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

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November 21, 2022

Abstract

This paper exploits the operation of a sea wall built to protect the city of Venice from increasingly high tides to provide evidence on the capitalization of public infrastructure investment in climate change adaptation into housing values. Properties above the sea wall activation threshold experience a permanent reduction in flood risk and expected damages, which are reflected in higher prices. Using a difference-in-differences hedonic design we show that the sea wall led to a 4.5% increase in the value of the residential housing stock in Venice, which is a lower bound on the total welfare gains generated by the infrastructure.

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

Keywords: Housing, Climate Change, Adaptation, Infrastructure

*We thank Laura Bartiloro, Aymeric Bellon, Andrea Beltratti, David Card, Federico Cingano, Guido De Blasio, Ivan Faiella, Christian Ferrarin, Stephie Fried, Harrison Hong, Òscar Jordà, Ben Keys, Chloe Larkou, Enrico Moretti, Stefano Neri, Monika Piazzesi, Paolo Pinotti, Tiziano Ropele, Alfonso Rosolia, Brigitte Roth Tran, Parinitha Sastry, Stijn Van Nieuwerburgh, Reed Walker, Roberta Zizza and seminar participants at 1st workshop of the ESCB Research Cluster on Climate Change, the Bank of Italy, Berkeley Haas, Bocconi University, the 2022 Site Conference on Climate Finance, Innovation and Challenges for Policy, and the San Francisco Fed for helpful comments and suggestions. We are extremely grateful to the municipality of Venice and to Immobiliare.it for providing the data and Andrea Luciani for his assistance. The opinions expressed are those of the authors and do not necessarily reflect the views of the Bank of Italy or of the Eurosystem. All remaining errors are our own.

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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 agents as well as countervailing policy by governments to reduce the damages from climate change.[1] 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; Hong et al., 2020; Fried, 2021). 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.[2]

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 and quantify the associated welfare gains. The sea wall activation 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] Built on stilts, Venice has been exposed to sea level changes since its foundation, with high tides and flooding becoming worse in recent years.[4] 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).

Figure 1 shows an increasing number of high tides in Venice between 2016 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

[1]For example, the World Bank (2011) estimates that the cost of adapting to an approximately 2 degrees warmer world by 2050 is in the range of $70 to $100 billion a year. 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.

[2]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 (See: `https://www.greenbiz.com/article/coastal-flooding-here-are-seawalls-answer-rising-tides` and `https://phys.org/news/2021-12-vulnerable-climate-york-seawall.html`).

[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`).

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

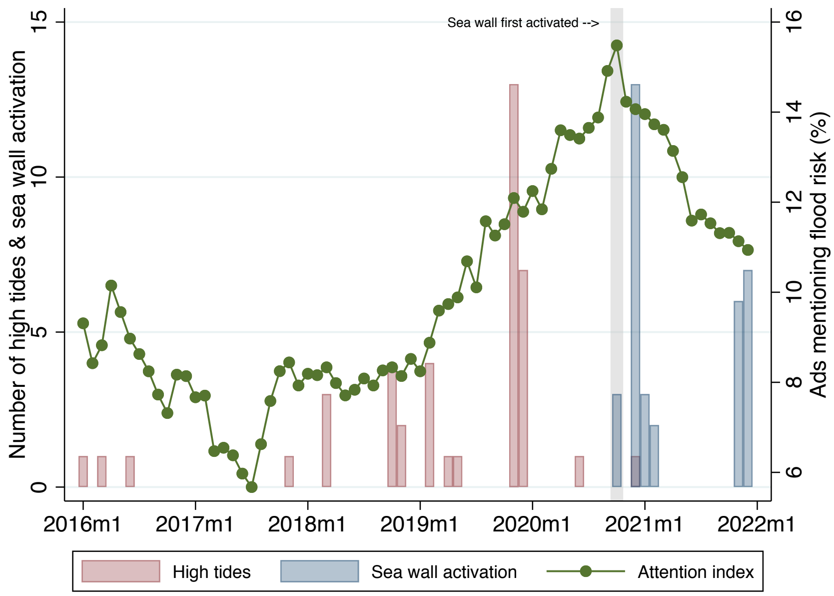


Figure 1: High tides, sea wall and attention to flood risk
Note: The green line shows the fraction of ads mentioning flood risk in their text. The red vertical bars show the number of times the sea level in Venice was higher than 110 cm. The blue vertical bars show the number of times the sea wall has been activated in the respective month.

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 exploit the quasi-experimental temporal discontinuity in the exposure to sea floods from the first activation of the sea wall to identify the causal effect on house prices, overcoming well-known econometric issues affecting cross-sectional studies (Greenstone, 2017; Giglio et al., 2021). Most notably, we implement a difference-in-differences (DD) hedonic design, using a rich high-frequency dataset on house listings from the largest online portal for real estate services in Italy (Immobiliare.it) and 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 increase in price of about 4% relative to higher floor properties in the same neighbourhood. This result is entirely driven by properties located in low-elevation areas (110-140 cm) and thus more exposed to flooding, which appreciate by 7%. 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 almost 3% relative to the price of high-elevation properties.

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 look as dependent variable at rental prices, which may capture changes in the flow utility of properties as a result of the sea wall activation. We do not find significant differential effects for rental prices following the sea wall activation, consistent with sale prices reflecting the present discounted benefit from lower high-tide risk, rather than just a temporary increase in the amenity value. Finally, we estimate a specification using property fixed effects and exploiting variation in listing prices within ad. Despite the limited times list prices are revised, we find that after the activation of the sea wall properties at lower elevation experience an increase in prices by about 0.5%, relative to the average price per square meter posted before the activation of the sea wall. Notice 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 propose a simple interpretation of the estimated effects of the sea wall on housing prices through the lens of an asset pricing equation for housing (Poterba, 1984). The revaluation after the activation of the sea wall can be traced back to (a combination of) three factors: (i) higher expected future rents, (ii) lower expected future damages, and (iii) a reduction in the discount factor. While a full decomposition requires stark assumptions, we find an important role for the expected damage channel under fairly general conditions. Assuming that the reduction in the risk premium is the same for ground and upper floor properties, we back out a reduction in average annual expected damages of about €1100 for an average ground floor apartment of 95 square meters. While we do not have data on maintenance costs to repair damages from floods, our estimate of expected maintenance expenses absent the sea wall is in line with additional data we collected on claimed damages from households and businesses after the high flood occurred in November 2019.

In the last part of the paper we quantify the overall valuation gains from the sea wall and how they are distributed across different property types and locations. We use census data and our listing data to obtain the value of the overall residential area in the center of Venice, distinguishing six categories based on three elevation levels (<110 cm, 110-140 cm, >140 cm) and two floor groups (ground floor vs higher floors). By combining our econometric estimates we obtain an overall increase in residential properties values from the activation of the sea wall of almost €340 millions. A year after the activation the impact is €670 millions, that is 4.5% of the residential housing stock of the city of Venice. Compared with the sea wall's cost, the revaluation of residential properties account for approximately 20% (10%) of the original (actual) costs.[5]

Our estimates provide a *lower bound* on the overall gain from the sea wall for at least two reasons. First, our DD hedonic design exploits the activation 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. Following Banzhaf (2021), we suggest that the DD hedonic estimates provide a lower bound on the total welfare effects of the policy. Second, we only focus on the residential properties, while the sea wall is likely to benefit commercial properties and related activities (e.g., tourism) as well. Under the assumption that ground floor commercial properties would appreciate as residential properties after the activation of the sea wall, we estimate an increase in the value of commercial properties used as shops and restaurants of about €165 millions after a year. Our estimated magnitudes are specific to the context that we study, but the capitalization result could be informative about the return on and financing of public investment in adaptation, which has attracted increasing attention of both policy makers and economists around the world.

Related Literature. Our paper is related 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., 2020; Dechezleprêtre et al., 2022; Carleton et al., 2022). A growing theoretical and quantitative literature has shown how adaptation could have profound effects on the damages from climate change. Desmet et al. (2021) studies in a general equilibrium framework the dynamic response of investment and migration to sea level rise, showing that these endogenous responses lower the losses in real GDP in 2200 from 4.5% to 0.11%. Fried (2021) studies adaptation and aid for disaster relief in a macro heterogeneous-agent model and finds that adaptation reduces the damage from climate change related storms by approximately one-third. Given the sensitivity of models' estimates to adaptation strategies, empirically grounded estimates of the impact of actual adaptation to sea level rise on labor and capital could be valuable. Our work is 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 shows 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 focusing only on one city, but exploiting granular *within-city* variation to identify the effect of adaptation, overcoming

[5]The comparison with the sea wall's cost is complicated by several additions to the original €3.3 billions budget (in terms of today euros) due to delays and scandals, which led to cumulative expenses reaching €7 billions. Additionally, the sea wall involves an estimated cost of €300 thousands for each activation (see: `https://www.metropolitano.it/mose-dietro-le-quinte-come-funziona/`).

potential issues with local idiosyncratic shocks or heterogeneous trends across different cities. We also study how house prices capitalize the benefit of lower exposure to sea level rise following the activation of the sea wall. Thus 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., 2020; Tsivanidis, 2018; Severen, 2019). We apply quasi-experimental techniques to retrieve a consistent estimation of the hedonic price schedule. We are the first to study the capitalization into property prices of a large public investment in climate change adaptation to mitigate the damages from flooding and sea level rise.

Finally, our paper also contributes to the growing empirical literature on the effect of climate change and environmental risk on the housing market. A large literature studies the capitalization of *current flood risk* in housing markets. 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).

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. Second, all the aforementioned papers study *increase* in actual or expected risk of flooding. Our work provides a new angle by looking into the effect on house values of a *decrease* in flood risk, as a result of infrastructure investment to adapt to sea level rise.

Overview. The rest of the paper is organized as follows. Section 2 discusses the setting. Section 3 describes the data. Section 4 presents the empirical results using the variation from ground floor and stilts elevation, and discusses the interpretation. Section 5 shows the results from the capitalization exercise. Section 6 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).

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 blue 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.

Figure 2 shows 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).[6]

The high-tide phenomenon has material implications for Venice. 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.[7] Panel (b) of Figure A1 in Appendix A shows days properties were flooded based on elevation level in the twenty years from 1930 to 1950, as well as in the twenty years from 1999 to 2019. Between 1930 and 1950 properties with an elevation below 110 cm were flooded no more than five times per year, properties with an elevation between 110 and 140 cm – the majority of properties in Venice – were flooded once or twice every year, while properties with an elevation above 140 cm were never flooded. In the more recent twenty years between 1999 and 2019 flooding has increases across the distribution of elevation. Properties

[6]Panel (a) of Figure A1 in Appendix A 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 feet.

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

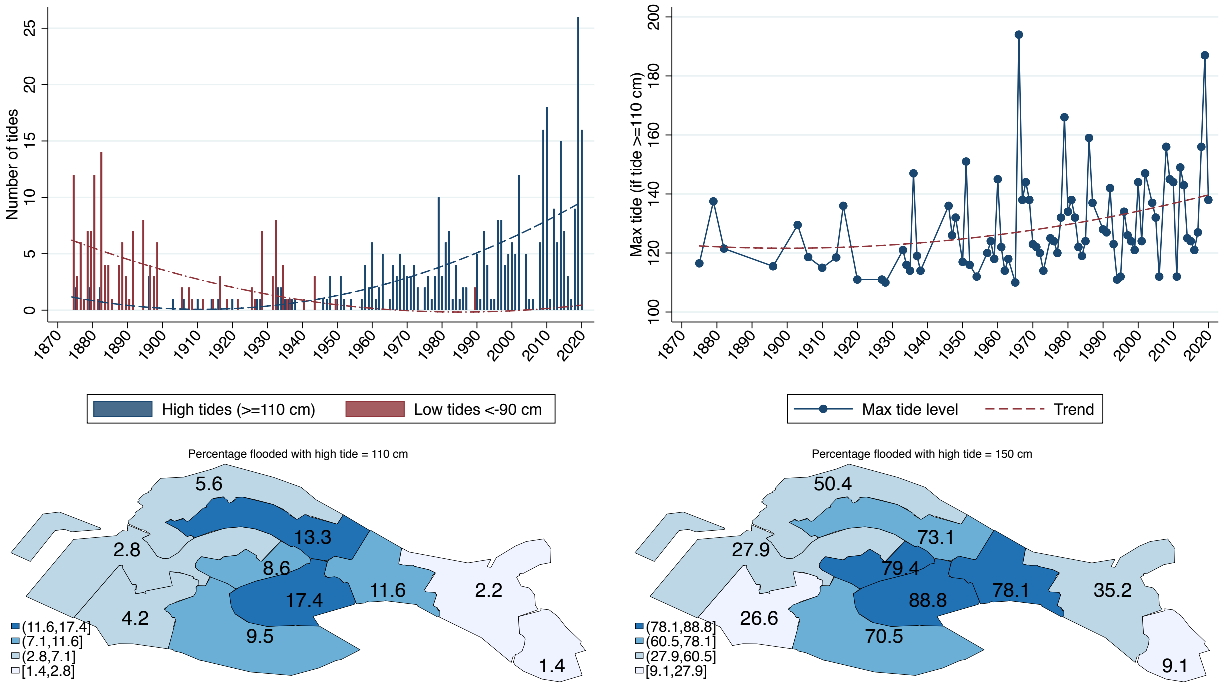


Figure 2: High Tides and Flooding

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 shows the fraction of different areas of Venice that are flooded for sea levels equal to 110 cm and equal to 150 cm.

with an elevation below 110 cm were flooded more than twenty times per year, properties with an elevation between 110 and 140 cm were flooded a few times every year, an even properties with an elevation above 140 cm have been flooded at least once per year. The year 2019 was particularly difficult for Venice, with the tide going above the 110 cm threshold almost 30 times.

The bottom panel of Figure 2 shows the fraction of different areas of Venice that are flooded for two different levels of high tides.[8] When the sea level is at 110 cm, about 12% of Venice is flooded, while tides reaching 150 cm cause 70% of the city to go underwater. The bottom panel of Figure 2 also shows significant heterogeneity in flooding across areas within Venice. 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

[8]Figure A2 in the Appendix shows the name and areas of the different neighborhoods in Venice main island.

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.[9]

2.2 The Sea Wall

Since the extreme high tides of 1966, the city of Venice has invested in adaptation strategies to cope with 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 €7 billion, plus an estimated €100 million of annual maintenance and operating costs. Up to now, in November 2022, this infrastructure is not completed and the deadline has been moved to 2023. 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 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.[10]

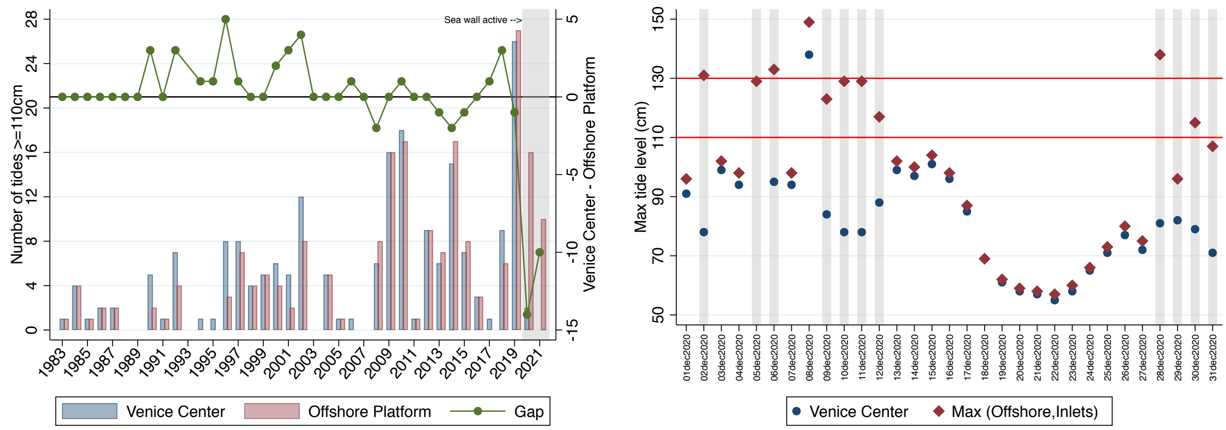
The sea wall is a system of four mobile barriers composed of 78 gates located in three inlets into the Venice lagoon.[11] This infrastructure is different from a classic Dutch sea wall. The latter could have done permanent damage to the lagoon ecosystem and impaired the activity of the port of Venice. In normal times, the barriers of the Venice sea wall 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 very innovative approach, combined with delays in construction, created additional uncertainty about the effectiveness of the infrastructure until it was firstly activated.

The sea wall has been activated 33 times since October 2020 until the end of 2021, preventing high tides from flooding the city of Venice. Panel (a) of Figure 3 shows the number of high tides

[9] 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.

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

[11] 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.



(a) Venice center VS Offshore Platform

(b) Tides in December 2020

Figure 3: Sea Wall

Note: The left figure shows the number of high tides (>=110 cm) registered in the city of Venice and the offshore platform and the gap between the two. The right figure 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 bar denote the dates when the sea wall is activated. The red horizontal lines denote the activation thresholds at 130 cm and 110 cm.

measured in the city center of Venice and in an offshore platform.[12] From 1983 until 2019 the number of high tides registered in the city of Venice and the offshore platform closely track each other. Some differences can be due to changing meteorological conditions (e.g., winds) which can affect the tides between the two locations. 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. In 2020, the offshore platform recorded 16 high tides events, while in Venice only 2 high tides were recorded. Similarly, 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. 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. 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. Our empirical strategy will thus exploit that the sea wall sharply reduced the risk of flooding for properties with an elevation above 110 cm.

To illustrate the activation process, panel (b) of Figure 3 shows the highest tide for each day

[12]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`).

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.[13] 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.

Panel (b) of Figure 3 provides two additional insights into the functioning of the sea wall. First, on December 8th the sea wall was not activated, as the predicted tide was below the 130 cm experimental threshold. The measured tide in the open sea reached almost 150 cm, and without the sea wall 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 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 end of 2020 for lower levels of the tide measured in the open sea. For example, on December 29th and 31st 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. 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. In the more recent period, the sea wall was activated even when the measured tide in the open sea was well below the 130 cm threshold and not more than 20 cm below the 110 cm threshold. 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 Descriptive Evidence

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 a 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

[13] In the right panel of Figure A4 we show the tide measured in the offshore platform and each of the inlets separately.

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).[14]

We combine our main dataset with two additional sources. First, we exploit the coordinate 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 centre paving with centimeter accuracy.[15] We then match this highly-detailed information on altimetry of the paving to each property in our main dataset located in the historical city center of Venice. Second, we obtain information on the frequency and level of high tides as well as on the activation of the sea wall from the historical archive of the city of Venice.[16]

The dataset is a panel of housing ads from 2016 to 2021. Table 1 shows the summary statistics for the main variables in our database at the monthly level. The average residential property price is €550 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 almost €5,000, again with wide range of variation from a minimum of about 570€/m2 to a maximum of 14,000€/m2. The average floor area is approximately 100 square meter. About 9% of properties in our data are ground floors. The vast majority (95%) are flat, and most properties are in good (33%) or very good (48%) conditions. Only 3% are new properties and 13% needs renovation.[17] The vast majority of properties have no garage (99%) or garden (81%), while about 10% are in buildings with an elevator.[18]

The average elevation of properties relative to the reference point is about 130 cm, with a wide range of variation.[19] 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%. Finally, we construct a measure of climate attention which is a dummy equal to one if the property description mentions flooding, high tide or the sea wall.[20] About 11% of

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

[15]Additional information and data are available here: `http://smu.insula.it/index.php@option=com_content&view=frontpage&Itemid=103&lang=en.html`.

[16]The data can be downloaded here: `https://www.comune.venezia.it/it/content/le-acque-alte-eccezionali`.

[17]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.

[18]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.

[19]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.

[20]The italian words used to compute the attention index are: "marea", "maree", "MOSE"and "acqua alta". The majority of listings in our attention index have descriptions that emphasize the lack of flood risk, consistent with the examples of property listings entering the climate attention index by Giglio et al. (2021). In the city of Venice, sellers

Table 1: Summary Statistics

	Observations	Mean	Std. Dev.	Minimum	Median	Maximum
Panel A: Property characteristics						
Price (€.000)	50,839	551.03	401.59	20.00	440.00	6,500.00
Price (€/m2)	50,839	4,987.91	1,460.95	571.43	4,793.10	14,444.44
Floor area (m2)	50,839	110.79	65.98	30.00	95.00	570.00
Ground floor (dummy)	50,839	0.09	0.28	0.00	0.00	1.00
Single family (dummy)	50,839	0.05	0.22	0.00	0.00	1.00
Flat (dummy)	50,839	0.95	0.22	0.00	1.00	1.00
Need renovation (dummy)	50,839	0.13	0.33	0.00	0.00	1.00
Good status (dummy)	50,839	0.33	0.47	0.00	0.00	1.00
Very good status (dummy)	50,839	0.48	0.50	0.00	0.00	1.00
New property (dummy)	50,839	0.03	0.17	0.00	0.00	1.00
Elevator (dummy)	50,839	0.10	0.30	0.00	0.00	1.00
No garage (dummy)	50,839	0.99	0.08	0.00	1.00	1.00
Parking slot (dummy)	50,839	0.00	0.02	0.00	0.00	1.00
Private box (dummy)	50,839	0.01	0.07	0.00	0.00	1.00
No garden (dummy)	50,839	0.81	0.39	0.00	1.00	1.00
Shared garden (dummy)	50,839	0.08	0.27	0.00	0.00	1.00
Private garden (dummy)	50,839	0.11	0.31	0.00	0.00	1.00
Elevation (cm)	40,693	131.79	26.49	80.31	125.11	285.30
Flood probability (%)	40,693	0.46	0.89	0.00	0.19	10.18
Attention index (dummy)	50,839	0.11	0.31	0.00	0.00	1.00
Panel B: Tide and sea wall variables						
Max tide Venice (cm)	72	99.12	19.07	72.00	94.00	187.00
High tides Venice (number)	72	0.57	1.87	0.00	0.00	13.00
Sea wall activation (number)	72	0.47	1.91	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 centre 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.

property listings in our dataset mention one of this flood-risk-related variables.

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 greater than 110 cm was about 0.6. 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 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 activation of the

have a strong incentive to advertise when a property is not/less exposed to the seasonal high tides.

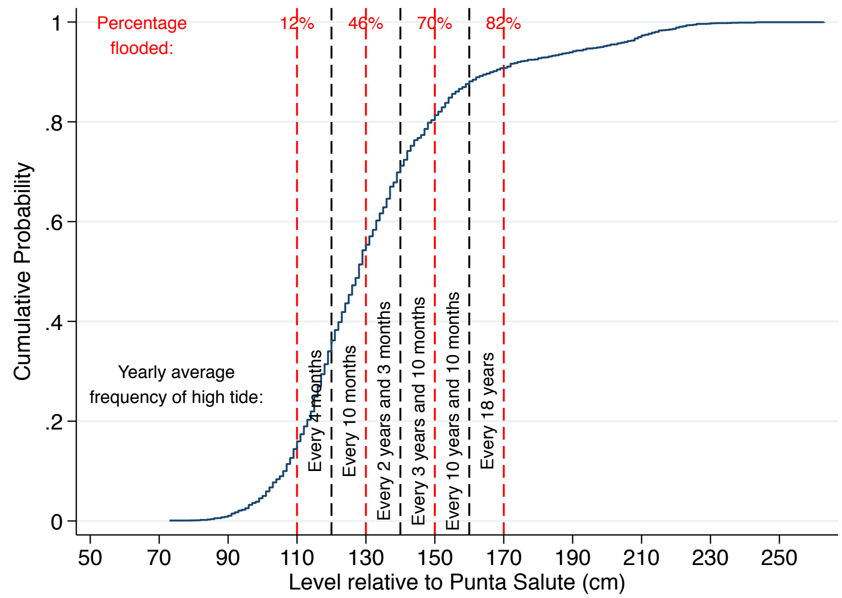


Figure 4: Properties across elevation

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.

sea wall. For example in December 2020 the sea wall has been raised 13 times.

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. Slightly less than 20% of properties have an elevation below 110 cm, which leads to frequent flooding each year. A large number of properties, about 40%, have an elevation between 110 cm and 130 cm, which is associated to one to three floods each year. About 20% of houses have an elevation between 130 cm and 150 cm and they are inundated every two to four years. Finally, the remaining 20% of properties are located at 150 cm or above the reference level and experience flooding only every 10 years or more.

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.[21] 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 boats stations. Our measures of exposure are: (i) the daily probability that the building is flooded based on its elevation and the historical measurements 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 2 shows the 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 from the well-known mis-specification issues in cross-sectional studies and we do not argue they have a causal interpretation. Yet, they can provide a useful guidance on the extent flood risk affected house prices before the activation of the sea wall.

In column (1) we look at the effect of a higher probability of flooding on house prices per square meter. A higher flood probability is associated to lower house prices. Most notably, a one-percentage-point higher probability of flooding is associated to 135€/m2 lower house prices. In column (4) we estimate the same specification, but using the logarithm of house prices per square meter. We find that a one-percentage-point higher probability of flooding is associated to a 3% lower house price.

Column (2) and (5) report the estimates of equation (1) using a dummy for ground floor as a measure of differential exposure to flooding. Properties on the ground floor suffer more directed damages as a result of high tides. We indeed find that that properties on the ground floor have significantly lower asking prices. Most notably, ground floor properties sell at about 300€/m2 less or a 7% discount relative to otherwise similar properties. While we control for several characteristics of house prices, the reason why ground floor properties sell at a discount relative to higher floor ones may be not necessarily related to flood risk. For example, ground floor properties may have a worse exposure to sunlight, which lowers their values relative to otherwise similar higher floor properties.

In column (3) and (6) of Table 2 we report the estimates interacting the probability of flooding with a dummy for ground floor properties. Both a higher flood probability and being on the ground

[21] 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 neighborhood in details in Appendix B.

Table 2: 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 boats stations. Standard errors are double clustered at at the location-type and year-month level. *, **, and *** denote significance at the 10%, 5% and 1% levels, respectively.

floor are associated to lower prices per square meter. As expected, ground floor properties in areas with a higher flood risk are listed at a *relative* higher discount that ground floor properties in areas with lower flood risk. Most notably, moving from the 25th to the 75th percentile of the flood risk distribution is associated to an increase in the ground floor discount by about 3.5%.[22] Overall, given the limitation of cross-sectional analyses discussed in the related literature, we interpret the results in Table 2 as descriptive and exploit joint variation across properties and over time for identification in our empirical strategy.

Finally, Table A1 in the Appendix reports the estimates of equation (1) in the year before the activation of the sea wall for rent prices. The correlation between a higher probability of flooding and rent prices per square meter is negative but non statistically significant, and the estimates are small in magnitudes. The ground floor discount for rent prices is only marginally significant and also small in magnitudes. Additionally ground floor properties in areas with a higher flood risk are not associated to significantly lower rents than ground floor properties in areas with lower flood risk. While rental properties exposed to floods are less attractive, leading to a negative relation between exposure and prices, counterbalances forces might weaken this relation. For example,

[22]The average discount for ground floor properties with a flood probability at the 25th percentile is about 5.5% relative to otherwise similar properties. Ground floor properties with a flood probability at the 75th percentile are listed for about 9% less than otherwise similar properties.

individuals interested in ground floor properties might prefer renting rather than buying it, if they are worried about flood risk, driving up rents in equilibrium. Another related possible explanation for the weaker and insignificant relation between exposure to flooding and rent prices – as compared to list prices – is that the burden of the damage for flooding falls on landlords, who pass some of it to renters in the form of higher rents.

4 Empirical Analysis of the Effects of the Sea Wall

4.1 The Effects of the Sea Wall on Ground-Floor Properties

Our first identification strategy exploits the activation of the sea wall and its differential effect on ground-floor properties. 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, 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:

$$y_{ilkt} = \alpha Ground\ Floor_i + \beta Ground\ Floor_i \times Sea\ Wall_t + \theta X_i + \gamma_{lk} + \gamma_t + \epsilon_{ilkt}, \qquad (2)$$

where *Ground Floor*$_i$ is a dummy equal to one if property i is on the ground floor; *Sea Wall*$_t$ is a dummy equal to one in all months after October 2020, when the sea wall was first activated; 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. Figure A7 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 Figure 5, but splitting the sample by the elevation of the property. We find that the differential increase after the first activation

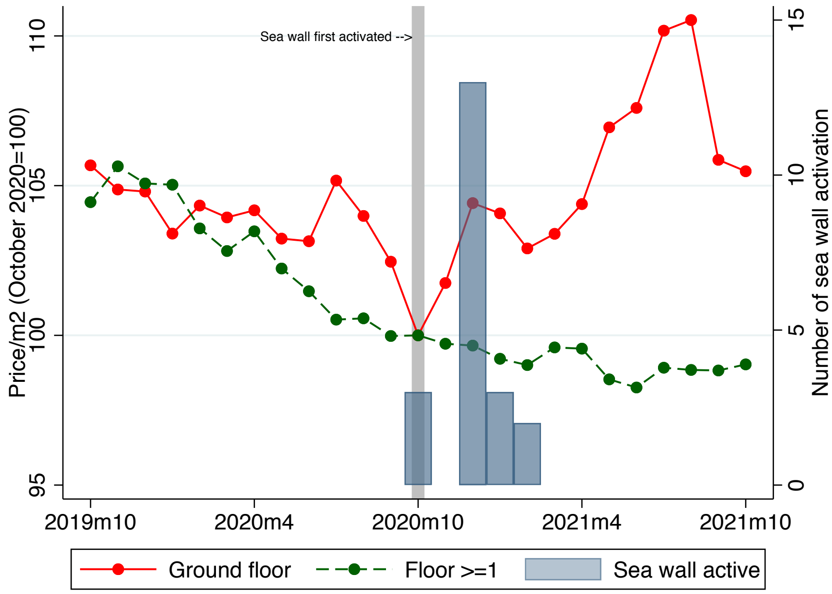


Figure 5: Prices per m^2: Ground vs higher floors

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

of the sea wall in ground floor property prices is driven by properties at lower elevation levels, as expected. To allow for heterogeneity across locations we estimate equation (2) both in the full sample and separately for properties with different elevation levels.[23]

In the estimation of equation (2) – and equation (4) in the next section, which exploit variation across elevation levels – we focus on properties with an elevation above 110 cm, which is the level of predicted tide when the sea barriers are activated, as we discussed in Section 2. Properties with lower elevation will also potentially benefit from the activation of the sea wall. On the one hand, properties with elevation level below 110 cm still experience flooding from high 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.[24]

Table 3 shows the main results. First, columns (1) and (4) report the results using all properties. In line with the results of Table 2 we find evidence of a ground floor discount. Ground floor properties sell at 317€/m2 (7%) less than comparable houses at higher floors. As we discussed,

[23]We consider properties below relative to above and elevation of 140 cm, which is approximately the median across properties in the full estimation sample.

[24]We discuss these issues further when we perform the capitalization exercise in Section 5.

Table 3: Effect of sea wall on ground-floor properties

	Price (level)			Price (log)		
	(1) All	(2) <=140	(3) >140	(4) All	(5) <=140	(6) >140
Ground floor	-317.22**	-497.31***	-225.09	-0.07**	-0.12***	-0.04
	(128.70)	(137.75)	(224.32)	(0.03)	(0.03)	(0.05)
Ground floor × Sea wall	249.32**	396.82**	14.45	0.04*	0.07**	-0.00
	(115.44)	(160.02)	(88.99)	(0.02)	(0.03)	(0.02)
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	4883.20	4947.31	4753.88	8.47	8.48	8.44
SD Y	1119.90	1147.43	1050.46	0.23	0.23	0.22
R2	0.35	0.35	0.47	0.37	0.38	0.47
Obs.	15581	10423	5156	15581	10423	5156

Note: The Table shows the estimates from equation (2) for the period October 2019 - December 2021. 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. 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 boats 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.

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 250€. The effect is significant and large in magnitude. This increase allows ground floor properties to recoup about 80% of the discount relative to similar higher floor properties. The results using the log of the price per square meter are similar in magnitude, but less precise. After the activation of the sea wall ground floor properties increase their price per square meter by about 4%, relative to a discount pre-sea wall of 7%.

Columns (2)-(3) and (5)-(6) of Table 3 report the estimates of equation (2) 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.[25]

[25] One potential concern is that ground floor dwellings might have been exposed to more investment that higher floors, following the floods – and associated damages – in November 2019. In the estimation we control for the

Ground floor properties with an elevation up to 140 cm experience an increase in price per square meter of almost 400€. This increase allows ground floor properties in low elevation areas to recoup about 80% of the discount relative to similar higher floor properties in the same low elevation areas. 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 a 12% discount on the price, but this discount is halved by the activation of the sea wall. 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.

4.1.1 Additional Analyses and Robustness

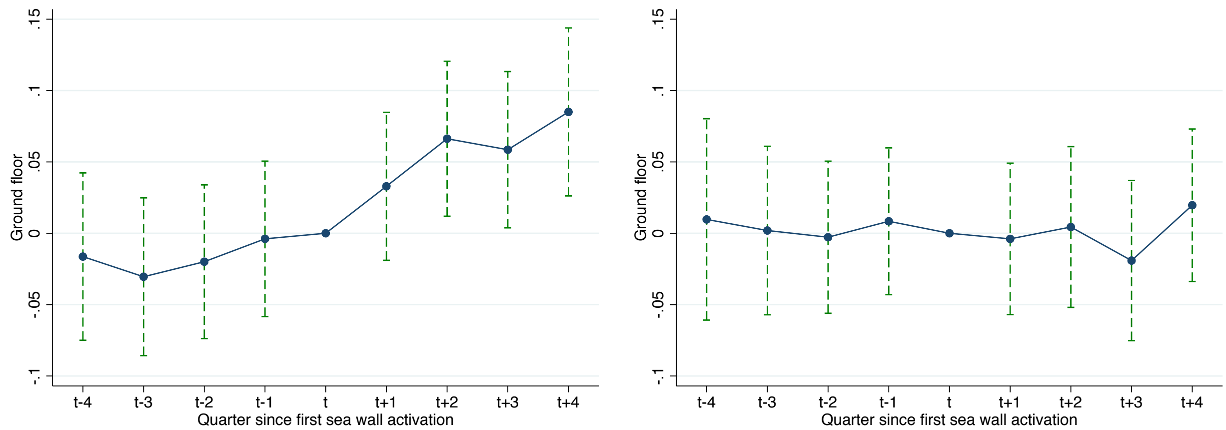
In the rest of the section we report the results of four additional analyses related to our main result in Table 3: (i) parallel trends; (ii) a placebo test; (iii) rent prices; and (iv) a within property specification.

Parallel trends. We explore pre-trends in the prices per square meter of ground floors. Most notably, we estimate a version of equation (2) in which we interact the dummy for ground floors 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. 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, we find that the price of ground floor properties with low elevation show an increasing trend over time. None of the interaction terms is significant for ground-floor properties in high elevation areas.

Placebo. We estimate a version of equation (2) in which we interact the ground floor dummy 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 two-year interval around October 2019. If the effect of the sea wall we identify in Table 3 is due to some differential behavior of ground floor properties in certain part of the years or to some longer-term trend rather than the sea wall itself, we may find similar effects the year before the sea wall was activated.

Panel A of Table 4 shows the results. 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

maintenance status of the property which captures, albeit imperfectly, renovation work that has been done to the property before listing. We also estimate specification (2) 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 slight 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.



(a) Elevation $\leq$ 140 cm

(b) Elevation $>$ 140 cm

Figure 6: Log prices per m^2

Note: The left figure shows the coefficients on the interaction terms between ground floor and quarter for properties with an elevation up to 140 cm relative to the reference point. The right figure 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 (2) 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 interval.

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.

Rent prices. We exploit information from the same data provider on rent prices per square meter and estimate equation (2) using now rent prices as dependent variable. Studying the effect of the sea wall on rent prices helps to shed light on the mechanisms behind the change in property prices, along the lines of Giglio et al. (2021). By the no-arbitrage condition, the price of a real estate property is equal to the present discounted value of future rents (net of maintenance costs), where the discount rates reflect not only the time preference but also climate risk exposure. Therefore the price increase determined by the activation of the sea wall could reflect either an increase in expected rents or a decrease in the risk premium (or both).[26]

Panel B of Table 4 shows the results. Ground floor properties have on average lower rent prices per square meter than similar higher floor properties, but the difference is not statistically significant. Most importantly, 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

[26]We discuss these different channels further in Section 4.3.

Table 4: EFFECT OF SEA WALL ON GROUND-FLOOR PROPERTIES: PLACEBO AND RENTS

	PRICE (LEVEL)			PRICE (LOG)		
	(1) ALL	(2) <=140	(3) >140	(4) ALL	(5) <=140	(6) >140
			PANEL A: PLACEBO			
Ground floor	-436.74***	-485.90**	-336.47**	-0.09***	-0.11**	-0.07**
	(151.00)	(178.34)	(126.91)	(0.03)	(0.04)	(0.03)
Ground floor × Sea wall (previous year)	71.90	-94.17	198.11	0.01	-0.02	0.05
	(117.49)	(167.18)	(186.78)	(0.03)	(0.04)	(0.04)
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	4973.49	5012.48	4895.32	8.49	8.49	8.47
SD Y	1137.27	1159.97	1086.30	0.23	0.23	0.22
R2	0.38	0.38	0.51	0.40	0.41	0.52
Obs.	10109	6745	3364	10109	6745	3364
			PANEL B: RENT PRICES			
Ground floor	-0.67	-0.35	-0.93*	-0.04	-0.02	-0.06**
	(0.43)	(0.74)	(0.46)	(0.03)	(0.04)	(0.03)
Ground floor × Sea wall	-0.24	-0.36	-0.17	-0.00	-0.01	0.00
	(0.40)	(0.63)	(0.74)	(0.02)	(0.04)	(0.04)
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	15.58	15.66	15.38	2.71	2.72	2.70
SD Y	4.24	4.40	3.79	0.27	0.27	0.27
R2	0.29	0.28	0.42	0.33	0.35	0.40
Obs.	6676	4751	1922	6676	4751	1922

Note: The Table shows the estimates from equation (2). 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. Panel A shows the results using asking prices for the period October 2018 - December 2020; panel B shows the results using rent prices for the period October 2019 - December 2021. 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 boats 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.

results on rent price indicates that the activation of the sea wall affects sale prices mainly through the present discounted benefit from lower high-tide risk, rather than by increasing flow utility of housing services, which is common to both rented and owner-occupied properties.[27]

Within property. Finally we exploit the panel structure of our data to estimate a version

[27]The lack of results for renters is in line with the descriptive results in Table A1 in the Appendix, which we discussed at the end of Section 3.

of (2) with property fixed effects. Most notably, we estimate the following difference-in-difference specification:

$$y_{it} = \beta \, Ground\ Floor_i \times Sea\ Wall_t + \gamma_i + \gamma_t + \epsilon_{it}, \tag{3}$$

where all variables are as in equation (2), but we now replace the location-type fixed effect (γ_{lk}) with a property fixed effect (γ_i). The coefficient of interest is β which captures the differential effect of the sea wall on ground floor properties. The coefficient is identified by difference in list prices after the first sea wall activation relative to before for the *same* property.

Table A2 in the Appendix shows the results. First, it is worth emphasizing the very high R^2 around 98-99%, which is the result of the property fixed effects and the relative limited times list prices are revised.[28] After the activation of the sea wall, we find that ground floor property in Venice experience an increase in price per square meter of about 45€. The effect if driven by properties with lower elevation, which experience an increase in prices by about €60 per square meter, or 1.2% relative to the average price per square meter before the activation of the sea wall. The interaction term between ground floor and sea wall is not significant and smaller in magnitude for ground-floor properties in high elevation areas. The results using the log of the price per square meter are similar.

4.2 The Effects of the Sea Wall on Low-Elevation Properties

We now exploit a second dimension of 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. 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. The price is normalized to 100 in October 2020, which is the month when the sea wall was first activated.

Properties with an elevation of 140 cm or higher have been on an declining trend since the start of the pandemic. Properties with an elevation level below 140 cm follow closely the declining pattern of higher elevation properties up until the end of 2020. From the beginning of 2021, after several successful activation 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.

To isolate the differential effect of the sea wall on lower-elevation properties, we estimate the

[28] More than 60% of ads do not experience any price revision, 22% have one price revision and the remaining 15% revise the price more than once.

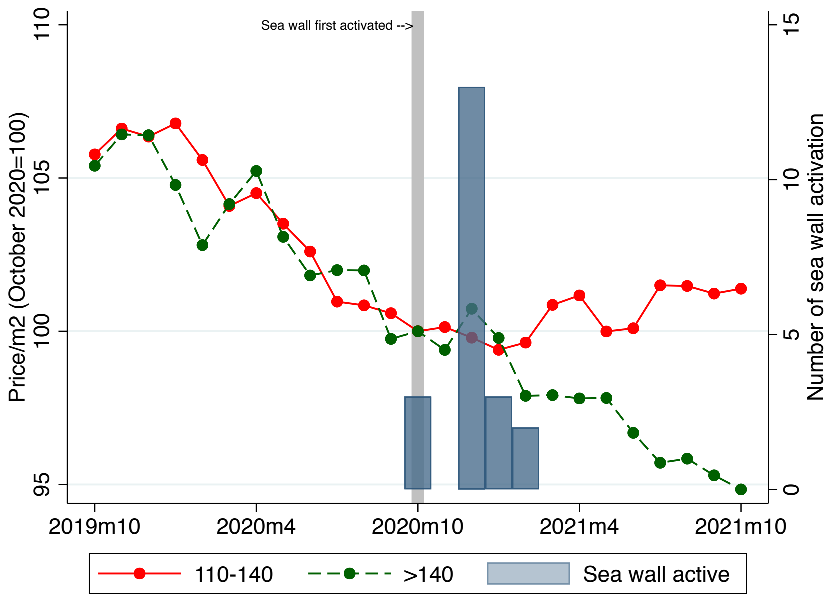


Figure 7: Prices per m^2: Low vs high elevation

Note: The figure shows the average price per square meter in a two-year window around around October 2020, which is the month when the sea wall was first activated. The figure shows the average prices for properties with an elevation between 110 and 140 cm and for properties at higher elevation levels. The price is normalized to 100 in October 2020. The blue vertical bars show the number of times the sea wall has been activated in the respective month.

following difference-in-difference specification:

$$y_{ilkt} = \alpha Low\ Elevation_i + \beta Low\ Elevation_i \times Sea\ Wall_t + \theta X_i + \gamma_{lk} + \gamma_t + \epsilon_{ilkt}, \qquad (4)$$

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 (2). The main coefficient of interest is β which captures the differential effect of the sea wall on lower elevation properties.

Columns (1) and (2) of Table 5 show the main results. Consistent with the descriptive evidence from Table 2, 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 €150, or 3% 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. After the activation of the sea wall, low-elevation properties increase their price per square meter by about 3% relative to similar properties at higher elevation levels.

Columns (3) and (4) of Table 5 show the results from the estimates of equation (4) comparing

Table 5: Effect of sea wall on low elevation properties

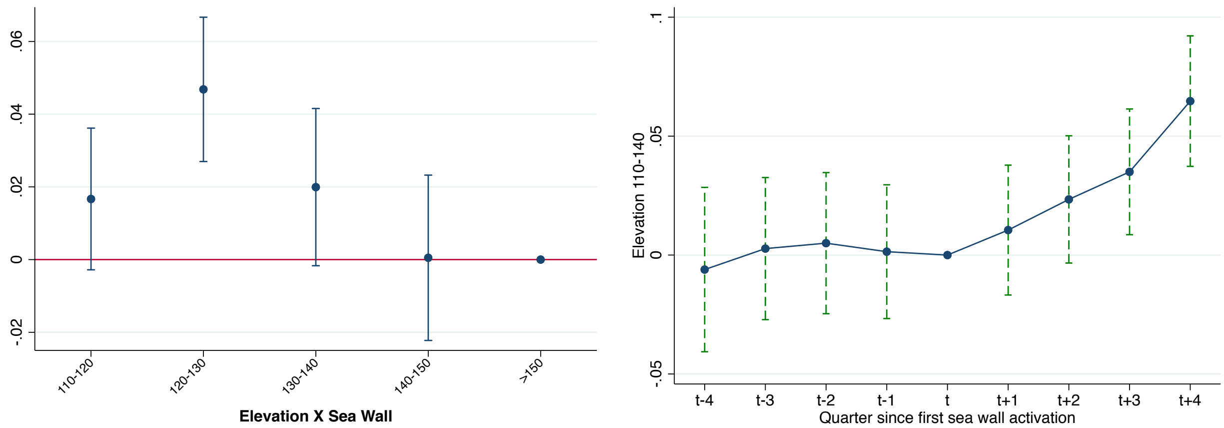
	Main		Robustness			
	(1) Level	(2) Log	(3) Level	(4) Log	(5) Level	(6) Log
Elevation: 110-140	-37.36	-0.00				
	(91.57)	(0.02)				
Elevation: 110-130			-93.16	-0.02		
			(110.22)	(0.02)		
Elevation: 110-150					210.50**	0.04**
					(78.09)	(0.02)
Elevation: 110-140 × Sea wall	149.07**	0.03**				
	(61.73)	(0.01)				
Elevation: 110-130 × Sea wall			122.08*	0.02*		
			(63.56)	(0.01)		
Elevation: 110-150 × Sea wall					108.08	0.02
					(81.96)	(0.02)
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	4979.78	8.49	4979.78	8.49	4979.78	8.49
SD Y	1098.28	0.22	1098.28	0.22	1098.28	0.22
R2	0.33	0.34	0.33	0.34	0.33	0.35
Obs.	12450	12450	12450	12450	12450	12450

Note: The Table shows the estimates from equation (4) for the period October 2019 - December 2021. In columns (1), (3) and (5) the dependent variable is the asking price in euro per square meter; in columns (2), (4) and (6) the dependent variable is the log of the asking price in euro per square meter. Elevation: 110-140 is a dummy equal to one for properties with an elevation between 110 cm and 140 cm. 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 boats 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.

properties with an elevation between 110 cm and 130 cm with properties above 130 cm. The results are similar to the baseline specification using the 140 cm threshold. The more noisy and slightly lower estimates may be the results of uncertainty around the exact activation threshold, which affects properties at elevation level below 130 cm more. The results with the threshold at 150 cm are reported in columns (5) and (6) of Table 5. When we repeat the analysis using a higher threshold at 150 cm the results loose significance, as we are including in the "treatment" group properties with higher and higher elevation, which are *relatively* less affected by flooding and hence by the activation of the sea wall.

4.2.1 Additional Analyses and Robustness

In the rest of the section we report the results of four additional analyses related to our main results in Table 5: (i) elevation bins (ii) parallel trends; (iii) a placebo test; and (iv) rent prices.



(a) Across elevation

(b) Over time

Figure 8: Log prices per m^2

Note: The left figure shows the coefficient on 10 cm elevation bins and their interaction with the post sea wall period. The estimated coefficients are based on equation (4) 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 right figure shows the coefficients on the interaction terms between elevation 110-140 cm and quarter. The estimated coefficients are based on equation (4) replacing the interaction term between elevation 110-140 cm and sea wall with interaction dummies of elevation 110-140 cm with time for quarter before and after the quarter of the first activation of the sea wall. The vertical bars are 95% confidence interval.

Elevation bins. We also estimate a version of equation (4) with 10 cm-bins for elevation levels. Panel (a) of Figure 8 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 110-120 cm and 130-140cm. The relative lower 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 level 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.

Parallel trends. We explore pre-trends in the prices per square meter at different elevation levels. Most notably, we estimate a version of equation (4) in which we interact the dummy for elevation between 110 cm and 140 cm with time dummies for quarter before and after the quarter of the first activation of the sea wall. Panel (b) of Figure 8 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 all the quarters before the activation of the sea wall, consistent with the parallel trend assumption. After the activation of the sea wall, properties with an elevation between 110 cm and

Table 6: Effect of sea wall on low elevation properties: Placebo and rents

	Placebo		Rents	
	(1) Level	(2) Log	(3) Level	(4) Log
Elevation: 110-140	49.33	0.01	0.00	-0.01
	(100.78)	(0.02)	(0.42)	(0.03)
Elevation: 110-140 × Sea wall (previous year)	2.95	-0.00		
	(82.90)	(0.02)		
Elevation: 110-140 × Sea wall			0.36	0.04
			(0.46)	(0.03)
FE location-type	Yes	Yes	Yes	Yes
FE year-month	Yes	Yes	Yes	Yes
Controls	Yes	Yes	Yes	Yes
Mean Y	5091.32	8.51	15.63	2.71
SD Y	1123.85	0.22	4.25	0.26
R2	0.33	0.34	0.29	0.31
Obs.	8053	8053	5697	5697

Note: The Table shows the estimates from equation (4). In columns (1) and (2) the dependent variable is the asking price in euro per square meter and the period is October 2018 - December 2020; in columns (3) and (4) the dependent variable is the rent price in euro per square meter and the period is October 2019 - December 2021. Elevation: 110-140 is a dummy equal to one for properties with an elevation between 110 cm and 140 cm. 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 boats 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.

140 cm experience a significant increase in prices per square meter. Most notably, the magnitude of the coefficient increases over time, from less than 2% in the quarter just after the sea wall activation to more than 5% in the fourth quarter after.

Placebo. We estimate a version of equation (4) in which we interact the elevation threshold 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 two year interval around October 2019, as we did for the empirical strategy using the ground-floor properties in Section 4.1. Columns (1) and (2) of Table 6 report the results. We do not find any differential positive effect on properties located 110-140 cm after October 2019. The lack of differential effect on properties located 110-140 cm after the placebo sea wall suggest that the effect we identify in Table 5 are coming from the sea wall activation, rather than seasonal or anticipation effects that are differential based on the property elevation.

Rent prices. We also estimate equation (4) using rent prices as dependent variable, as we did in Section 4.1 for ground-floor properties. After the activation of the sea wall rent prices of low-elevation properties increase relative to rents of higher-elevation properties, but the results are not statistically significant. An increase in rent prices is consistent with renters benefiting from less flooding in the area where they live, which can impair the quality of living in an area. However, the lack of significant results on rent price is consistent with sale prices capturing the majority of the benefit from lower current and expected flooding.

4.3 Interpretation of the Estimates

We propose a simple interpretation of the estimated effects of the sea wall on housing prices through the lens of an asset pricing equation for housing (Poterba, 1984). We 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 $C_{h,t}$:

$$P_{h,t} = \mathbb{E}_t \left[\sum_{j=0}^{\infty} \xi^j_{h,t+j} (R_{h,t+j} - C_{h,t+j}) \right], \tag{5}$$

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 (5) simplifies to:

$$P_{h,t} = \frac{\bar{R}_{h|t} - \bar{C}_{h|t}}{\bar{i}_{h|t}}, \tag{6}$$

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:

$$\Delta P_h = P_{h,t+1} - P_{h,t} = \frac{\bar{R}_{h|t+1} - \bar{C}_{h|t+1}}{\bar{i}_{h|t+1}} - \frac{\bar{R}_{h|t} - \bar{C}_{h|t}}{\bar{i}_{h|t}}, \tag{7}$$

where t ($t+1$) denotes the period before (after) the activation of the sea wall. Rearranging equation (7) we obtain:

$$\Delta P_h = \frac{1}{\bar{i}_{h|t}} \left[\Delta \bar{R}_h - \Delta \bar{C}_h \right] - \frac{\Delta \bar{i}}{\bar{i}_{h|t}} P_{h,t+1}. \tag{8}$$

Equation (8) 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 ($\frac{\Delta \bar{i}}{\bar{i}_{h|t}} < 0$). Although a precise quantification of these three channels is beyond the scope of the paper, our estimates offer some guidance on the relative magnitudes of the different channels.

First, we find that rents did no react to the activation of the sea wall. By assuming that our results hold for future rents as well, we can argue that this channel is negligible ($\Delta \bar{R}_h \approx 0$). Renters are potentially affected by periodic floods in their everyday life during Winter months, but this utility loss does not seem of first order importance in rental pricing, which therefore does react to the introduction of the sea wall. As we discussed in Section 3 and 4, the lack of an effect on rent prices could also be because the burden of floods falls on landlords, who are responsible for damage reparation after flooding.

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 (8) and assuming that the reduction in the risk premium is the same for ground and upper floor properties, with an interest rate of 3% we obtain $\Delta \bar{C}_{\text{ground floor}} =$ -€12/m2 or around -€1100 for an average apartment of 95 square meters.[29] This number represents the average annual expected damage that ground floor properties would have suffered absent the sea wall.

While we do not have data on maintenance costs to repair damages from floods, we obtained access to partial information on the claimed damages from households and businesses after the high flood occurred in November 2019. Figure A9 in the Appendix shows the distribution of such claims. Many private owners claimed damages up to €5000 (the maximum amount that could be granted). Considering that likelihood of such high floods is low based on historical probabilities but it is expected to increase because of SLR and that lower floods should cause smaller damages, our estimates of expected maintenance expenses backed out from the asset price equation seems plausible.

Finally, we take advantage of our two empirical strategies, which deliver an estimate of equation (8) for both ground floors and upper floors, to provide some insights on the role played by the discount factor. The results in Tables 3 and 5 shows that the estimated impact of the sea wall is significantly higher for ground floor than for higher floors (€400/m2 more). This differential is likely due to apartments on upper floors being less exposed to flood-related physical damages. The owners of these apartments must still bear their share of the maintenance expenditures for the common parts of the building. However, these would be very small compared to the potential damage to the entire apartment. Under the extreme case that $\Delta \bar{C}_{\text{upper floors}} = 0$, the estimated effect of the sea wall on upper floor properties in low elevation areas is mainly informative about the reduction in the riskiness of future cash flows. With this assumption, the price change on upper floor properties ($\Delta P_{\text{upper floors}}$) corresponds to a reduction in the discount factor ($\Delta \bar{i}$) by

[29] An interest rate of 3% is an intermediate value between the near-zero time discount rate advocated by Nicholas 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).

about 3%.[30]

5 Capitalization of the Sea Wall

In this Section we combine the empirical estimates from Sections 4.1 and 4.2 to compute the overall gain from the sea wall on the stock of residential properties in Venice. We implement several steps to quantify valuation gains and how they are distributed across property types and locations. We then discuss in details the magnitudes of the capitalization of the sea wall relative to the total residential housing stock, the cost of the sea wall, and expected damages from future floods, as well as some limitations of our analysis.

5.1 Approach and Results

First, we obtain from census data the overall residential area 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. Panel A of Table 7 reports some descriptive statistics about the residential area in the center of Venice. The total area is about 3.3 millions of square meter. 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.

Second, for each of the categories we compute the average price per square meter from the listing data. As discussed in Section 3, we observe the listing price, not the transaction price. However, we collected local-level average transaction prices from the Italian tax office and we find that the correlation with local-level average listing prices is 0.99. Figure A8 in the Appendix shows that average transaction and listing prices for different areas are close to the 45 degree line.

Panel B of Table 7 shows the average price per square meter from our listing dataset. 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 4.8 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 4.1. 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.[31]

[30] Notice that through equation (8) we can only identify the relative change in i. If we assume that the interest rate before the activation of the sea wall was 3%, a 3% reduction corresponds to roughly 10 basis points.

[31] 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

Table 7: Capitalization of sea wall in housing stock

	<110	110-140	>140	Total
Panel A: area (m2 thousands)				
Ground floors	46.6	174.9	78.0	299.5
Upper floors	468.4	1740.1	757.5	2966.0
Total	515.0	1915.0	835.6	3265.5
Panel B: avg. price (€/ m2)				
Ground floors	4722	4575	4424	4574
Upper floors	5009	4945	4665	4873
Average	4866	4760	4544	4723
Panel C: gain from sea wall (%)				
Ground floors	.	10%	0	
Upper floors	.	3%	0	
Panel D: overall gain from sea wall (€M)				
Ground floors	.	80.0	0.0	
Upper floors	.	258.1	0.0	
Total		338.1		

Note: The Table shows: i) Panel A: the estimates of total residential area in the center of Venice according to 2011 census data; the split between ground and upper floors reflects the share of housing ads for these types of houses in our listing dataset; 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 3 and 5; iv) Panel D: the overall effect of sea wall, i.e. the product between the corresponding cells in Panel A, B and C.

Third, for each of the six categories based on elevation and floor level we compute the percentage gain from the sea wall, combining the estimates from Table 3 for ground floors and from Table 5 for elevation levels. Based on our estimates, Panel C of Table 7 shows that the largest gain, equal to 10%, comes from ground floor properties with an elevation between 110 cm and 140 cm. The total gain combines the 7% differential increase for ground floor properties – column (5) of Table 3 – with the 3% differential increase for properties with an elevation between 110 cm and 140 cm – column (2) of Table 5. Upper floors with an elevation between 110 cm and 140 cm gain 3%. We assume there is no gain for all properties with an elevation below 110 cm and discuss below the implications for our estimates.

Fourth, we multiply the average area in square meter by the average price per square meter and the percentage gains to compute the increase in value for each category. Panel D of Table 7 shows that the sea wall led to a differential increase for ground floors with an elevation of 110-140 cm by about €80 millions. The largest city-wide gains come from upper floors with an elevation

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 2.

of 110-140 cm that contributed for almost €260 millions. Summing across all affected categories, we obtain an overall increase in residential properties values from the activation of the sea wall of almost €340 millions.[32]

Finally, we also allow the capitalization to be time-varying using our estimates from Figure 6 for ground floors and Panel (b) of Figure 8 for elevation. Figure 9 shows the result.[33] The gains in values for the housing stock are increasing over time going from approximately €120 millions in the first quarter after the first activation of the sea wall to about €670 million one year after. These dynamics are consistent with agents learning over time about the effectiveness of the sea wall and gradually adjusting new listing prices.

5.2 Discussion

Our estimates of the capitalization effect on residential house prices provide a *lower bound* on the welfare gains from the construction of the sea wall for several reasons.

First, our empirical strategy lies in the tradition of hedonic models, which aim at estimating the (unobserved) implicit value of amenities through (observable) variations in housing prices. Under stark assumptions, estimates from standard hedonic models using cross-sectional data can be used to infer the buyer's marginal willigness 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 Gallagher, 2008; Kuminoff and Pope, 2014; Banzhaf, 2021). This is also the approach adopted by this paper.[34]

Our difference-in-differences (DD) hedonic design exploits the activation 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. For a large change in the supply of the amenity – which is likely the case in our setting – the capitalization result cannot be interpreted as a WTP, because the hedonic price function might change as well.[35] However, Banzhaf (2021) shows that DD hedonic estimates

[32]We replicate the same calculation behind Table 7 using the local-level average transaction prices from the Italian tax office. Table A3 in the Appendix reports the results which are remarkably similar to the baseline results using the listing prices. Summing across all affected categories, we obtain an overall increase in residential properties values from the activation of the sea wall of about €350 millions.

[33]Confidence bands are obtained by applying the same procedure described above by adding and subtracting to the central coefficient estimates their standard deviations. Notice that for ground floors in areas located between 110 and 140 centimeters on the sea level the estimated impact is the sum of the effects of elevation and ground floors. For this category we take into account both the standard deviation on the effect of elevation and that on the impact of ground floors.

[34]In Appendix C we formally discuss the interpretation of our empirical estimates within the hedonic framework.

[35]The capitalization effect can be interpreted as an average WTP for sea wall only if the hedonic price function is constant over time. If the gradient of the hedonic price function changes after the treatment, the capitalization effect cannot be interpreted as a welfare measure because it conflates the public's WTP for the sea wall with changes in the shadow price for flood risk and other amenities that may have occurred in the meanwhile (Kuminoff and Pope,

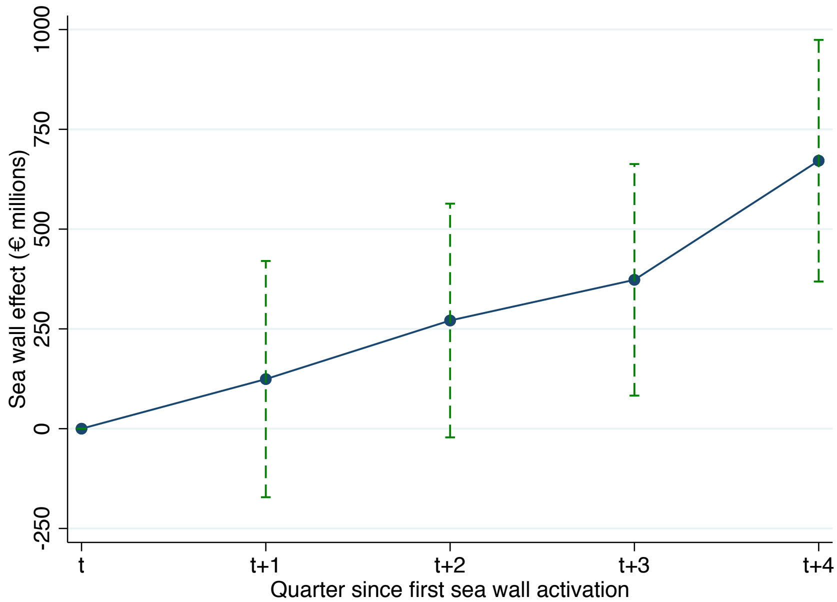


Figure 9: Capitalization over time

Note: The figure shows the effect of the sea wall activation on the residential housing stock of Venice. For each quarter we multiply the estimated impact of the sea wall (in percentage terms) on the average asking price of the corresponding housing category (ground floors or upper floors) using the estimates from Figure 6 for ground floors and Panel B of Figure 8 for elevation. This gives us an estimate expressed in euros per square meters, that we multiply by the relevant housing surface areas, distinguishing the following categories ground and upper floors between 110 and 140 cm. The sum of the impacts on these two categories provides us with an evaluation of the overall effect of the sea wall on the housing stock. Confidence bands are obtained by applying the same procedure described above by adding and subtracting to the central coefficient estimates their standard deviations. Notice that for ground floors in areas located between 110 and 140 centimeters on the sea level the estimated impact is the sum of the effects of elevation and ground floors. For this category we take into account both the standard deviation on the effect of elevation and that on the impact of ground floors.

provide a lower bound on the total welfare effects of the policy. Hence our baseline capitalization result finds a large lower bound on general equilibrium welfare for residential homes in Venice, at about €670 million for the present value of the realized decrease in flood risk.[36]

Second, the post treatment period is only one year, while adjustments in the housing market may take many years to fully materialize. A relative short time period is both a curse and a blessing. On the one hand, we cannot observe longer run adjustments to listing (and possibly transactions) prices related to the sea wall. On the other hand, one issue with analyses based on longer time periods is that other changes to the economic environment could shift the price functions (Kuminoff and Pope, 2014; Banzhaf, 2021). Our approach based on short-term variations

2014).

[36] This number would likely be larger if we include potential benefits to properties with an elevation below the activation level of the sea wall. As we discussed in Section 4, while this properties can still experience flooding from high tides, that do not trigger the sea wall activation, they also benefits from the introduction of the sea wall, as they are protected from potentially even more damaging floods from high tides that lead to the sea wall activation.

in listing prices around the policy change is less likely to be affected by shifts in the hedonic price functions. We re-estimate equations (2) and (4) allowing for time-varying hedonics as advocated by Banzhaf (2021), by interacting all characteristics with a dummy for the period after the sea wall activation. Tables A6 and A7 in Appendix C show the results. Our estimates of the effects of the sea wall are almost unaffected when we allow for time-varying coefficients, suggesting that conflation bias coming from a change in the price function is unlikely to be a concern in the short time period after the shock that we analyze.

Third, we focus on residential properties only, while the sea wall is likely to benefit economic activities (e.g., tourism) and commercial properties – which occupy a large fraction of ground-floor space in Venice – as well. Unfortunately, we do not have data on listing for commercial properties, that would allow us to implement the same analysis we have for residential properties. However, we collect additional data on shops and restaurants – usually at the street level – from the municipality of Venice (see Appendix B). Under the assumption that ground floor commercial properties would appreciate as residential properties after the activation of the sea wall, we estimate an increase in the value of commercial properties used as shops and restaurants of about €110 millions (Table A4) – or €165 millions after a year. Again, this estimate is a lower bound because: (i) we consider only shops and restaurants as we have no information on the surface area of properties used as accommodations; (ii) the damage suffered by commercial activities is likely to be greater than that suffered by a house – as shown by damage claims in Figure A9 – so the benefit from the activation of the sea wall is likely to be greater for commercial dwellings.

With these caveats in mind, we construct two relative comparisons, to provide a better sense of the magnitude of the capitalization effect from the sea wall on the residential market in Venice. Most notably we look at the benefit from the sea wall relative to: (i) the total value of the stock of residential properties in Venice; and (ii) the total cost of the sea wall. First, multiplying the average price per square meter times the total square meter we can get an estimate of the value of the total residential area of Venice, which is approximately €15 billions. Hence, one year after its first activation, the sea wall leads to a re-evaluation of about 4.5% of the total residential housing stock of the city of Venice.

Finally, we compare our capitalization effect with the cost of the sea wall. The original project expected cost was 3,200 billions of Italian lira in 1989, which correspond to about €3.3 billions today. However, due to delays, increased costs and political scandal the actual cost as of 2020 amounted to almost €7 billions.[37] While this number is large, the potential benefits in terms of avoided future damages could also be high. A study based on future tide projections estimate benefits of about €6 billions over the next 50 years under a central SLR scenario (Caporin and Fontini, 2016). According to our estimates, the benefits in terms of higher prices for residential

[37]See https://www.contocorrenteonline.it/2020/12/09/mose-non-funziona-costo-venezia-acqua-alta/ and https://it.wikipedia.org/wiki/MOSE. Additionally, the sea wall involves an estimated cost of €300 thousands for each activation (See: https://www.metropolitano.it/mose-dietro-le-quinte-come-funziona/).

properties in the first year after the first activation of the sea wall already account for approximately 20% (10%) of the original (actual) costs.

6 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 3% for properties above the activation threshold and by an additional 7% for ground-floor properties. Our baseline capitalization provides a large lower bound on general equilibrium welfare for residential homes in Venice, at about €670 million for the present value of the realized decrease in flood risk, which corresponds to about 4.5% of the value of the total residential housing stock in Venice.

More broadly, our results show that forward-looking property prices capture the benefits of government investment to reduce the damage from climate change, suggesting that targeted property tax increases might represent a way to finance adaptation policies. Our analysis accounts only imperfectly for additional benefits from commercial properties revaluation and does not consider the impact on other economic activities that may benefit from the introduction of the sea wall and associated reduction in flood risk. Additionally, longer-term effect on the value of the housing stock in Venice are subject to uncertainty on future tide increases and the ability of the sea wall to cope with them. These additional dimensions of adjustment and uncertainty might be interesting avenues for future research.

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Internet Appendix

Appendix A provides supplementary figures and tables, including robustness checks. Appendix B discusses data sources, variables and the construction steps for the final dataset. Appendix C discusses the implications of the empirical results in welfare terms.

A Additional Figures and Tables

Table A1: Effect of flood risk on property values: Rent prices

	Price (level)			Price (log)		
	(1)	(2)	(3)	(4)	(5)	(6)
Flood probability	-0.23		-0.24	-0.01		-0.01
	(0.17)		(0.17)	(0.01)		(0.01)
Ground floor		-0.56	-0.63		-0.03	-0.04*
		(0.44)	(0.36)		(0.03)	(0.02)
Flood probability × Ground floor			-0.37			-0.01
			(0.94)			(0.06)
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	16.50	16.58	16.50	2.77	2.77	2.77
SD Y	4.67	4.62	4.67	0.26	0.26	0.26
R2	0.28	0.27	0.28	0.35	0.34	0.36
Obs.	2563	2841	2563	2563	2841	2563

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 rent price in euro per square meter; in columns (4) to (6) the dependent variable is the log of the rent 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 boats stations. Standard errors are double clustered at at the location-type and year-month level. *, **, and *** denote significance at the 10%, 5% and 1% levels, respectively.

Table A2: Effect of sea wall on ground-floor properties: Within ad

	Price (level)			Price (log)		
	(1) All	(2) <=140	(3) >140	(4) All	(5) <=140	(6) >140
Ground floor × Sea wall	43.117***	59.450***	9.876	0.003**	0.005***	-0.001
	(5.351)	(6.478)	(9.500)	(0.001)	(0.001)	(0.002)
FE property	Yes	Yes	Yes	Yes	Yes	Yes
FE week	Yes	Yes	Yes	Yes	Yes	Yes
Mean Y	5153.59	5219.87	4980.24	8.51	8.52	8.48
SD Y	1522.09	1548.84	1435.45	0.28	0.29	0.26
R2	0.98	0.98	0.99	0.98	0.98	0.98
Obs.	60065	43451	16614	60065	43451	16614

Note: The Table shows the estimates from equation (3) for the period October 2019 - December 2021. 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. 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 weeks after October 3rd 2020, when the sea wall was first activated. Standard errors are robust. *, **, and *** denote significance at the 10%, 5% and 1% levels, respectively.

Table A3: Capitalization of sea wall in housing stock: Transaction prices

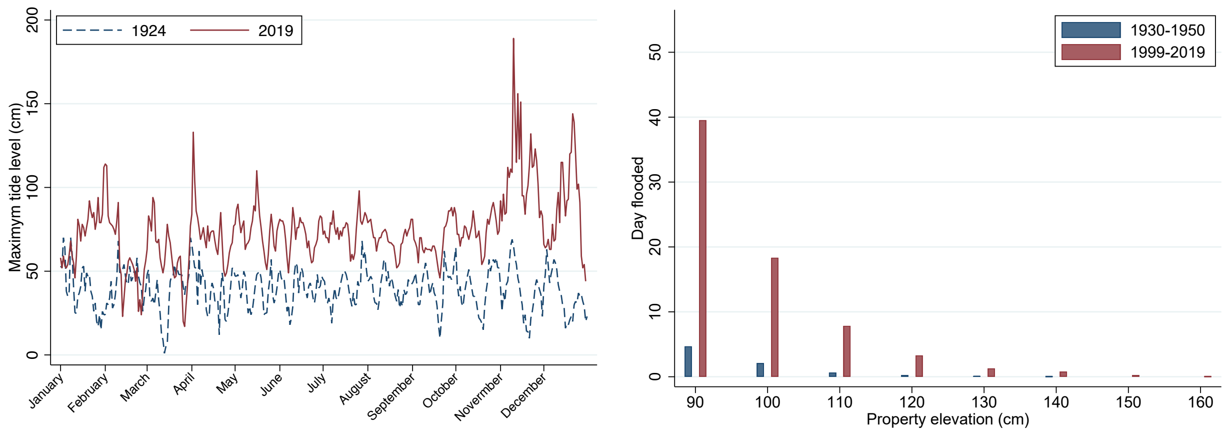
	<110	110-140	>140	Total
Panel A: area (m2 thousands)				
Ground floors	46.6	174.9	78.0	299.5
Upper floors	468.4	1740.1	757.5	2966.0
Total	515.0	1915.0	835.6	3265.5
Panel B: avg. price (€/ m2)				
Ground floors	4973	4682	4682	4754
Upper floors	5295	5100	4870	5088
Average	5134	4891	4738	4921
Panel C: gain from sea wall (%)				
Ground floors	.	10%	0	
Upper floors	.	3%	0	
Panel D: overall gain from sea wall (€M)				
Ground floors	.	81.9	0.0	
Upper floors	.	266.2	0.0	
Total		348.1		

Note: The Table shows: i) Panel A: the estimates of total residential area in the center of Venice according to 2011 census data; the split between ground and upper floors reflects the share of housing ads for these types of houses in our listing dataset; ii) Panel B: the average price per square meter from the Italian tax office; iii) Panel C: the average price gain from the implementation of the sea wall according to the estimates in Tables 3 and 5; iv) Panel C: the overall effect of sea wall, i.e. the product between the corresponding cells in Panel A, B and C.

Table A4: Capitalization of sea wall in housing stock: Commercial properties

	<110	110-140	>140	Total
Panel A: area (m2 thousands)				
Shops	31.8	78.0	29.0	138.8
Restaurant	14.3	43.0	17.1	74.4
Total	46.1	121.0	46.1	213.2
Panel B: avg. price (€/ m2)				
Shops	11237.9	9510.9	8796.5	9848
Restaurant	9862.7	8329.1	7844.2	8679
Average	10809.5	9090.6	8443.0	9321
Panel C: gain from sea wall (%)				
Ground floors	.	10%	0	
Panel D: overall gain from sea wall (€M)				
Shops	.	74.2	0.0	
Restaurant	.	35.8	0.0	
Total		110.0		

Note: The Table shows: i) Panel A: the estimates of total floor area of shops and restaurants in the center of Venice in 2017; we assume that all these commercial properties are at the street level and their spatial distribution in each neighborhood is the same as residential properties; ii) Panel B: the average price per square meter from the Italian tax office; iii) Panel C: we assume that the average price gain from the implementation of the sea wall equal to ground floor residential properties (Table 7); iv) Panel C: the overall effect of sea wall, i.e. the product between the corresponding cells in Panel A, B and C.



(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 level were flooded in 1930-1950 and 1999-2019.

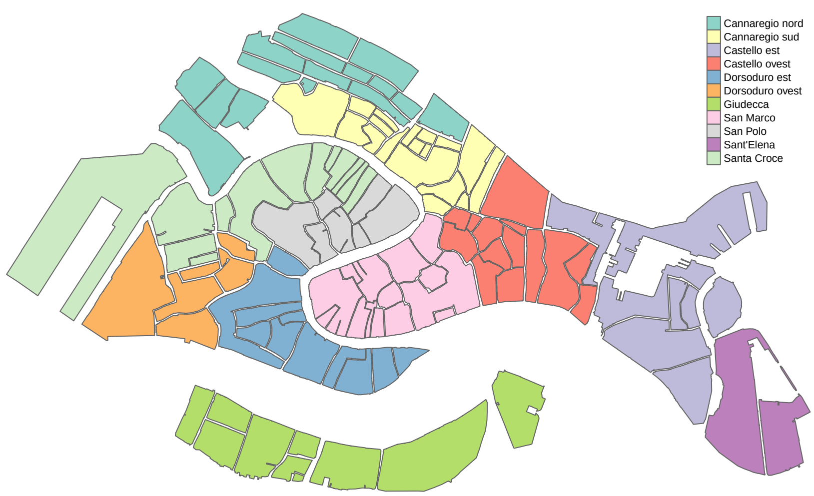
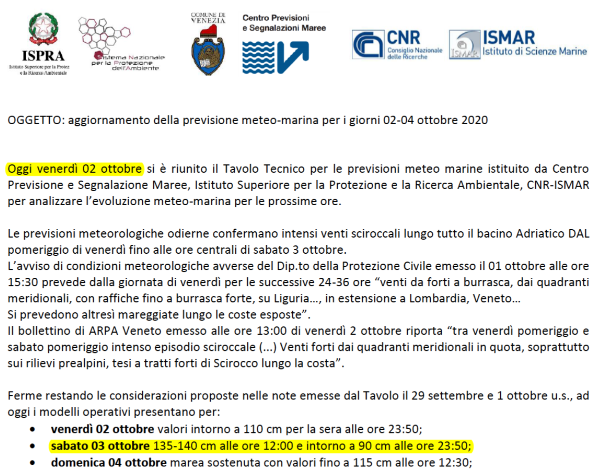


Figure A2: Venice Neighbourhoods
Note: The figure shows the name and areas of the different neighborhoods in Venice main island.



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

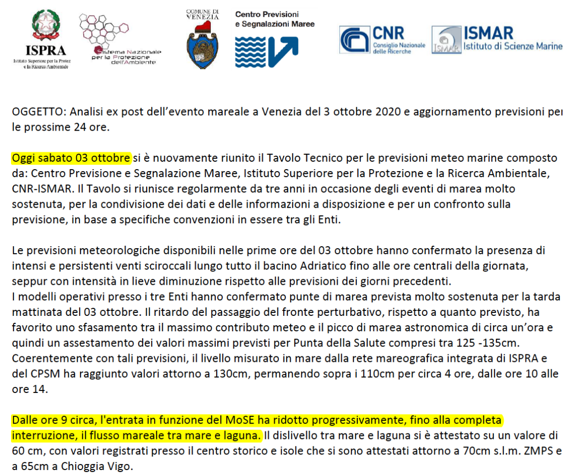
Oggi venerdì 02 ottobre si è riunito il Tavolo Tecnico per le previsioni meteo marine istituito da Centro Previsione e Segnalazione Maree, Istituto Superiore per la Protezione e la Ricerca Ambientale, CNR-ISMAR per analizzare l'evoluzione meteo-marina per le prossime ore.

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 of 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".

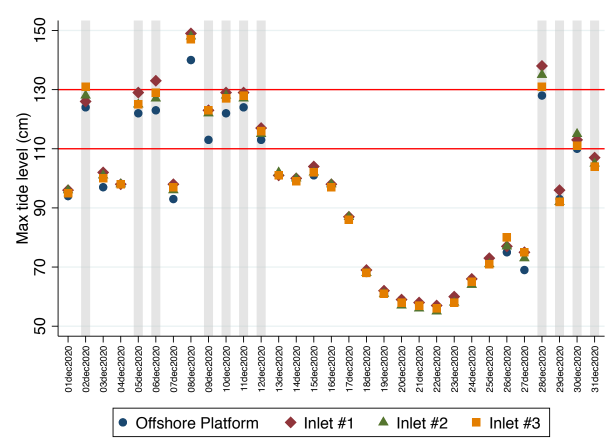


Figure A4: Offshore platform and inlets
Note: The left figure shows the location of the offshore platform, the three inlets, and the city of Venice. The right figure shows the highest measured tide offshore and in the three inlets in December 2020.

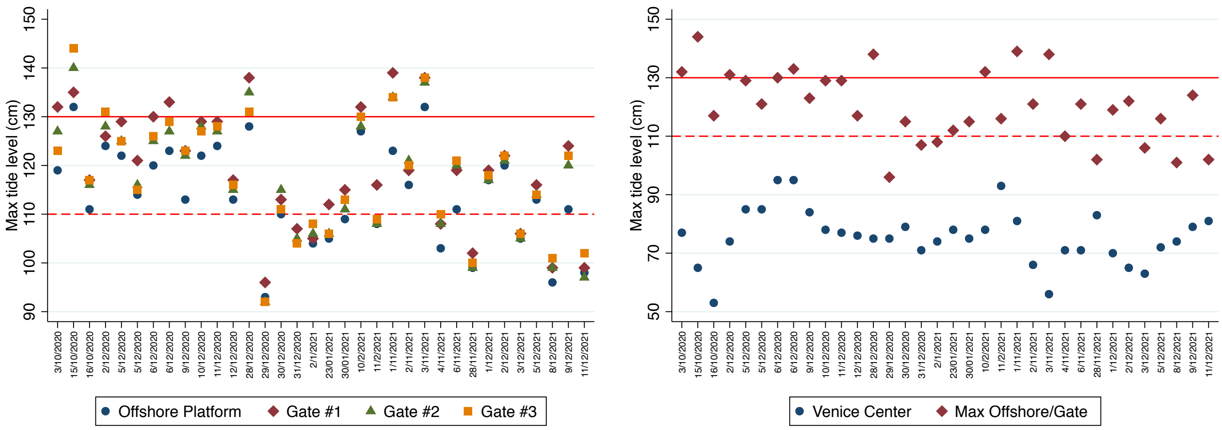


Figure A5: Sea Wall Activation Dates

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.

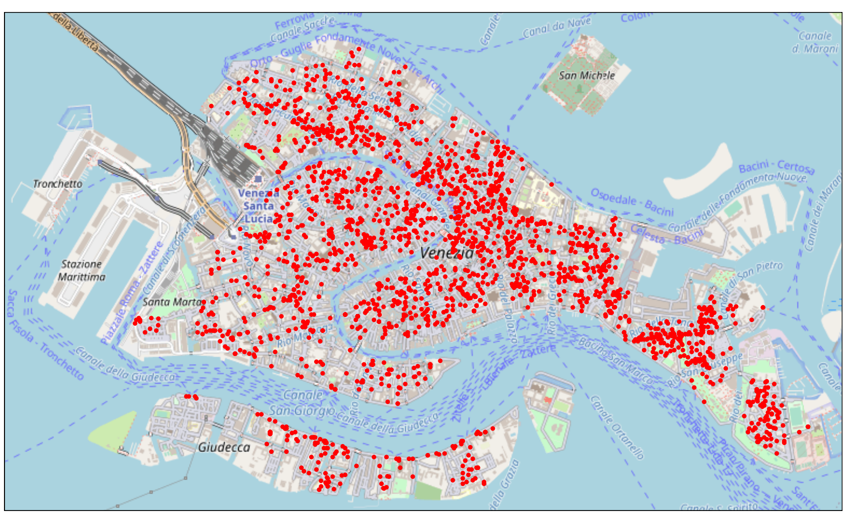
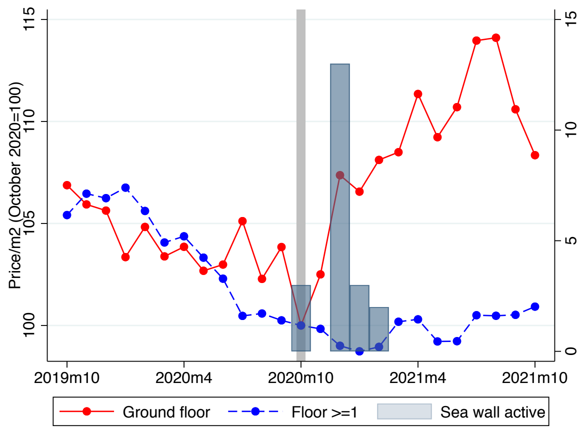
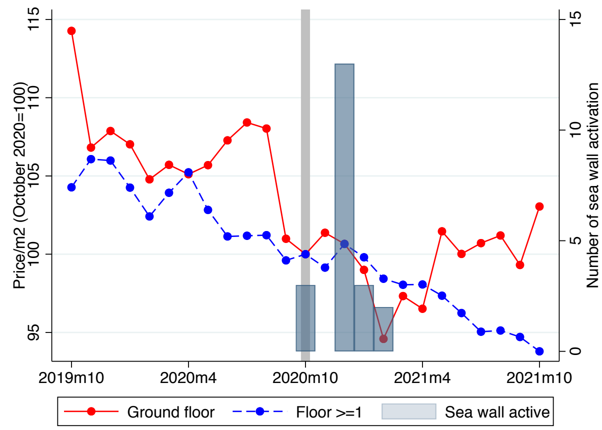


Figure A6: Properties across location

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



(a) Elevation $\leq$ 140 cm



(b) Elevation $>$ 140 cm

Figure A7: Prices per m^2

Note: The figure shows the average price per square meter from the start of 2019 to the end of 2021 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 left figure focus on properties with an elevation up to 140 cm relative to the reference point. The right figure focus 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.

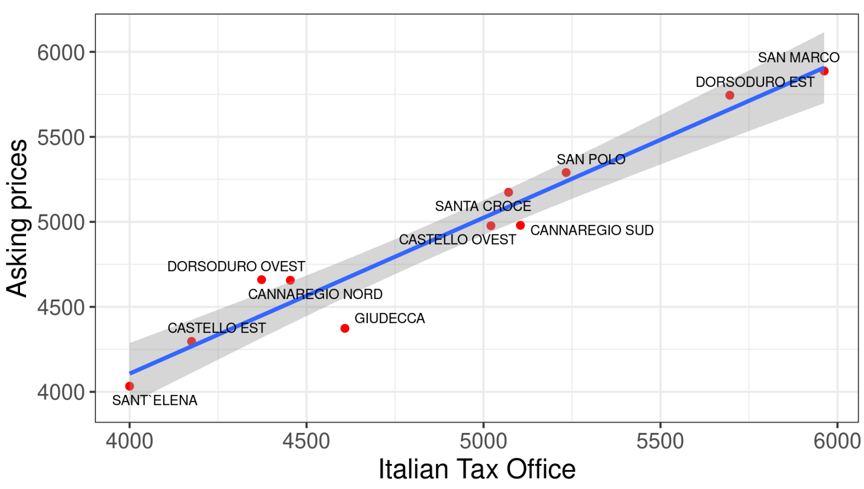


Figure A8: Listing and Transaction Prices by Area

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

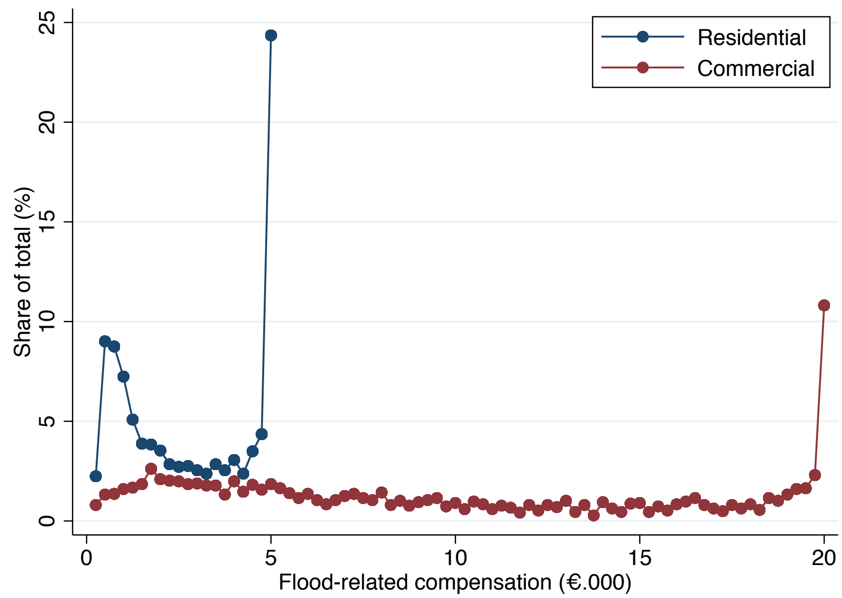


Figure A9: Residential and Commercial Claims after November 2019 Flood
Note: The figure shows the distribution of claims for residential and commercial properties after the November 2019 Flood.

B Data

Listings. We obtained from Immobiliare.it (www.immobiliare.it) a list of weekly files including all listed residential properties in Venice on their website between January 1, 2016 and December 31, 2021. 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 eliminate also ads that are related to foreclosure sales. This procedure is described in Loberto et al. (2022). We end up with a sample of 5,467 unique homes in the city center of Venice. For comparison, during the period 2016-2021 the number of house sales in the same area was 4,130.

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 in 11 zones. These zones are contiguous areas of the city territory that satisfy strict requirements regarding the homogeneity of house prices, urban characteristics, and the endowment of services and urban infrastructures. OMI microzones are periodically revised to satisfy these criteria and to better approximate local housing markets. The last revision dates back to 2014.

The Italian Tax Office disseminates estimates of minimum and maximum home values in euros per square meter in each zone. These are estimated based on a limited sample of home sales and valuations by real estate experts. We use these data to check the consistency between asking and transaction prices (see Figure A8). Figure A10 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.

Table A5: 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) reports 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.

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 A5). 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 A11 shows the distribution of houses' elevation by neighborhoods.

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 $\bar{x}$.

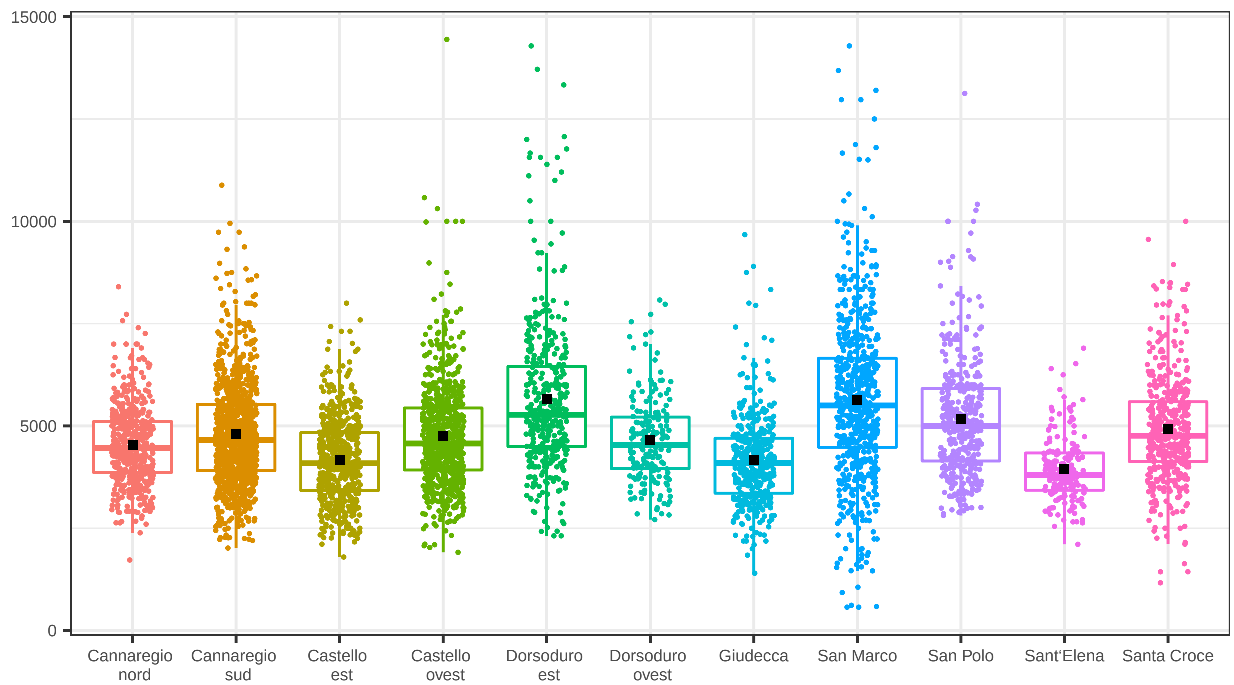


Figure A10: Listing prices by Neighborhood

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.

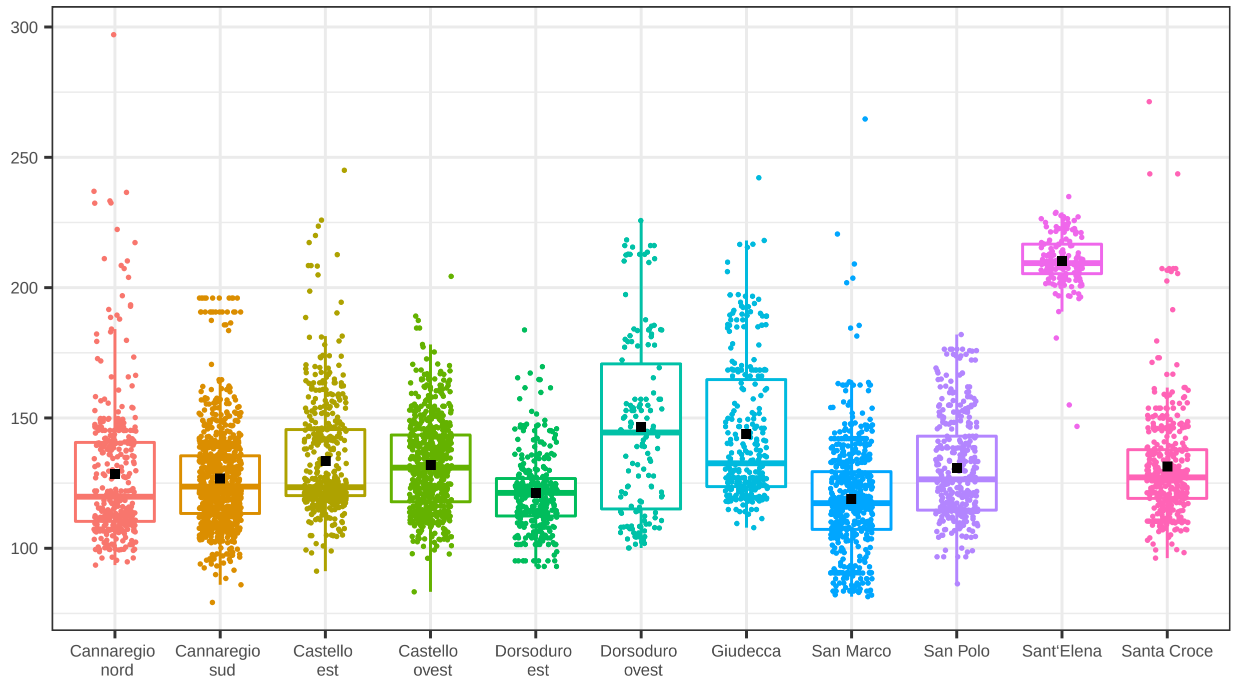


Figure A11: Houses' elevation by Neighborhood

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

C Hedonic interpretation of DD estimates

In this section, we formally discuss the implications of our results in welfare terms. A long-standing literature starting with Rosen (1974) has explored the possibility of extracting information on the consumer's willingness-to-pay (WTP) for non-marketable amenities from the observed prices of houses. Indeed, the price of a house can be defined as a function of its characteristics, $P_i = P(\mathbf{x}_i)$, where the vector of characteristics $\mathbf{x}_i$ include both structural attributes of the house and other amenities related to the location, such as neighborhood services or local environmental amenities. According to the hedonic model, the hedonic price function is generated by the equilibrium interactions of consumers and producers in a frictionless market.

A key feature of the hedonic model is that the hedonic price function is useful for welfare analysis. The gradient of the price function reveals the marginal willingness-to-pay (MWTP) of those consumers that have chosen a specific combination of quantity and price of a relevant characteristic. Therefore, the knowledge of the price function allows an assessment of the average welfare gain associated with a marginal change in a given amenity. However, empirical applications of the hedonic model based on cross-sectional data are plagued by the concern that omitted variables lead to misspecifications of the hedonic price function, introducing a bias in the estimation of MWTP (Greenstone, 2017).

This issue has been overcome in the last twenty years by exploiting quasi-experimental techniques, as we do in this paper. This approach allows consistent estimation of the hedonic price schedule, but the economic interpretation of the estimated parameters has been controversial. As shown by Kuminoff and Pope (2014), the average treatment effect on the treated that we recover from a DD approach is a measure of WTP if the hedonic price schedule does not change following the treatment (even for reasons exogenous to the treatment). Otherwise, the reduced-form estimates from DD conflate WTP with changes in the shadow price for amenities that may have occurred in the meanwhile. Given that the activation of the sea wall represents a large shock for the city of Venice, this is a potential concern for conducting welfare analysis in our setting.

A recent paper by Banzhaf (2021) shows that the DD methodology can still provide economically meaningful welfare measures, even if there is a shift in the hedonic price schedule. Introducing in the regression model time-varying hedonic parameters (to account for the shift in the hedonic prices) allows a consistent estimation of the average treatment effect on the treated along the ex-post hedonic price function. A key result in Banzhaf (2021) is that the estimates coming from DD, summed over houses, represent a lower bound on the total welfare effects of a nonmarginal change in the supply of an amenity, such as the flood protection provided by the sea wall. In particular, it is a lower bound on the Hicksian expected surplus, i.e., the change in money that holds utility constant at ex-post levels for a change in the amenity. Under mild assumptions, this bound holds even accounting for general equilibrium effects, endogenous changes in the supply of other amenities, and households sorting in the new equilibrium.

In this appendix we re-estimate equations (2) and (4) allowing for time-varying hedonics as advocated by Banzhaf (2021). Most notably, we rewrite equations (2) and (4) as:

$$\begin{aligned} y_{ilkt} = {} & \alpha \textit{Ground Floor}_i + \beta \textit{Ground Floor}_i \times \textit{Sea Wall}_t \\ & + \theta_1 X_i + \theta_2 X_i \times \textit{Sea Wall}_t + \gamma_{lk} + \gamma_t + \epsilon_{ilkt}, \end{aligned} \tag{9}$$

and

$$\begin{aligned} y_{ilkt} = {} & \alpha \textit{Low Elevation}_i + \beta \textit{Low Elevation}_i \times \textit{Sea Wall}_t \\ & + \theta_1 X_i + \theta_2 X_i \times \textit{Sea Wall}_t + \gamma_{lk} + \gamma_t + \epsilon_{ilkt}. \end{aligned} \tag{10}$$

The relevant amenity is the protection from sea floods, and *Low Elevation* and *Ground Floor* are our measures of protection. Before the activation of the sea wall, ground floors (upper floors in low elevation areas) had a higher exposure to sea floods than their respective control groups. After the activation of the sea wall, their exposure was the same as that of the control group. Therefore, the estimates of β in (9) and (10) – summed over all treated houses – provide a lower bound on the total welfare effects from increased protection from sea floods.

Although equations (9) and (10) both allow estimating the impact of reduced flood risk, their structural interpretation is slightly different because they refer to complementary aspects of the same amenity. Equation (9) measures the increase in welfare stemming only from reduced damages, as ground floor properties are compared to higher floor properties in the same low-elevation area. Equation (10), instead, measures the benefits from less flooding of common areas and the street access to the premises. Hence, the total welfare effects for ground floor properties in low-elevation areas is given by the sum of the β coefficients in (9) and (10), as we do in Table 7.

Tables A6 and A7 show the results. While we lose a bit of precision due to the larger number of coefficients, our estimates of the effects of the sea wall are almost unaffected when we allow for time-varying coefficients. This result suggests that conflation bias coming from a change in the price function is unlikely to be a concern in the short period after the shock that we analyze.

Table A6: Effect of sea wall on ground-floor properties - Time-varying hedonics

	Price (level)			Price (log)		
	(1) All	(2) <=140	(3) >140	(4) All	(5) <=140	(6) >140
Ground floor	-318.54**	-504.97***	-211.33	-0.07**	-0.12***	-0.04
	(126.83)	(137.88)	(215.81)	(0.03)	(0.03)	(0.04)
Ground floor × Sea wall	244.11**	406.26**	-3.87	0.04*	0.07**	-0.00
	(115.19)	(154.83)	(100.09)	(0.02)	(0.03)	(0.02)
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
Controls × Post	Yes	Yes	Yes	Yes	Yes	Yes
Mean Y	4883.20	4947.31	4753.88	8.47	8.48	8.44
SD Y	1119.90	1147.43	1050.46	0.23	0.23	0.22
R2	0.35	0.36	0.47	0.37	0.38	0.47
Obs.	15581	10423	5156	15581	10423	5156

Note: The Table shows the estimates from equation (2) for the period October 2019 - December 2021. 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. 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 boats stations. All controls are interacted with the sea wall dummy. 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 A7: Effect of sea wall on low elevation properties - Time-varying hedonics

	Main		Robustness			
	(1) Level	(2) Log	(3) Level	(4) Log	(5) Level	(6) Log
Elevation: 110-140	-42.49	-0.01				
	(90.90)	(0.02)				
Elevation: 110-130			-102.22	-0.02		
			(109.33)	(0.02)		
Elevation: 110-150					205.32**	0.04**
					(85.27)	(0.02)
Elevation: 110-140 × Sea wall	149.45*	0.03*				
	(73.79)	(0.01)				
Elevation: 110-130 × Sea wall			132.99**	0.02*		
			(63.42)	(0.01)		
Elevation: 110-150 × Sea wall					112.08	0.02
					(89.87)	(0.02)
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
Controls × Post	Yes	Yes	Yes	Yes	Yes	Yes
Mean Y	4979.78	8.49	4979.78	8.49	4979.78	8.49
SD Y	1098.28	0.22	1098.28	0.22	1098.28	0.22
R2	0.33	0.34	0.33	0.34	0.34	0.35
Obs.	12450	12450	12450	12450	12450	12450

Note: The Table shows the estimates from equation (4) for the period October 2019 - December 2021. In columns (1), (3) and (5) the dependent variable is the asking price in euro per square meter; in columns (2), (4) and (6) the dependent variable is the log of the asking price in euro per square meter. Elevation: 110-140 is a dummy equal to one for properties with an elevation between 110 cm and 140 cm. 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 boats stations. All controls are interacted with the sea wall dummy. Standard errors are double clustered at the location-type and year-month level. *, **, and *** denote significance at the 10%, 5% and 1% levels, respectively.