2008 – and $High\ tide_{t-1}$ 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 ($Carnival_t$) 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 8 shows the results. Under the counterfactual scenario, the number of tourists is considerably higher, especially 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.[39] 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.

5.2 Claims for Flood-related Damages

Our second measure of flow benefits from the sea wall is based on the avoided damages from floods. We obtained detailed data on claims 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.[40] 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.[41]

Figure 9 shows that variation in average claims per property is negatively correlated with elevation, as we expected.[42] 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.[43] 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

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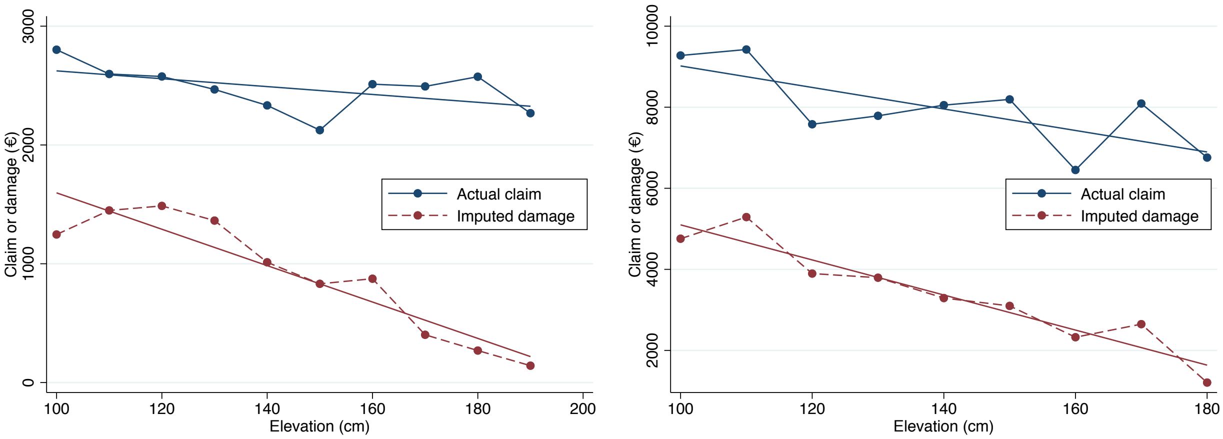
[39] See Città di Venezia (2019).

[40] 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.

[41] 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).

[42] Figure D2 in the Appendix shows the binscatter.

[43] Figure D1 shows that about 20% (7%) of residential (commercial) properties claimed the highest possible amount.



(a) Residential

(b) Commercial

Figure 9: 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.

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.[44] Figure 9 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. Notice that, although being derived from different data and methodologies, the average imputed damage for residential properties is very close to the estimates for damages to ground floors derived from the asset pricing equation in Section 4.1.

Finally, we combine imputed damages with information on the frequency of high tides to compute the expected benefit from the sea wall. Table 5 shows the results. Panel A represents the scenario based on observed high tides in the last ten years. The annual number of tides above 110 cm – the activation threshold of the sea wall – is about 11. The total damages to residential

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[44] We discuss the procedure in detail in Appendix D.

Table 5: Flood-related damages in different scenarios

	Elevation								Total
	110	120	130	140	150	160	170	180	
Panel A: 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 B: 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 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 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 B 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 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).

properties amount to €5.6 millions per year, while damages to commercial properties reach about €45 millions. 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 110 cm are similar to total commercial damages at 140 cm. The former are due to many tides with relatively limited effects, while the latter come from only a few tides with larger impacts.

Panel B of Table 5 reports our baseline *counterfactual* damages with no sea wall for the years 2021-2022. As Figure 3 shows, we have two measurements of the tides for each event: one in the city center of Venice and one in the offshore platform. Absent the wall the tide in the two locations is almost identical.[45] Therefore, we can construct a counterfactual tide that would have affected the city of Venice if the sea wall was not present. We find Venice would have experienced a total of 24 high tides, with a very high tide at 170 cm. 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.

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[45] As we discussed in relation to panel (a) of Figure 3 in Section 2 some gaps might be due to changing meteorological conditions (e.g., winds).

Finally, in Panel C of Table 5 we also show *expected* damages using predicted high tides in 50 years by Caporin and Fontini (2014). As a result of sea level rise, the number of annual high tides increases to about 30. Tides below 120 cm triple and tides above 150 cm double compared to the last ten years. As a result, 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

We now compare the benefits from the sea wall capitalized in property values and proxied by higher tourist flows and lower damages with the cost of the sea wall. Panel A of Table 6 reports the costs associated with the sea wall. Official documents from the Italian court of auditors estimate the construction cost of the sea wall at about €6.4 billions.[46] 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.[47]

Panel B summarizes the benefits coming from our two complementary approaches. The benefits capitalized in property prices amount to almost €1 billion (see Table 4). The annual flow benefits from higher tourist flows and lower damages amount to about €80 million in the baseline case, and can increase to about €172 million with sea level rise (see Section 5). Before comparing costs and benefits, we briefly discuss the pros and cons of our two approaches to measure the benefits from the sea wall and what we can learn by comparing them.

Our empirical strategy in Section 4 lies in the tradition of hedonic models, which aim at estimating the (unobserved) implicit value of amenities through (observable) variations in housing prices.[48] Most notably, our difference-in-differences (DD) hedonic design exploits the activation

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

[47] 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).

[48] Under stark assumptions, estimates from standard hedonic models using cross-sectional data can be used to infer the buyer's marginal willingness to pay (WTP) for a given amenity of interest (Rosen, 1974). In practice, however, unobserved attributes and endogenous sorting could bias the estimates from cross-sectional hedonic models. As discussed by Greenstone (2017), to overcome these issues a recent stream of literature has combined hedonic price functions with the econometric framework for program evaluation (Chay and Greenstone, 2005; Greenstone and

Table 6: Costs and Benefits Analysis of the Sea Wall

	Present value	Annual flow		Different discount rates			
		Baseline	SLR	Upper bound	Baseline	Break-even	
						Baseline	SLR
				8.00%	2.50%	1.10%	2.53%
Panel A: Costs (€M)							
Construction	6400						
Maintenance		10	10	125	400	905	396
Total				6525	6800	7305	6796
Panel B: Benefits (€M)							
Capitalization							
Residential	455						
Commercial	535						
Total	990						
Flow Analysis							
Tourism		29	29				
Damages		52	143				
Total		81	172	1009	3228	7305	6796
Panel C: Benefits/Costs							
Benefits Capitalized in House Prices/Costs				15%	15%	14%	15%
Benefits from Flow Analysis/Costs				15%	47%	100%	100%

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 flow analyses of Section 5. Panel C reports the ratio of benefits over costs.

of the sea wall as a permanent shock to amenities (a reduction in flood risk) and identifies how this shock has been capitalized into housing prices. Thus, a key advantage of our capitalization approach is that it provides a present-value measure of benefits that is market-based, empirically identified using high-frequency price variation around the unexpected activation of the sea wall, 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 may not capture all the benefits from the sea wall. First, while the first activation of the sea wall and its success was a surprise, its construction has been a decade-long process. Property prices might then have already incorporated some of the benefits from expected future adaptation. Additionally, residents might fail to fully internalize the

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Gallagher, 2008; Kuminoff and Pope, 2014; Banzhaf, 2021). This is also the approach adopted by this paper.

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.[49] For these reasons, we interpret the capitalized benefits as a lower bound and support this claim by comparing them to different present values of estimated flow benefits.

The second approach, based on estimates of annual lost tourist revenues and damages to buildings due to floods provides a direct measure of benefits, rather than an indirect one through property prices. On the other hand, the flow analysis requires potentially strong assumptions on: (*i*) the future likelihood of floods; and (*ii*) the discount rate to obtain a present value measure. In Table 6 we consider how both these factors affect our cost and benefit calculations.

First, we report compute the present value of avoided damages both in the baseline counterfactual with no sea wall for the years 2021-2022 (Baseline), as well the expected avoided damages using predicted high tides in 50 years by Caporin and Fontini (2014) (Sea level rise - SLR). Second, 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). We consider three different discount rates. We calibrate an upper bound for the discount rate to match the capitalized benefits, which gives a discount rate of 8%. The baseline choice of 2.5% is motivated by the work of Drupp et al. (2018) and Giglio et al. (2021). Finally, 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%. 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). 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%.[50] Finally, in the case with sea level rise the break-even rate is almost identical to our baseline rate of 2.5%.

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[49] 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/`).

[50] See `https://www.whitehouse.gov/wp-content/uploads/2023/02/M-23-12-Appendix-C-Update_Discount-Rates.pdf`.

Panel C of Table 6 reports the ratio between costs and benefits. Using the capitalization approach we find that the benefits reflected in residential and commercial properties cover approximately 15% of the costs. This conclusion is not very sensitive to the choice of the discount rate, since the latter only affects the present value of the maintenance costs. The conclusions of the flow analysis rely heavily on the discount factor, confirming its central role in affecting policy recommendations, as well as on projection about future high tides. In our baseline case with a 2.5% discount rate the benefits account for almost 50% of the cost. If tides remain stable over the next several years, the sea wall becomes a positive net-present-value investment for discount rates below 1.1%. However, with sea level rise, the sea wall becomes a positive net-present-value investment already with a discount rate below 2.5%.

In Appendix D we also explore the role of cost inflation from planned to actual. Most notably, Table D1 replicates Table 6, but showing the original planned costs rather than the final costs, which have been affected by delays and political scandals. The original project expected cost was 3,200 billions of Italian lira in 1989, which correspond to about €3.4 billions at the time of the first sea wall activation (we leave the maintenance costs unaffected).[51] In this case, the capitalized benefits already cover almost 30% of the costs, and the estimated flow benefits discounted at the baseline rate of 2.5% account for about 85% of the costs. The break-even discount rate without sea level rise is about 2% and the break-even discount rate with sea level rise is 4.75%.

To summarize, our analysis comparing the different estimated benefits with the costs of the sea wall yields two main results. First, the benefits capitalized in residential and commercial prices cover about 15% (30%) of actual (planned) the cost of the sea wall. This represents a lower bound, which is consistent with property values already incorporating some benefits before the first activation of the sea wall, as well as with residents underestimating future floods or having very high discount rates. Second, the combination of realistic flood-related damages to properties and economic activity with a low discount rate makes the sea wall a positive net-present-value investment.

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[51] See `https://www.contocorrenteonline.it/2020/12/09/mose-non-funziona-costo-venezia-acqua-alta/` and `https://it.wikipedia.org/wiki/MOSE`)

7 Conclusions

This paper exploits the activation of a sea wall to protect the city of Venice to provide new evidence on the capitalization of infrastructure investment reducing flood risk into housing values. Using new high-frequency data on house listings from the largest online portal for real estate services in Italy, we implement a difference-in-differences identification strategy that exploits variation in the activation of the sea wall – based on expected tides – as well as in the exposure of different properties – based on characteristics (ground vs higher floors, stilts elevation). We find that the sea wall increases house prices by 4% for properties above the activation threshold and by an additional 9% for ground-floor properties. An event study analysis for commercial properties finds even larger appreciation at about 15-25%.

Combining the empirical estimates for residential and commercial properties, we find that capitalized benefits from a permanent decrease in flood risk reach almost €1 billion, which account for about 15% of the costs of the sea wall. Using additional data on tourist revenues losses and claims for property damages due to floods, we show that capitalized benefits are a likely lower bound on total benefits. If tides remain stable over the next several years, the sea wall becomes a positive net-present-value investment only with low discount rates low (around 1%). However, with sea level rise, However, with sea level rise, the sea wall becomes a positive net-present-value investment already with discount rate below 2.5%.

More broadly, our results show that forward-looking property prices capture the benefits of public investment to reduce the damage from climate change, albeit imperfectly if government interventions compensate residents in the case of extreme events. Additionally, we show that combining market-based capitalization measures with flow-based estimates of potential economic damages and different assumptions on discount rates can provide reasonable bounds on cost-benefit calculations. Exploring the financing of adaptation policies – for example via targeted property tax increases – and studying the interaction of adaptation investment with private and public insurance would be interesting areas for future research that could yield additional insights for policymakers.

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Internet Appendix

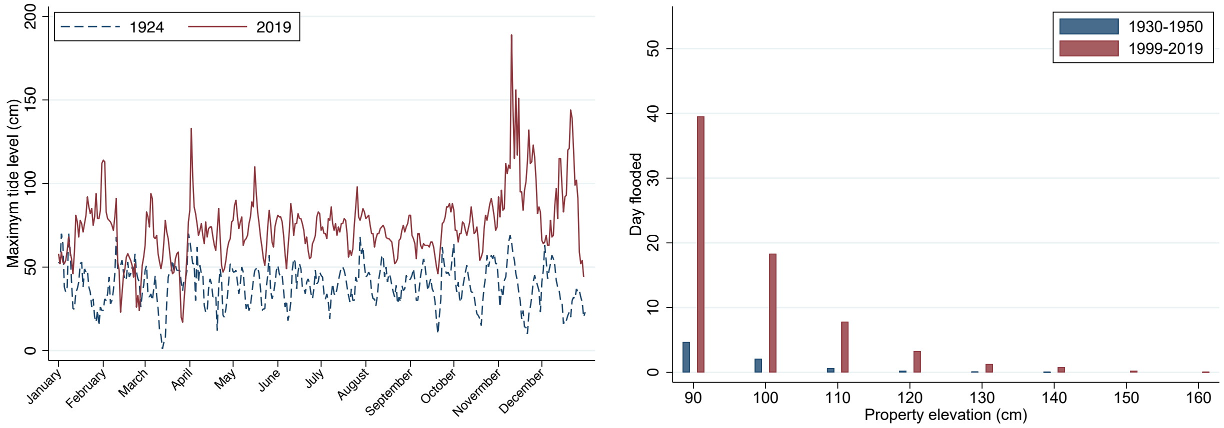
Appendix A provides supplementary figures and tables for the data and setting. Appendix B discusses data sources, variables and the construction steps for the final dataset. Appendix C provides supplementary figures and tables for the empirical analysis of residential and commercial properties, as well as the capitalization exercise. Appendix D provides supplementary analysis of the 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 from equation (1) 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.

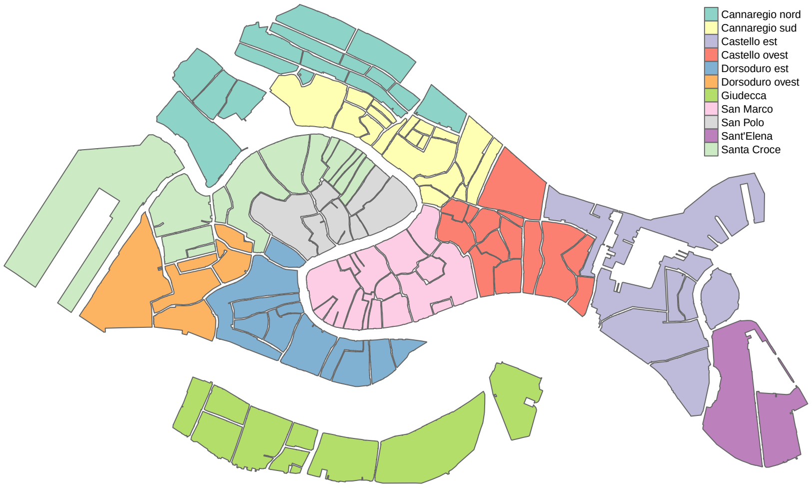
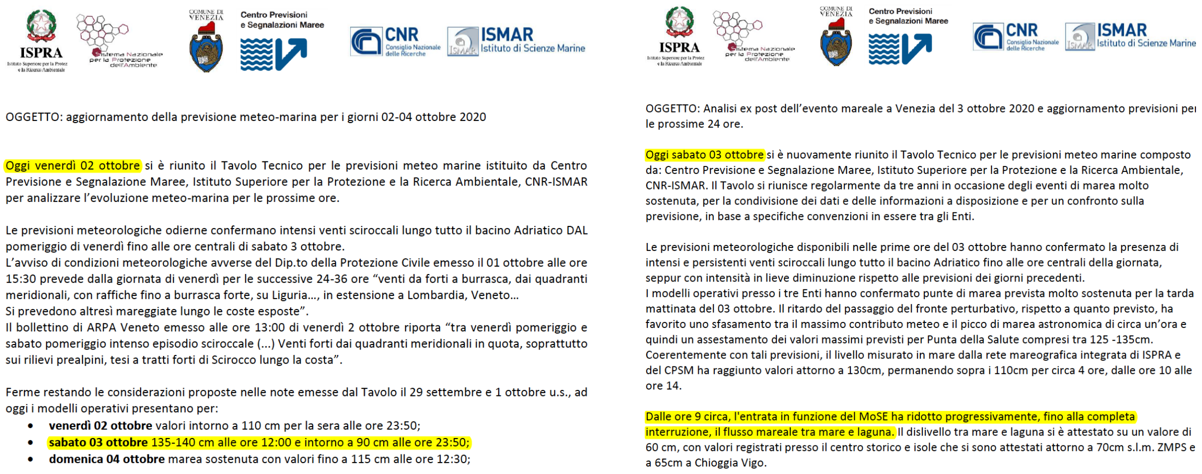


Figure A2: Venice Neighborhoods
Note: The figure shows the name and areas of the different neighborhoods in Venice main island.



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 A3: 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".

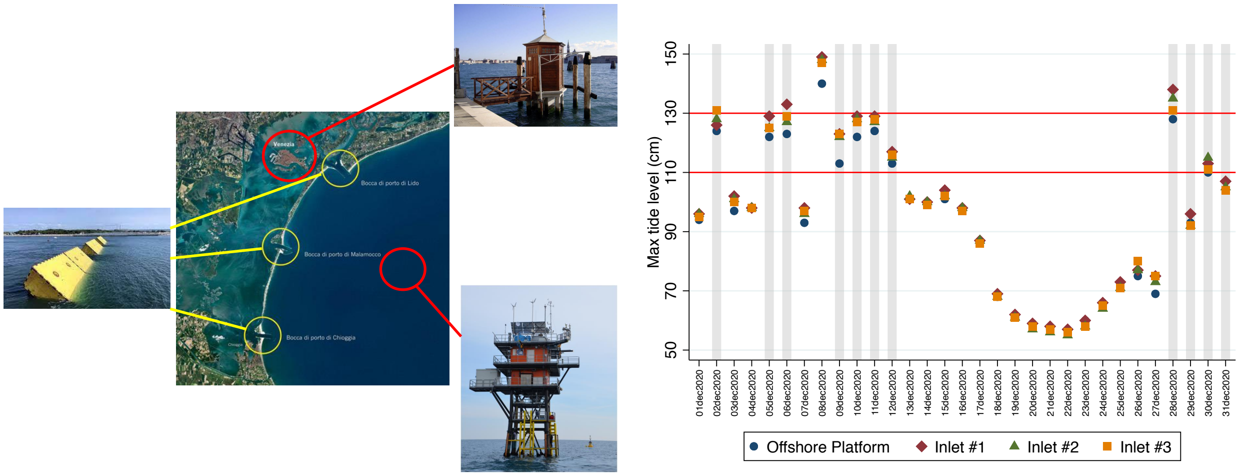


Figure A4: Offshore platform and inlets
Note: The left figure shows the location of the offshore platform, the three inlets, and the city of Venice. The right figure shows the highest measured tide offshore and in the three inlets in December 2020.

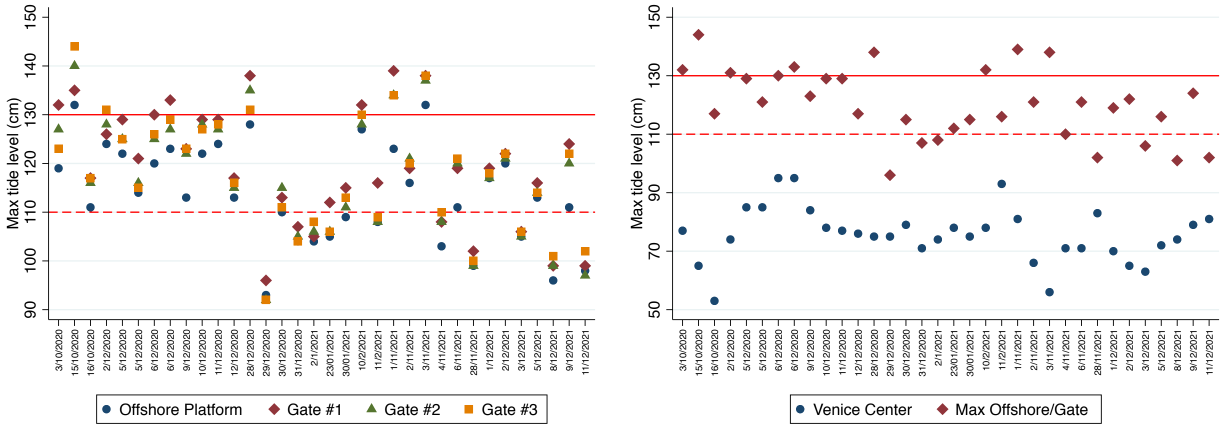


Figure A5: Sea Wall Activation Dates

Note: The figures show the highest measured tide offshore, in the inlets and in the center of Venice for all dates in which the sea wall has been activated in 2020-2021.

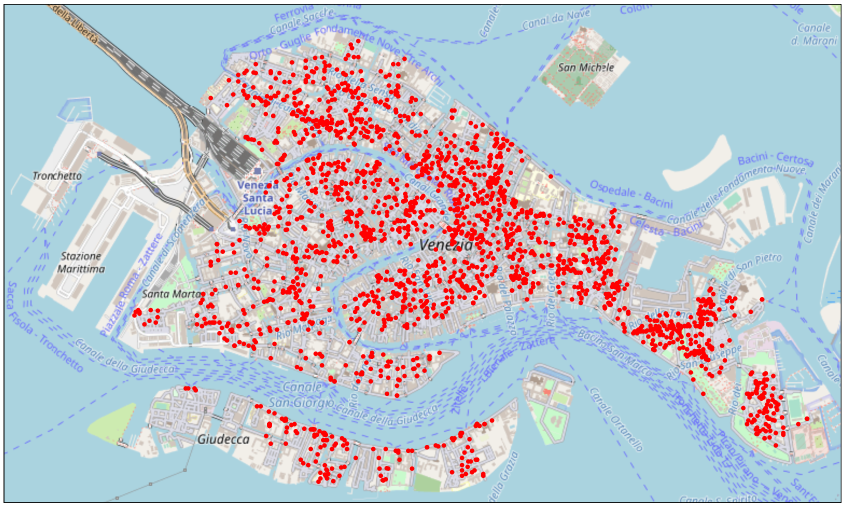


Figure A6: Properties across location

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

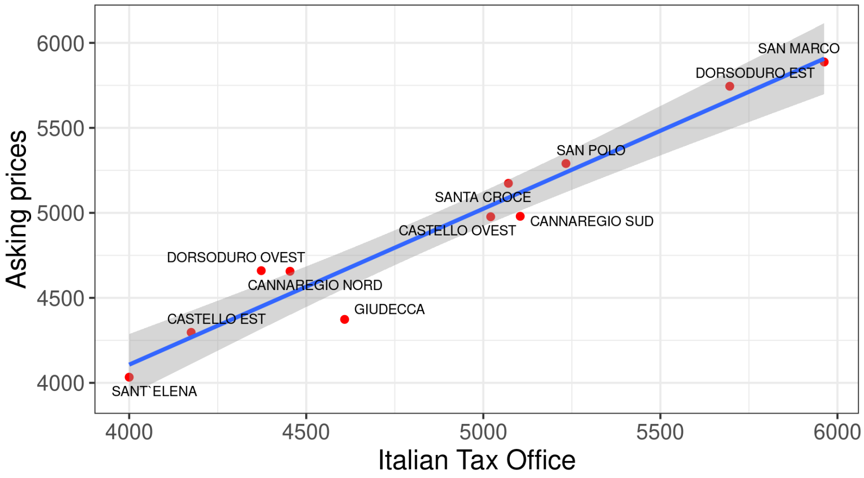


Figure A7: Listing and Transaction Prices by Area

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 A7). 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.

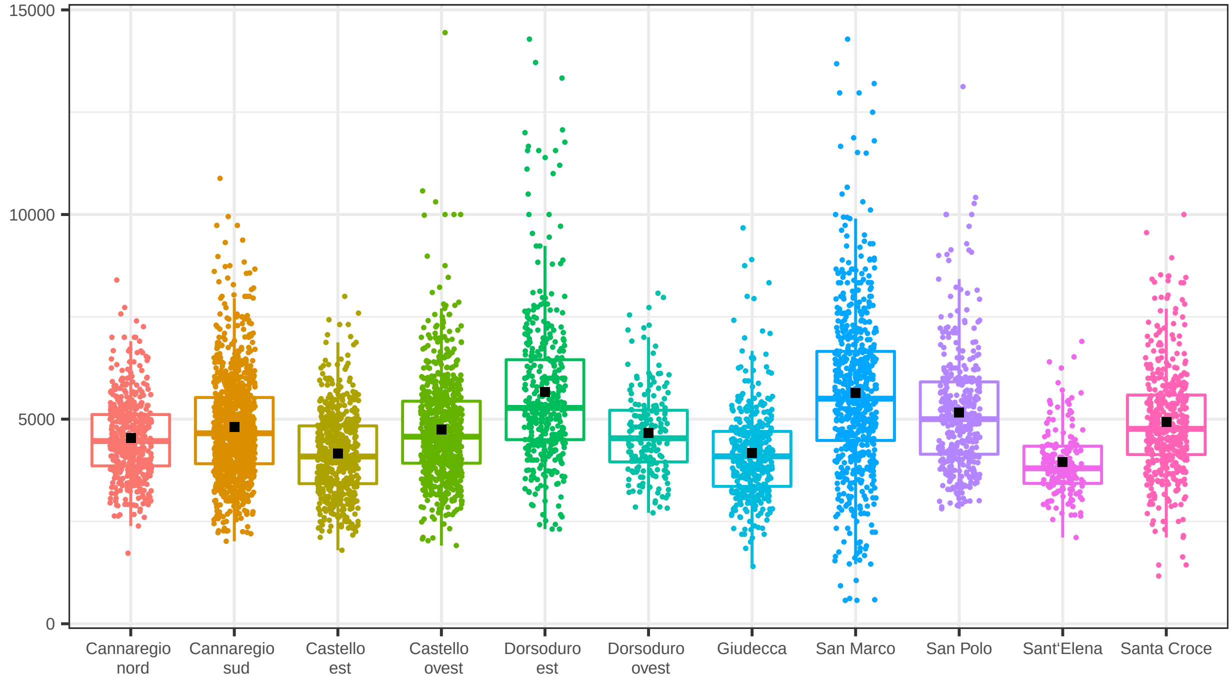


Figure B1: Listing prices by Neighborhood

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/.

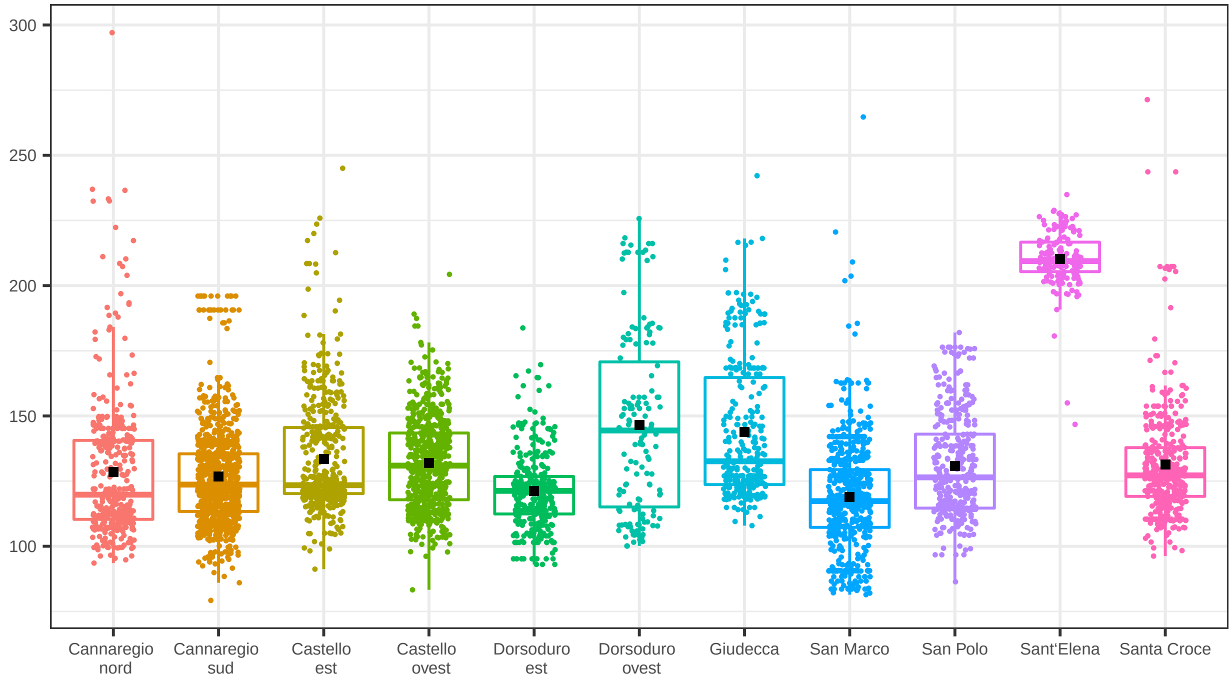


Figure B2: HOUSES' ELEVATION BY NEIGHBORHOOD

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 5, 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 (5) and (6) 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.

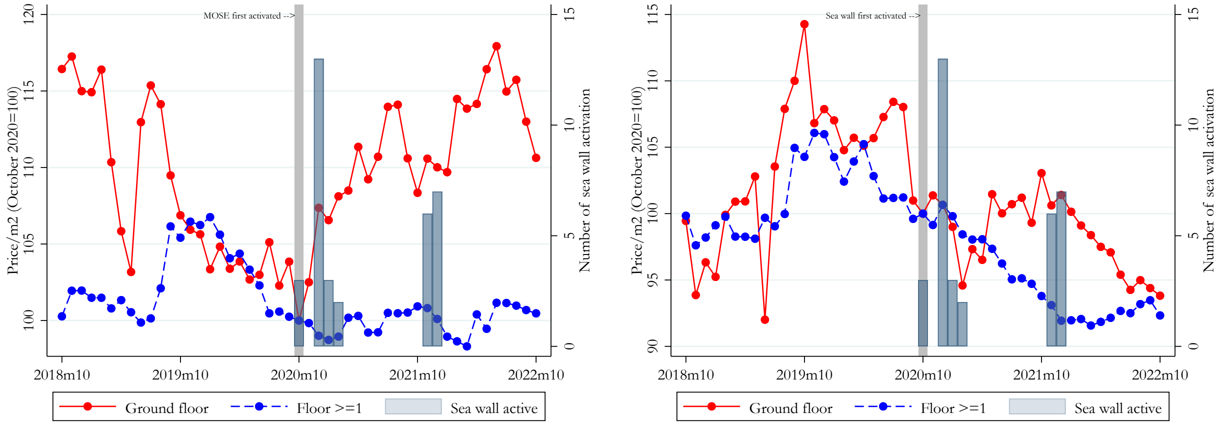
Table C2 shows the results using the same equations (5) and (6) from the main text and rent prices per square meter as dependent variable. Ground floor properties have on average lower rent prices per square meter than similar higher floor properties, but the difference is only marginally significant. 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 (5) as controls, now as dependent variables. We estimate the following specification:

$$y_{ilkt} = \beta Sea\ Wall_t + \theta X_i + \gamma_{lk} + \epsilon_{ilkt}, \tag{9}$$

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 ≤ 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.

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 (5) and (6) 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 (5) and (6) 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 (9). 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.

D Additional Results on Flow Benefits and 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 D1 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 D2 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. 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.

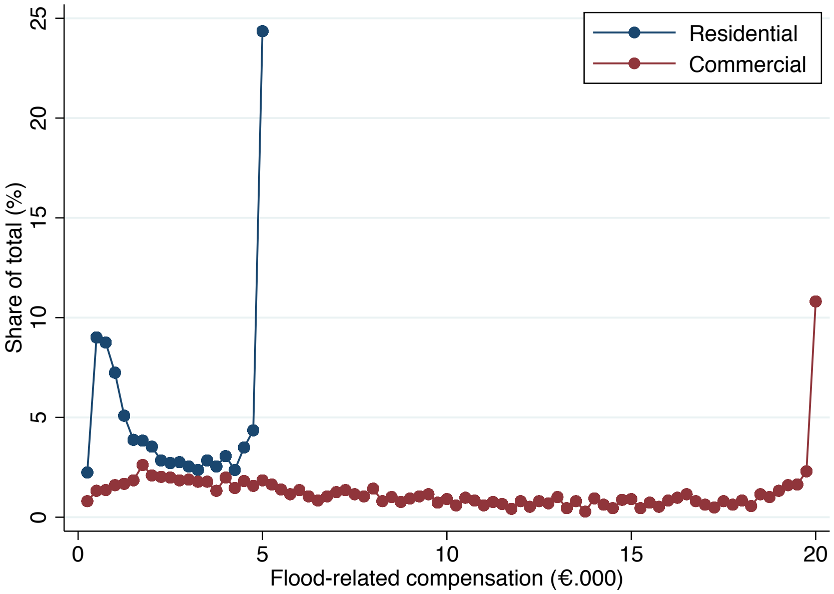
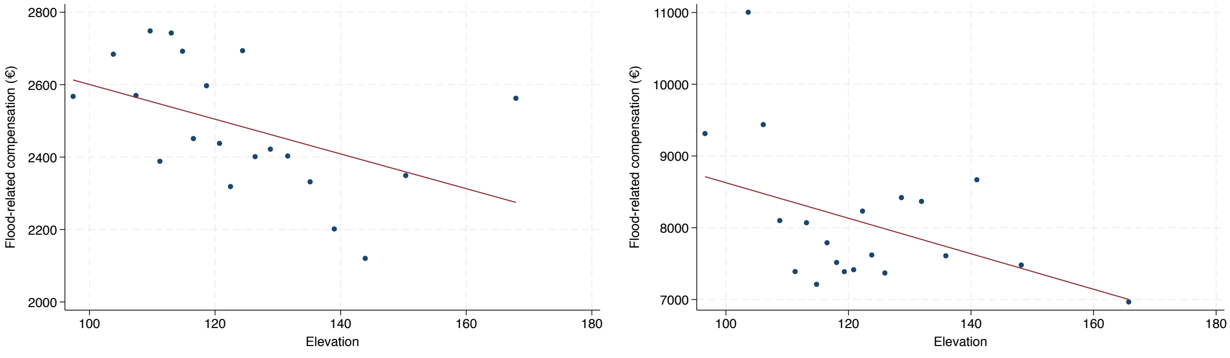


Figure D1: Residential and Commercial Claims after November 2019 Flood

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



(a) Residential

(b) Commercial

Figure D2: 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.

Table D1: COSTS AND BENEFITS ANALYSIS OF THE SEA WALL: ORIGINAL COSTS

	Present value	Annual flow		Different discount rates			
		Baseline	SLR	Upper bound	Baseline	Break-even	
						Baseline	SLR
				8.00%	2.50%	2.08%	4.75%
	Panel A: Costs (€M)						
Construction	3400						
Maintenance		10	10	125	400	483	211
Total				3525	3800	3881	3610
	Panel A: Benefits (€M)						
Capitalization							
Residential	455						
Commercial	535						
Total	990						
Flow Analysis							
Tourism		29	29				
Damages		52	143				
Total		81	172	1009	3228	3881	3610
	Panel C: Benefits/Costs						
Benefits Capitalized in House Prices/Costs				28%	26%	25%	27%
Benefits from Flow Analysis/Costs				29%	85%	100%	100%

Note: The Table shows the costs and benefits of the sea wall. Panel A shows the planned construction costs and the 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 flow analyses of Section 5. Panel C reports the ratio of benefits over costs.