Capitalizing Flood Risk Protective Measures in Residential Real Estate

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Abstract

This study utilizes 1.4 million residential transactions incorporating flood hazard estimates derived from a nationwide elevation model and hydrological data to examine the role of flood protections to mitigate the negative impact of flood risk on home prices. We find that low-rise homes in unprotected flood-prone areas face a 3.5% price discount, whereas mid-/high-rise properties are unaffected. Post-installation, homes near flood protections experience price increases of 10.7%, with no significant difference across home types. This premium mirrors the pre-protection discount observed for the same homes. Robustness checks using manual flood risk assessments confirm our findings, offering valuable insights for various stakeholders.

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1. Introduction

With the adverse effects of climate change, natural disasters such as floods are becoming more frequent and severe (Gariano and Guzzetti 2016). This increase can be attributed to accelerated melting of ice and snow due to rising temperatures, more extreme weather events, rising sea levels, and changes in land use such as deforestation and urbanization. In addition to significant impacts on infrastructure and property, floods can pose serious risks to human lives. The threat of floods is particularly critical for households in areas with a history of flooding or those predisposed to future flood events. While Zhang (2010) demonstrates that flood hazards play a significant role in housing decisions, with homebuyers often opting for less vulnerable areas over flood zones, many households still live in areas of varying risk.

To mitigate the consequences of flooding, protections can be constructed in riskier areas. These measures may involve physical protection structures, such as flood embankments and the reinforcement of riverbanks and riverbeds with stone or other materials. In a review of the real estate climate risk literature, Contat et al. (2024) note that the field has primarily focused on the effects of floods and sea level rise. While the effects of flood events have been widely studied, the impact of flood protections has received comparatively little attention.

Norway is an ideal country for such studies due to its data availability, regulatory system, and varied geography, which includes coastlines, rivers, and mountainous regions. Under Norwegian law, a seller may be held liable for failing to disclose relevant information about a property. According to the Disposal/Alienation Act § 3-7, the seller is responsible for omissions that significantly affect the buyer's decision-making.[1] Case law confirms that information about flood risk falls under the seller's duty of disclosure.[2] For example, in FKN-2009-351, the Insurance Complaints Board ruled that a failure to disclose flood risks constituted a breach of this obligation under the Disposal/Alienation Act § 3-7. Furthermore, Norwegian insurance providers are not permitted to charge higher premiums for homeowners in flood-prone areas, as coverage for natural perils, including floods, is included in fire insurance. This system is regulated by the Norwegian Natural Perils Pool, which ensures that premiums are uniform across all insurance segments nationwide.[3] Beyond the legal requirements, flood events receive

[1] Lov om avhending av fast eigedom (avhendingslova) [Disposal/Alienation Act] § 3-7, July 3, 1992, available at: https://lovdata.no/dokument/NL/lov/1992-07-03-93/KAPITTEL_3#%C2%A73-7.
[2] Forsikringsklagenemnda, FKN-2009-351, ruling of December 8, 2009.
[3] Settlement through the Norwegian Natural Perils Pool is governed by the provisions of the Insurance Contracts Act of 16 June 1989, and the Natural Perils Insurance Act of 16 June, 1989.

extensive media coverage whenever they occur, contributing to a high level of public awareness about flood-prone areas. This visibility, combined with the disclosure obligation, means that both legal and social mechanisms reinforce transparency regarding flood risk in Norway.

In addition to the duty of disclosure and uniform insurance costs, its diverse landscape makes Norway susceptible to different types of flooding, such as coastal, river and flash floods. Flood protections have been established along several waterways by the Norwegian Water Resources and Energy Directorate (NVE). The costs of planning and implementing flood protection measures are mostly covered by national funding schemes managed by the NVE, which provides financial assistance to municipalities for both planning and execution. Typically, these grants cover a significant share of expenses (80–100%), while local authorities contribute the remainder. This system works well in Norway due to strong governmental support and centralized risk management, but its applicability elsewhere depends on governance structures, public funding availability, and legal frameworks. In countries with limited national resources, alternatives such as insurance schemes, public-private partnerships, or international aid may be necessary.

Furthermore, the impacts of climate change, including rising temperatures and increased precipitation, are already being felt, making the study of flood protections particularly relevant (Norwegian Environment Agency 2023; Vormoor et al. 2016). A Norwegian survey from 2021 reveals that a clear majority of respondents are concerned about climate change, with severe rainfall being regarded as the most critical event (Vindegg et al. 2023). Lastly, the availability of high-quality housing market data, along with detailed flood risk maps and information on flood protections from the NVE, provides an ideal setting for this study.

Our study contributes to the literature not only by assessing the price effects of flood risk, but also evaluating the significance of these effects on low-rise and mid-/high-rise properties with and without flood protections. This is one of few studies to empirically evaluate the ex-post price effects of implementing flood protection measures (Beltrán, Maddison, and Elliott 2018) and, to the best of our knowledge, the first to examine this in the Norwegian residential market. Using a dataset of more than 1.4 million home transactions from 2010 to 2023, we employ hedonic pricing models that control for a wide array of observable and unobservable factors. Additionally, we adopt a difference-in-differences (DiD) approach to isolate the causal impact, as some risk areas constructed flood protections during the sample period.

We find a statistically significant nationwide price discount of approximately 3.5% for low-rise dwellings located in unprotected flood hazard zones. In contrast, no such discount is observed for mid- and high-rise housing. Similarly, properties situated in close proximity to flood protection systems exhibit a post-construction price premium, with coefficient estimates of around 10.7% for homes situated downstream within 200 meters of a protection. This premium mirrors the pre-protection discount for the same homes, suggesting that flood protections are targeted toward areas with the highest initial risk and effectively eliminate the prior price penalty. Flood hazard is identified using a nationwide elevation model, a comprehensive river and lake database, and estimates of maximum water level rise. This reflects the information faced by potential homebuyers in sales advertisements.

To ensure robustness, we conduct a subsample analysis focusing on areas manually assessed for flood risk by experts. The results confirm our main findings, albeit with lower statistical significance due to limited in-risk observations, demonstrating negative price effects for homes exposed to 10-, 20-, 50-, and 100-year flood risk. However, no price discount is detected for homes with flood protection. Our findings are important for policymakers and stakeholders, including real estate developers, homeowners, investors, insurance companies and local communities in risky areas. Our study contributes to the existing literature on the impact of flood risk and climate change adaptation on housing markets. For instance, Lee and Li (2009) use data on flood control detention basins, specifically, undeveloped detention basins (UDBs) and multi-use detention basins (MDB), from College Station, Texas. Using hedonic price modeling, the authors find that UDBs do not have a significant effect on residential property values, while MDB have a statistically significant impact. Their results suggest that integrating park features into detention basins, which are basically stormwater amenities, can increase surrounding property values. However, their study is geographically limited and focuses on a narrow, and localized context. On the other hand, our study covers the entire country and uses 1.4 million residential transactions, which enables us to examine the relation between flood protections and property values on a much larger scale. We focus on large-scale flood-protection infrastructure such as levees, barriers, and floodwalls, which is designed primarily for hazard mitigation and does not incorporate local amenities or landscaping features. Moreover, we analyze dynamic pricing effects, comparing property values before, during, and after construction of flood protections. To the best of our knowledge, such temporal analysis has not been conducted in the extant literature, particularly in the context of Norway.

Moreover, Beltrán, Maddison, and Elliott (2018) use repeat home sales data from 1995 to 2014 in England to estimate the impact of flood protections on home prices. They find that flood protections increase house prices in urban areas but have a negative impact on rural areas. Our study contains broader national coverage and includes properties in both defended and non-defended areas. We combine transaction data with flood inundation modeling datasets to distinguish between properties that are protected and those that are not. This approach allows us to separate hazard reduction effects from correlated spatial amenities, a distinction that is more difficult to achieve in repeat-sales frameworks. We also estimate heterogeneous effects of flood protection across building types, showing that the price impacts differ between low-rise properties and mid-to-high-rise properties, which is an important dimension and not explored by Beltrán, Maddison, and Elliott (2018).

A recent study by Mutlu, Roy, and Filatova (2023) examines the impact of flood risk on property values and explores whether flood protection infrastructure based on nature-based solutions (NbS) increase home prices in the Netherlands. The authors find that flood risk has a significant impact, leading to price discounts up to 10.9%. In contrast, green amenities associated with NbS provide a price premium of about 15% on nearby residential properties. Our study substantially adds to this strand of literature by focusing on flood protections based on hard-infrastructure protections such as levees, floodwalls, and barriers. These two types of flood protections differ from NbS in terms of their hydrological effects, visibility, and expected performance during extreme events. While Mutlu, Roy, and Filatova (2023) focus on homebuyers' risk perception, we estimate the reduction in physical flood inundation associated with flood protections by using nationwide elevation and flood modeling data. This allows us to distinguish objective risk reductions from changes in expectations or preferences. Our study also provides important heterogeneity across home construction types, showing that before protection, only low-rise homes have a significant price discount, whereas mid- and high-rise houses do not. This housing infrastructural-level heterogeneity, which reflects differences in structural vulnerability and perceived exposure, has not been examined in previous studies. We also identify a temporary price decline during the construction of the flood protections, which captures short-term disruptions and uncertainty that arise while projects are being built.

Moreover, our study also contributes to the hazard insurance literature. For instance, Gallagher (2014) shows that flood insurance take-up increases immediately after flood events. Oh, Sen, and Tenekedjieva (2021) demonstrate that insurance premiums in the United States do not reflect climate risks but are mainly shaped by state regulations. They show that insurers do not

adjust their rates in highly regulated states but instead compensate by raising premiums in less regulated states. Keys and Mulder (2024) document a 33% increase in average premiums from 2020 to 2023 due to reinsurance shocks linked to climate disaster risks. This leads to increased household expenses and reduced housing demand, especially in high-risk geographies. Garbarino, Guin, and Lee (2024) examine the effects of subsidized insurance using a granular dataset of property transactions and flood events in England and show that this scheme increases both prices and transaction volume in flood-prone properties, offsetting the negative effects of flood risk on property values. Our study context is very different. In Norway, natural-perils insurance is universal and uniformly priced, so premiums do not vary with local climate risk. Therefore, the capitalization effects we observe do not stem from insurance-premium savings but from pure physical flood-risk reduction. The above literature shows that when insurance markets fail to convey risk information, homebuyers and lenders may take on excessive exposure. Our study provides a different but related perspective by showing that physical flood protection infrastructure becomes the primary carrier of information and housing markets respond strongly to the introduction of these protections.

The remainder of the study is structured as follows: Section 2 reviews the relevant literature; Section 3 describes the data and flood risk estimation methods; Section 4 presents the research design and main results, while Section 5 provides concluding remarks and suggestions for future research.

2. Literature Review

Physical risks due to climate change and natural disasters can be grouped into acute and chronic risks, where acute risks are short-term events such as floods, while chronic risks are longer-term issues like sea level rise (Contat et al. 2024). The existing literature has found varying results regarding the effect of the latter risk (Baldauf, Garlappi, and Yannelis 2020; Bernstein, Gustafson, and Lewis 2019; Keenan, Hill, and Gumber 2018; Murfin and Spiegel 2020). However, due to land uplift, sea level rise is of lesser concern in Norway compared to other parts of the world, whereas the acute physical risk related to flooding remains significant (Norwegian Environment Agency 2023).

Numerous studies have examined the effect of floods on real estate prices, with most reporting a discount after such an event (Atreya, Ferreira, and Kriesel 2013; Bin, Kruse, and Landry

2008; Bin and Landry 2013; Daniel, Florax, and Rietveld 2009; Kousky 2010; Zhang 2016; Zhang and Leonard 2019).[4] Turnbull, Zahirovic-Herbert and Mothorpe (2013) expand the scope of analysis by further examining the combined effect of prices with selling time, while Galster, Galster and Vachuska (2024) widen the lens by measuring flood risk exposure by race and income. Returning to prices, Atreya, Ferreira, and Kriesel (2013) and Jung and Yoon (2018) find that the immediate negative effects of flooding dissipate over a relatively short period of time (1–4 years), suggesting a short-lived salience effect on prices. While there is active debate in the literature over whether observed price discounts stem from flood risk itself or from the capitalization of flood insurance premiums into property prices (Atreya, Ferreira, and Kriesel 2013; Bin, Kruse, and Landry 2008; Bin and Polasky 2004; Harrison, Smersh, and Schwartz 2001; Zhang 2016; Zhang and Leonard 2019), the uniform premiums in the Norwegian market allow us to isolate the effect of flood risk and flood protections from that of insurance premiums. Nevertheless, the presence of flood protections should eliminate the discount regardless of the underlying channel.

The literature on flood protections is sparse. In addition to older studies from the US (Damianos and Shabman 1976; Thompson and Stoevener 1983), only a few recent papers investigate the potential benefits of flood protection implementation. While Lee and Li (2009) find that the visual disamenity of flood protection can outweigh the benefits on property prices in a US study, Mutlu, Roy, and Filatova (2023) find a 15% premium to residential property prices in vicinity to nature-based solutions in the Netherlands. Beltrán, Maddison, and Elliott (2018) find that flood protections in England are capitalized in property prices but also suggest disamenity effects, the risk of flooding elsewhere and the type of property (i.e., elevation above ground floor) generate a more nuanced picture.

The existing literature demonstrates insurance provides an important hedge against natural disaster hazards for homeowners, which is notably relevant for understanding the relation between flood risk and home prices. Gallagher (2014) finds that insurance purchases increase after flood events, and that news media coverage also prompts non-flooded homeowners to buy insurance. This suggests homeowners react more strongly when risks become more visible. Oh, Sen, and Tenekedjieva (2021), using states' regulatory rules as an instrumental variable along with a regression discontinuity design, analyze how regulations affect home insurance

[4] A recent and related study by Doerner, Seiler and Suandi (2025) shows that when flood disclosure requirements increase, prices actually tick up in areas with substantial historical flooding exposure.

premiums in the United States. They find that insurance premiums in highly regulated states do not adjust to rising climate risks, instead insurers adjust premiums by increasing rates in less regulated states. This suggests less regulated states indirectly subsidize highly regulated states. In the long-run, asymmetry in insurance rate adjustments across states can lead to a growing disconnect between insurance rates and underlying risk, possibly causing insurers to exit highly regulated states (Oh, Sen, and Tenekedjieva 2021). Moreover, Keys and Mulder (2024) show that reinsurance shocks linked to climate disasters led to a 33% increase in average insurance premiums between 2020 and 2023, putting pressure on household budgets and reducing housing demand, especially in high-risk areas. In England, Garbarino, Guin, and Lee (2024), using detailed property transaction data and flood events, show that subsidized insurance schemes increase both prices and transaction volume for flood-prone properties, offsetting the negative effects of flood risk on property values. Overall, this literature shows that insurance pricing, public insurance program design, and regulations are very important factors to understand the relation between flood risks and housing markets.

3. Data and Flood Risk Estimation

This section presents the data sources and the different measures of flood risk. To examine the impact of risk and protections on home prices, we integrate four distinct datasets (Table 1). The first dataset comprises housing transactions. The subsequent two datasets provide various measures of flood risk. The flood hazard estimation is derived from nationwide elevation models and estimates of maximum water level rise. The expert flood risk assessment dataset results from a detailed manual inspection of the local area. These two risk measures enable us to evaluate not only whether flood protections are reflected in residential property transactions, but also to determine which types of homes are most affected: those identified as risky by expert assessment or those situated in generally risky locations based on elevation and proximity to bodies of water. The final dataset, the flood protection dataset, contains historical records of flood protection systems.

Table 1: Overview of Datasets

Dataset	Description	Time span	Source
Housing	Hedonic attributes of Norwegian home transactions.	2010–2023	Ambita AS

Estimated flood hazard	Nationwide estimates for areas more likely to experience floods. Based on a nationwide elevation model, a nationwide river and lake database, and estimates for maximum water level rise.	2020	Norwegian Water Resources and Energy Directorate (NVE)
Manual flood risk	Local regions where human experts have analyzed flood risk at different flood levels. Based on manual, local inspection.	2000–2024	Norwegian Water Resources and Energy Directorate (NVE)
Flood protections	Flood protection systems. Based on historical archives and records of newer installations.	1885–2024	Norwegian Water Resources and Energy Directorate (NVE)

Note: This table provides an overview of the datasets used in the analysis, including housing transactions, estimated flood hazard zones, flood protection infrastructure, and manually assessed flood risk. The datasets originate from different sources and cover varying time spans, reflecting both historical records and more recent assessments. The flood-related data are derived from national models, databases, and expert evaluations, while the housing data include detailed transaction characteristics.

3.1 Housing data

The housing data include sales transactions in Norway from January 2010 to August 2023. This dataset, provided by the Norwegian PropTech company Ambita AS, incorporates information from the Norwegian land register, the Norwegian cadaster, and sales advertisements on the digital platform Finn.no.[5] Norwegian residential real estate is typically divided into two forms of homeownership: freeholders and shareholders. Freeholders own the specific physical property. Alternatively, shareholders are found in housing cooperatives where the cooperative owns the property, and the shareholder purchases the rights to reside in a specific unit. When purchasing such a residency right, the unit often comes with common debt, which is a share of the debt incurred by the housing cooperative during the construction and/or renovation of the property. Since this common debt is assumed by the new owner after a transaction, the market value of the unit is equal to the transaction price paid to the seller plus the common debt associated with the unit. This total sales price is our target variable of the analysis.

The original dataset comprises over 3 million house transactions, spanning from 1991 to 2023. After cleaning and restricting the sample period, 1,413,735 transactions remain. We exclude sales of homes with a total sales price exceeding NOK 30,000,000 or a price per m² of NOK

[5] According to parent company, Schibsted, the platform of Finn.no lists 98% of all home transactions in Norway.

200,000, as these are considered erroneous values or outliers. We also remove records lacking a registered transaction date, observations of properties smaller than 10 m² or larger than 700 m², properties with more than 20 rooms or more than 5 bathrooms.[6] Next, we eliminate records with incorrect coordinates, and finally, we exclude holiday homes such as cabins and properties partly used for commercial purposes, such as car mechanic workshops and stores.

Table 2 gives descriptive statistics for a selection of the hedonic attributes in our dataset. These home characteristics are separated into property and location controls. In addition to the controls listed in the table, we have data on attributes such as total sales price, municipality codes, ZIP codes, sales month, and sales year.

As shown in Table 2, the dataset includes four categories of homes: condominiums, houses, semi-detached homes, and row homes. While the latter three are typically attached to the ground,[7] condominiums may be located on higher floors within a building. Consistent with the previous literature such as in Beltrán, Maddison, and Elliott (2018), the location of a home within a structure can influence the capitalization of flood risk. Therefore, we distinguish between low-rise and mid-/high-rise homes. For condominiums, the floor variable captures the living unit's position within the building: the "ground" floor corresponds to the 1st floor, "low" refers to the 2nd and 3rd floors, "mid" includes the 4th to 7th floors, and "high" represents the 8th floor or above.

Table 2: Descriptive Statistics for Housing Dataset

Property controls	N	Mean / %	Std. Dev.	Min	Pctl. 25	Pctl. 50	Pctl. 75	Max
Size (m^2)	1,413,735	103	59	11	63	86	130	700
Age (years)	1,413,735	34	34	0	4	27	53	223
Rooms (#)	1,413,735	3.6	1.4	1.0	3.0	3.0	4.0	20.0
Bathrooms (#)	1,413,735	1.2	0.4	1.0	1.0	1.0	1.0	5.0
Standard (cat.)	1,413,735							
... High	342,083	24%						
... Medium	567,248	40%						
... Low	43,621	3%						
... Unlabeled	460,783	33%						
Energy score (cat.)	1,413,735							
... A	17,381	1%						

[6] Some of the homes were listed with zero rooms and/or bathrooms. We impute the zero values for these count variables using a quasi-Poisson generalized linear model (GLM), in accordance with Raghunathan et al. (2001), based on size, build year, municipality, and home type.

[7] Although some semi-detached homes are vertically separated, they only have two stories and are therefore also considered low-rise.

... B	120,345	9%
... C	183,304	13%
... D	216,120	15%
... E	174,874	12%
... F	219,596	16%
... G	263,838	19%
... Unlabeled	218,277	15%
Unit type (cat.)	1,413,735	
... Condominium	789,523	56%
... House	377,965	27%
... Semi-detached	127,607	9%
... Row home	118,640	8%
Condo floor (cat.)	789,523	
... High	15,297	2%
... Medium	162,920	21%
... Low	370,371	47%
... Ground	240,935	31%

Location controls	N	Mean / %	Std. Dev.	Min	Pctl. 25	Pctl. 50	Pctl. 75	Max
Distance to public transport (m)	1,413,735	954	1,684	0	366	610	998	81,640
Distance to school (m)	1,413,735	2,459	4,206	5	463	1,127	2,560	115,931
Waterfront (cat.)	1,413,735							
... Yes	435,843	31%						
... No	977,892	69%						
Fishing nearby (cat.)	1,413,735							
... Yes	40,377	3%						
... No	1,373,358	97%						

Note: This table presents descriptive statistics for the final housing dataset after data are cleaned and categorized into property and location characteristics. The dataset includes homes sold as primary residences within the sampling period. Distances to public transport and schools are measured as straight-line distances from each home to the nearest relevant facility. Waterfront measures whether the property borders a body of water, while fishing nearby indicates whether the sales advertisement listed nearby fishing possibilities as an amenity.

During the study period, the average home sold for NOK 3,393,893 and had a size of 103 m². However, there are substantial differences between urban and rural areas, as well as across time. From 2010 to 2023, average house prices in our dataset increased by approximately 90%, aligning with trends observed in national home price indices for the same period.[8] It is important to note that these figures represent national averages and do not account for differences in the types of homes sold. Additionally, there is significant variation in distances

[8] Statistics Norway reports an 88% price increase from the second quarter of 2010 to the second quarter of 2023. For more details, see https://www.ssb.no/en/kalkulatorer/boligpriskalkulator.

to the nearest school and public transportation, reflecting the spatial differences between urban and rural regions.

3.2 Flood risk estimation and data

The methodology for estimating flood hazard combines digital terrain modeling and hydrological data, employing a national height model with a resolution of 10x10 meters. The calculation involves estimating maximum water level rise based on the size of the catchment area during a flood event. A flow accumulation algorithm is initially used to calculate water flow direction and accumulation. It works by determining the direction of water flow for each cell in a digital elevation model based on the slope (i.e., elevation gradient), by tracking which direction water would move from each raster cell, following the steepest descent. Once the flow direction is established, the algorithm calculates the flow accumulation by summing the number of upstream cells that flow into each downstream cell.

This results in a map where each cell's value represents the total number of upstream cells that contribute runoff to that particular cell. By using this flow accumulation output, the size of the catchment area, A, for any cell in the river network is identified as all upstream cells that contribute water to that cell. Once the catchment area is determined, the specific formula for calculating the maximum water level rise, $dH(m)$, is applied:

$$dH(m) = \begin{cases} 2 \text{ if } A \leq 1 \text{ km}^2 \\ 0.965 \times \ln(A) + 2 \quad \text{if } 1\text{km}^2 < A \leq 500 \text{ km}^2 \\ 8 \quad \text{if } A > 500 \text{ km}^2 \end{cases} \tag{1}$$

This gives a maximum water level rise value, $dH(m)$, for each cell, which can be added to the terrain model's original height to get the maximum height of the river during a flood. Adjustments are then made for terrain slope to prevent unrealistic horizontal spreading of the floodplain. Estimated flood hazard for minor streams include a minimum buffer of 20 meters on each side.

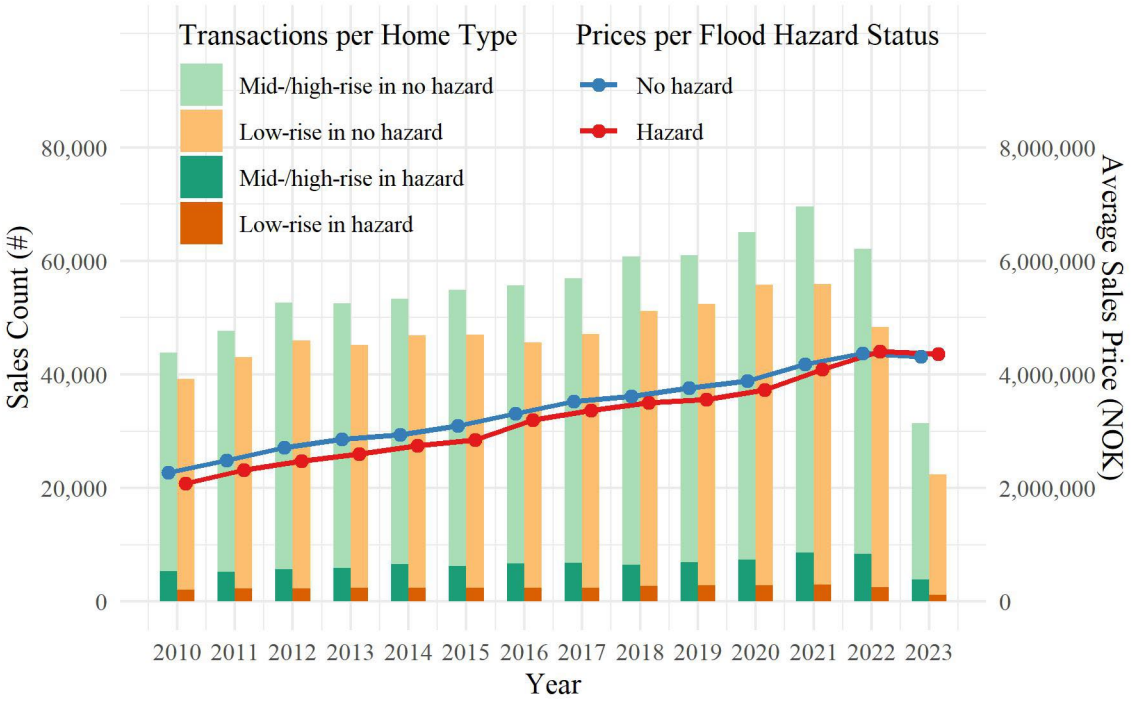


Figure 1: Number of Sales and Prices of Homes by Flood Hazard Status

Note: This figure presents a time series of home sales and average sale prices of homes in Norway from 2010 to 2023. The bars represent the number of homes sold (left y-axis), differentiated by color to distinguish between low-rise and mid-/high-rise housing, as well as whether or not the properties are located in flood hazard zones. The lines represent the average sale prices (right y-axis), with colors indicating whether or not the homes are in flood hazard zones. Data sources: Housing transaction data from Ambita AS (2010–2023) and flood hazard data from the Norwegian Water Resources and Energy Directorate (NVE).

Figure 1 presents the annual number of homes sold within estimated flood hazard zones throughout the sample period. The figure reveals that the number of mid-/high-rise homes sold in flood hazard zones is more than twice that of low-rise homes. In contrast, outside flood hazard zones, the difference in sales volumes between low-rise and mid-/high-rise homes is considerably smaller. Given that low-rise housing may be more vulnerable to flooding, this pattern could suggest lower demand for such properties in flood-prone areas. This relation appears to be relatively stable over time. Additionally, a preliminary comparison of average sales prices suggests homes in flood hazard zones tend to sell for slightly less than those outside these zones. However, these averages do not account for differences in home characteristics, necessitating further empirical analysis to draw definitive conclusions. Nevertheless, the visual trends align with the theory that flood risk may be capitalized in housing markets.

As a robustness check to the estimated flood hazard, we also use manual flood assessments across various mapping regions examined by human experts gathered by the NVE. These mapping regions, typically located near rivers or other bodies of water, have undergone flood

risk assessments requested by local authorities. The NVE evaluates which areas within these mapping regions are at risk of flooding under different flood scenarios, ranging from a 10-year flood to a 1000-year flood. For this study, we focus specifically on the flood risk areas associated with the 10-year, 20-year, 50-year, and 100-year flood events.[9]

Manual flood risk areas are identified through a systematic process consisting of four key steps: flood calculation, water level calculation, creating a digital terrain model, and flood risk analysis. Flood calculation involves statistical analysis to estimate the size and frequency of floods within a river system. Water level calculation employs hydraulic modeling to determine water levels for various flood scenarios. A digital terrain model is developed using laser data. Finally, manual flood risk analysis integrates the water levels with the digital terrain model in a GIS to accurately delineate the flood risk zones.

The dataset comprises a total of 213 distinct mapping regions across Norway from 2000 to 2024. Although this provides an assessment of manual flood risk in various parts of the country, the majority of the land has not been mapped in such detail by the NVE. Of the 1,413,735 home transactions recorded in our cleaned housing dataset, only 134,481 occurred within areas that have been mapped for manual flood risk areas. Among these 134,481 transactions, almost 5,000 were identified as occurring within a flood risk area.

3.3 Flood protections

The final component of our dataset consists of flood protection systems, including both older installations digitized from NVE archives and more recent constructions. In total, the dataset comprises 1,586 individual flood protection systems, encompassing 2,995 distinct protection measures.[10] These protections are distributed across the country, as illustrated in Panel B of Figure 2. However, municipalities in central Norway generally have a higher density of flood protections per 100 km² compared to other regions.

Panel A of Figure 2 indicates that these same regions also exhibit a high proportion of transacted homes located within estimated flood hazard zones. Additionally, several of Norway's northernmost municipalities have a significant share of homes sold in flood-prone

[9] The manually assessed NVE data include substantial missingness for the 200-, 500-, and 1,000-year flood zones, as these levels were not evaluated by the expert in most locations. For this reason, we focus on the more frequently assessed flood types, where data coverage is sufficient to support robust inference.

[10] The reason for the greater number of protective actions is that these actions reflect multiple interventions in the same part of a river, or upgrades of an existing protection system.

areas. However, due to low population densities and widely dispersed housing, the number of flood protections in these areas remains limited.[11]

A) Share of Sold Homes in Flood Hazard B) Flood Protections per 100 km^2

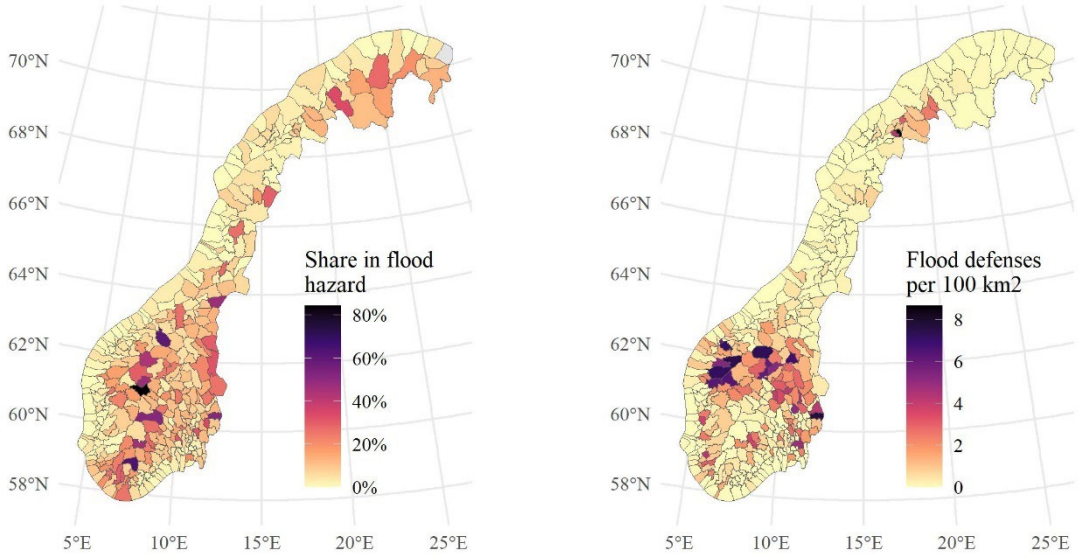


Figure 2: Distribution of Flood Hazard and Flood Protections per Municipality

Note: This figure presents maps of all municipalities in Norway, illustrating flood-related housing and infrastructure characteristics. In Panel A (left), the color represents the share of sold homes located within flood hazard zones for each municipality. In Panel B (right), the color indicates the average number of flood protections per 100 km² in each municipality. Data sources: Housing transaction data are from Ambita AS (2010–2023), municipal boundary data are from the Norwegian Mapping Authority, and flood protection data come from the Norwegian Water Resources and Energy Directorate (NVE).

Around 30% of the homes within manually assessed flood risk areas were sold while a flood protection system existed in the same mapping region. However, while a flood protection system may have an impact over a broad area due to downstream effects, the protections will be too distant to have a significant protective effect on most properties in the same mapping region. Among in-risk homes, situated in a manually assessed flood risk area, the median distance to the nearest flood protection system is 872 meters. Around 3.6% of all homes sold in such risky areas had an existing flood protection system within 100 meters of the home, compared to only 0.8% of homes with no risk. This is expected, as risky areas are typically situated closer to rivers, making it more likely that they are also located near flood protection systems.

[11] The 18 northernmost municipalities, which together form the county of Finnmark, account for 15% of Norway's total land area but are home to only 1.3% of the population as of 2025, according to Statistics Norway. For more details, see: https://www.ssb.no/en/statbank/table/11342.

The median distance between homes in estimated flood hazard and the closest existing flood protection is higher than in the expert-assessed risky areas, at 4,789 meters. The share of home transactions within estimated flood hazard with a flood protection located 100 meters or less from the home is 1.41%. This is lower than the corresponding shares within the manual flood risk areas, but noticeably higher than the share of non-risky homes with close protections.

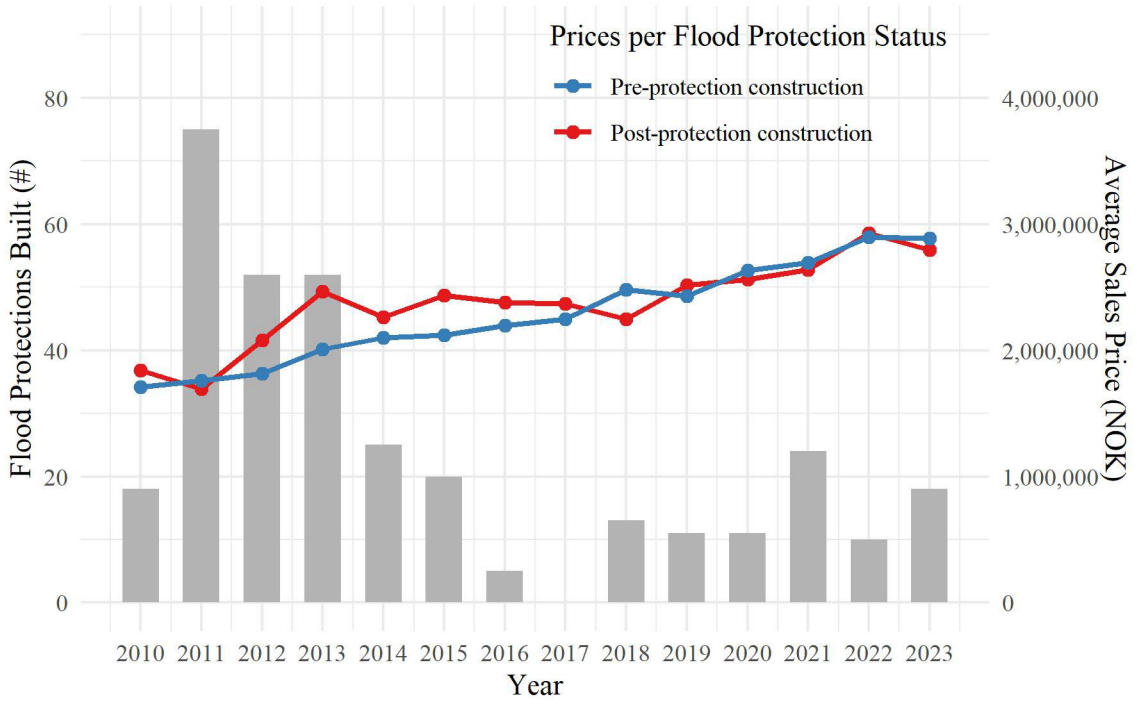


Figure 3: Number of Protections Built and Home Prices by Protection Status

Note: This figure presents a time series of protection constructions finalized and average sales prices of homes in Norway from 2010 to 2023. The bars represent the protections built each year (left y-axis). The lines represent the average sale prices of homes located within a 200m distance of an existing or future flood protection (right y-axis), with colors indicating whether the transaction took place before or after the protection was built. Data sources: Housing transaction data from Ambita AS (2010–2023) and flood hazard data from the Norwegian Water Resources and Energy Directorate (NVE).

Figure 3 provides a visual representation of the number of flood protections constructed per year during the sample period.[12] The red and blue lines illustrate the average sales prices of homes that either already have an existing flood protection or will have one built within 200 meters in the future. The trends suggest sales prices are generally slightly higher after the construction of a flood protection compared to before. However, these averages do not account for differences in housing characteristics or property types, necessitating further analysis to

[12] Construction year refers to the year the flood protection was completed. In some cases, the construction phase extends over multiple years, meaning the protection may have been initiated one or more years before its finalization.

isolate the impact of flood protections on prices. Table 3 presents the number and share of homes in different exposure categories for flood risk and protection.

Table 3: In-risk and Protected Homes

Exposure category	Sample	Sample size	Exposed (#)	Exposed (%)
Flood hazard	Full	1,413,735	124,043	8.77%
Manual 10-year flood risk	Expert assessed	134,481	1,690	1.26%
Manual 20-year flood risk	Expert assessed	134,481	2,569	1.91%
Manual 50-year flood risk	Expert assessed	134,481	3,391	2.52%
Manual 100-year flood risk	Expert assessed	134,481	4,945	3.68%
Protection (< 200 m) × Post	Repeat sales	858,398	1,596	0.19%
Protection (< 50 m) × Post	Repeat sales	858,398	208	0.02%
Protection (50-100 m) × Post	Repeat sales	858,398	389	0.05%
Protection (100-150 m) × Post	Repeat sales	858,398	564	0.07%
Protection (150-200 m) × Post	Repeat sales	858,398	501	0.06%

Note: This table reports the number and share of homes exposed to different types of flood risk and protections. Manual flood risk data are only available for regions where experts have conducted site-specific assessments. When analyzing the price effect of flood protections using difference-in-differences models, the sample is restricted to homes sold more than once during the study period to ensure intra-property variation. Post refers to the transaction taking place after the relevant protection was built. Data sources: Flood hazard, manual flood risk, and flood protection data from the Norwegian Water Resources and Energy Directorate, and Ambita AS housing data, January 2010–August 2023.

4. Research Design and Results

In the following section, we outline the research design employed to analyze the impact of flood risk and flood protections on home prices. Flood risk, whether due to rising sea levels or river water levels, might play a critical role in affecting real estate market dynamics. Thus, it may influence market participants to incorporate discounted potential flood risk into their decision-making. Homes located in flood risk areas are often sold at discounts due to actual or perceived risks related to flooding. On the other hand, properties with flood protections in flood risk areas are expected to be priced at a premium compared to those in flood risk areas without such protections. We assume flood protections provide safety to these properties, which ultimately enhances their value. First, we assess the capitalization of estimated flood hazard through hedonic pricing models. We then examine the effects of flood protections using a difference-in-differences approach and an event study framework.

4.1 Flood hazard capitalization

The first aim of this empirical study is to investigate whether properties exposed to flood risks are indeed sold at a discount compared to properties not exposed to such risks. We estimate the effect of being in flood hazard using the following model:

$$\ln(\mathrm{P}_{i,t}) = \beta_0 + \beta_1 \mathrm{FloodHazard}_i + X_i\gamma + \delta_{\mathrm{Zip}_i} + \lambda_{\mathrm{Mun}_i \times \mathrm{Year}_t} + \varepsilon_i, \quad (2)$$

where $\ln(P_{i,t})$ is the natural logarithm of the price of property i sold at time t. $\mathrm{FloodHazard}_i$ is an indicator variable equal to 1 if the property is located in a flood hazard zone, and 0 otherwise. X_i is the vector of control variables, including property controls such as the natural logarithm of the size, age categories, number of rooms, number of bathrooms, standard, energy label, housing type, and floor category, in addition to location controls such as waterfront, nearby fishing, distance to closest school, distance to public transport, distance to water, and relative altitude within the municipality.[13] We also include nested fixed effects for ZIP code and the interaction between municipality and year.[14] By incorporating these controls and interacted fixed effects, β_1 provides a credible estimate of the impact of flood risk on property prices.

Table 4 reports the regression results. For the full data sample, flood hazard originally has a negative and statistically significant association with home prices before including the control variables, indicating that homes exposed to flood hazard sell at a discount of 4%. However, when including property controls, the sign of the coefficient changes, suggesting homes in a flood hazard zone might have other differing price characteristics than just the flood hazard itself. After controlling for positive location characteristics that can follow a location close to bodies of water, we find no relation between flood hazard and home prices on a nationwide, average basis.

Table 4: Flood Risk Capitalization

	(1)	(2)	(3)
Sample	Full	Full	Full
Dependent variable	ln(P_{it})	ln(P_{it})	ln(P_{it})
Flood hazard	-0.040***	0.012**	-0.004
	(0.009)	(0.004)	(0.006)
Year × Municipality FE	Yes	Yes	Yes
ZIP code FE	Yes	Yes	Yes
Property controls	No	Yes	Yes
Location controls	No	No	Yes
Observations	1,413,735	1,413,735	1,413,735
Adjusted R^2	0.484	0.705	0.707

[13] Distance to water is included as buckets for distance to water to control for water amenity following Bernstein, Gustafson, and Lewis (2019). These buckets include distances of 0-50m, 50-100m, 100m-150m, 150m-200m, and +200m.

[14] Our results are robust to different selections of location fixed effects.

Note: The coefficients represent the percentage relation with home prices from an OLS regression for low-rise residential real estate. Low-rise is defined as single-family homes, semi-detached homes, row homes, and single-story condominiums. Property controls include size, age, number of rooms, number of bathrooms, energy label, condition, and home type. Location controls include waterfront, nearby fishing, distance to closest school, distance to public transport, distance to water, and relative altitude within the municipality. The models have nested fixed effects for ZIP code and the interaction between year and municipality. Robust standard errors, clustered at the ZIP code level, are in parentheses. *p<0.1; **p<0.05; ***p<0.01.

Because the risk of personal injury and property damage is higher for low-rise homes, we include an interaction term between these structures and flood hazard.[15] The remaining regression model is identical to that in Equation (2), with a new aim of identifying whether the relation between flood hazard and home prices differs between low-rise and mid-/high-rise homes.

As seen in Table 5, column (1), low-rise homes in flood hazard zones sell for 3.5% less than their mid-/high-rise counterparts, significant at the 1% level. In light of this finding, we then re-estimate the models across different subsamples. First, we consider only the low-rise properties. Next, we apply propensity score matching to ensure homes without flood risk more closely resemble those exposed to flood risk. Matching is conducted one-to-one based on propensity scores, with a caliper of 0.01 times the standard deviation of the propensity score to enhance match quality. This matching procedure is performed on the full sample. Comparisons of pre- and post-matching means, along with additional matching details, are presented in Appendix 1. Lastly, we apply a border discontinuity approach, following Bosker et al. (2019) using only control homes located within 200 meters of a flood risk area.

Table 5: Flood Hazard for Low-Rise vs. Mid- and High-Rise Housing

	(1)	(2)	(3)	(4)
Sample	Full	Low-rise	PS matched	Border Disc.
Dependent variable	$\ln(P_{i,t})$	$\ln(P_{it})$	$\ln(P_{it})$	$\ln(P_{it})$
Flood hazard	0.008	-0.022***	0.002	0.005
	(0.008)	(0.005)	(0.008)	(0.007)
Flood hazard × Low-rise	-0.035***		-0.036***	-0.024**
	(0.011)		(0.011)	(0.011)
Year × Municipality FE	Yes	Yes	Yes	Yes
ZIP code FE	Yes	Yes	Yes	Yes
Property controls	Yes	Yes	Yes	Yes
Location controls	Yes	Yes	Yes	Yes
Observations	1,413,735	646,170	248,026	674,116

[15] Ground-floor apartments in mid- and high-rise buildings are not classified as low-rise, as these structures typically have basements and hallways that are more prone to flooding than the apartments themselves. Nevertheless, results remain robust when they are included in the low-rise category.

Adjusted R^2	0.707	0.686	0.727	0.730

Note: The coefficients represent the percentage relation with home prices from an OLS regression for low-rise residential real estate. Low-rise is defined as single-family homes, semi-detached homes, row homes, and single-story condominiums. The matching in column (3) is done one-to-one by propensity score with a caliper of 0.01. The border discontinuity in column (4) uses only homes within 200 meters of a flood hazard area as control group. Property controls include size, age, number of rooms, number of bathrooms, energy label, condition, and home type. Location controls include waterfront, nearby fishing, distance to closest school, distance to public transport, distance to water, and relative altitude within the municipality. The models have nested fixed effects for ZIP code and the interaction between year and municipality. Robust standard errors, clustered at the ZIP code level, are in parentheses. *p<0.1; **p<0.05; ***p<0.01.

Comparing only low-rise homes in column (2), flood risk is associated with a statistically significant 2.2% price discount. In the propensity score-matched sample reported in column (3), flood risk has no evident price effect for mid-/high-rise properties, while the price discount for low-rise homes increases to 3.6%. The border discontinuity model shows similar results, with a discount of 2.4%. The smaller discounts from the low-rise and border discontinuity models are more credible, as these approaches incorporate stricter controls and better isolate the effect of flood risk. These findings indicate that flood risk is not capitalized in the prices of mid-/high-rise residential properties but instead leads to price discounts for low-rise homes located in flood-prone areas. With an average low-rise home in the final year of the study period selling for NOK 4,113,777, a price discount of 2.4% would amount to around NOK 98,731. For comparison, an average household in Norway in 2023 spent NOK 158,000 on housing expenses.[16] The price difference is thus both statistically and economically significant.

4.2 Flood protection capitalization

After establishing a negative association between flood hazard and low-rise home prices, the next step is to study whether the installation of flood protections is capitalized into sales prices. For these flood protections, we observe a distinct time of installment, allowing for temporal analysis. Although we control for observable and unobservable factors that may correlate with both flood protections and home prices, the risk of omitted variable bias remains. For example, government infrastructure policies could simultaneously drive the construction of flood protections and increase local property values, confounding the relation. Furthermore, there is potential for reverse causality, whereby higher house values may influence the decision to construct flood protections rather than the protections themselves affecting home prices. To

[16] These expenses include both mortgage installments and costs. For more information, see Statistics Norway: https://www.ssb.no/en/statbank/table/14062.

mitigate concerns related to selection bias and reverse causality, we employ a difference-in-differences (DiD) approach.

Since flood protections are constructed over a period of time rather than all at once, we specifically use the staggered DiD method. This enables us to capture the different timings of flood protection implementation and compare homes with and without flood protections across different time periods. For our DiD regressions, we use property fixed effects to capture property-specific characteristics that may correlate with the price and the proximity of flood protections. This allows us to study whether homes sold before and after the installment of a flood protection leads to an average price increase that exceeds unprotected homes in the same area. The DiD method consequently relies on intra-property variation across time. We therefore use a repeat sales sample, only including homes that have been sold multiple times in our study period. This reduces our sample by 39%.[17] We estimate the following regression models:

$$\ln(\mathrm{P}_{i,t}) = \beta_0 + \beta_1(\mathrm{Protection}_i \times \mathrm{Post}_t) + \delta_i + \lambda_{\mathrm{Mun}_i \times \mathrm{Year}_t} + \varepsilon_{i,t}, \quad (3)$$

and:

$$\ln(\mathrm{P}_{i,t}) = \beta_0 + \sum_{d \in D} \beta_d(\mathrm{ProtectionProximity}_{i,d} \times \mathrm{Post}_t) + \delta_i + \lambda_{\mathrm{Mun}_i \times \mathrm{Year}_t} + \varepsilon_{i,t}, \quad (4)$$

where $\mathrm{Protection}_i$ is a binary variable equal to one if home i has or will have a future flood protection within 200 meters and is situated downstream, and Post_t is equal to one if the sale took place after the flood protection was built. δ_i are property fixed effects, while $\lambda_{\mathrm{Mun}_i \times \mathrm{Year}_t}$ are fixed effects for the interaction between municipality and year to capture regional price trends. However, as closer flood protections should provide more defense, Equation (4) introduces $\mathrm{ProtectionProximity}_{i,d}$. This is a categorical variable indicating whether property i is within d meters of a protection installation, where $d \in \{< 50, 50-100, 100-150, 150-200\}$. This allows us to estimate a coefficient for the price effect of flood protections at different proximities from the homes. While differences models often include the treatment variable in addition to the treat × post interaction, the individual protection term is captured by the property fixed effects.

[17] Of the total 1,413,735 transactions in our dataset, the distribution of sales by the number of times a property was sold is as follows: 39% of properties were sold once, 34% twice, 18% three times, 7% four times, and 1% five times. An additional 1% of properties were sold six or more times during our study period (2010–2023).

Table 6 presents the regression results for the DiD models examining the impact of flood protections. The first two models, shown in columns (1) and (2), are estimated using the full repeat sales dataset, while the final two models, in columns (3) and (4), are restricted to homes located within flood hazard zones. For the full repeat sales sample in column (1), the results indicate a significant and positive protection × post coefficient of 10.7% for flood protections within 200 meters. Differentiating distances to protection in column (2) shows strong and diminishing effects, but these findings are only statistically significant at the 10% level. For properties in flood hazard zones in column (3), the estimated price impact of protections within 200 meters aligns with the column (1) results, with a premium of 12.6%. Similarly, the post-installation price effect in column (4) is consistent with the column (2) results, but with a statistically significant coefficient for the 50-100m group of 16.2%.

Table 6: Capitalization of Flood Protections

	(1)	(2)	(3)	(4)
Sample	Repeat sales	Repeat sales	Hazard repeat sales	Hazard repeat sales
Dependent variable	$\ln(P_{i,t})$	$\ln(P_{i,t})$	$\ln(P_{i,t})$	$\ln(P_{i,t})$
Protection × Post	0.107***		0.126**	
	(0.032)		(0.051)	
Protection (< 50 m) × Post		0.173*		0.206*
		(0.098)		(0.11)
Protection (50-100 m) × Post		0.102*		0.162**
		(0.057)		(0.080)
Protection (100-150 m) × Post		0.087*		0.009
		(0.050)		(0.041)
Protection (150-200 m) × Post		0.092		0.080
		(0.057)		(0.074)
Year × Municipality FE	Yes	Yes	Yes	Yes
Property FE	Yes	Yes	Yes	Yes
Observations	858,398	858,398	77,696	77,696
Adjusted R^2	0.854	0.854	0.870	0.870

Note: The coefficients represent the percentage effect on home prices from a difference in differences regression for different specifications. Protection indicates a home has a flood protection within 200 meters and downstream in the river. The sample for Models 1 and 2 consists of homes sold more than once post January 1, 2010, while the sample for Models 3 and 4 consists of homes in flood hazard zones sold more than once post January 1, 2010. The models have property fixed effects to capture time-invariant home characteristics, in addition to fixed effects for the interaction between year and municipality to capture spatio-temporal development. Robust standard errors, clustered at the property level, are in parentheses. *p<0.1; **p<0.05; ***p<0.01.

In Subsection 4.1, Table 5, we identified a negative interaction effect between estimated flood hazard and low-rise housing, suggesting these homes are more adversely affected by flood risk. To investigate whether similar differences exist in the positive price effects of flood

protections, we re-estimate the regressions in Equations (3) and (4), this time including interaction terms with low-rise housing.[18]

The main results, presented in Table 7, columns (1) and (2), are broadly consistent with the previous findings. Premiums for protected homes remain higher in the in-hazard sample and for properties located nearer a flood protection. Regarding the interaction effects with low-rise housing, there is no clear evidence of a significant relation. Across different model specifications, the interaction terms exhibit high standard errors and inconsistent coefficient signs, leading to statistically insignificant results. This suggests that while low-rise homes may be more adversely affected by flood risk, the positive price effect of flood protections appears to be uniform regardless of a property's elevation within a building. One possible explanation is that the observed price increase is driven by the signaling effect of flood protections rather than by a direct reduction in perceived flood risk. The visibility of a nearby protection and its mention in sales documents may reassure buyers, leading to higher prices, even if the initial flood risk before the protection installation was not a primary concern.

There could also be potential negative spillover effects, as suggested by Bradt and Aldy (2025) To address this, we re-estimate the equations using the variable Near Protection, which includes homes located within 200 meters of a flood protection structure, but without the downstream condition. We then include an interaction term with downstream location to separate potential spillover effects from the protection effect. The assumption is that homes located upstream from the protection do not receive benefits from reduced flood risk but are still exposed to potential spillover effects. The results in column (3) and (4) show that there are no significant post-protection effects of being situated near flood protection, unless the home is situated downstream and thereby being protected by the structure.

Table 7: Protections for Low-rise Housing and Potential Spill-over Effects

	(1)	(2)	(3)	(4)
Sample	Repeat sales	Hazard repeat sales	Repeat sales	Hazard repeat sales
Dependent variable	$\ln(P_{i,t})$	$\ln(P_{i,t})$	$\ln(P_{i,t})$	$\ln(P_{i,t})$
Protection × Post	0.075**	0.125***		
	(0.030)	(0.049)		
Protection × Post × Low-rise	0.097	0.003		
	(0.076)	(0.124)		

[18] In Appendix 3, we additionally apply a pseudo-panel DiD analysis by aggregating data at the municipality–year level.

Near Protect. × Post			-0.060*	-0.028
			(0.032)	(0.047)
Near Protect. × Post × Downstream			0.166***	0.154**
			(0.044)	(0.067)
Year × Municipality FE	Yes	Yes	Yes	Yes
Property FE	Yes	Yes	Yes	Yes
Observations	858,398	77,696	858,398	77,696
Adjusted R^2	0.854	0.870	0.854	0.870

Note: The coefficients represent the percentage effect on home prices from a difference in differences regression for different specifications. Protection indicates a home has a flood protection within 200 meters and downstream in the river. Near Protect. indicates that a home is located within 200 meters of a flood protection structure, while Downstream identifies homes situated downstream along the river and thus protected by the structure. This breaks down potential spill-over effects on homes in proximity to flood protections that are outside the protection area. The sample for Model 1 and 3 consists of homes sold more than once post January 1, 2010, while the sample for Model 2 and 4 consists of homes in flood hazard zones sold more than once post January 1, 2010. The models have property fixed effects to capture time-invariant home characteristics, in addition to fixed effects for the interaction between year and municipality to capture spatio-temporal development. Robust standard errors, clustered at the property level, are in parentheses. *p<0.1; **p<0.05; ***p<0.01.

Although we find significant post-protection effects, these are considerably larger than the flood hazard discounts reported in Table 5. This difference arises because the flood hazard discount applies to all dwellings in risk zones, which are not directly comparable to the homes that receive protection during the sample period. Risk levels likely vary more among all hazard-zone homes than among those prioritized for protection, as the latter are very likely to have faced the highest risk before measures were implemented. Appendix 4 supports this assumption: when isolating the flood hazard discount for homes that later receive protection, we find that it mirrors the post-protection premiums. This pattern suggests flood protection is targeted toward areas with the greatest initial risk and effectively removes the prior price penalty.

The existing academic literature shows homebuyers also price uninsurable losses, which may occur due to floods, including damage to personal belongings, displacement, stress, community infrastructure disruptions, death or injury risk. For instance, Bin and Polasky (2004) examine the effects of flood hazards on residential property values before and after Hurricane Floyd in Pitt County, North Carlina, and find that before the Hurricane price discount for homes in the floodplain was lower than the long-run cost of flood insurance, but after the storm, the price discount became larger than the insurance cost. The authors show that the actual flood event increased the "perceived risk associated with flooding," thereby raising the discount buyers require. This suggests discounts existed even before the storm, and after the storm discounts doubled.

Another study by Gallagher (2014) analyzes how flood events affect flood insurance policies in the United States and finds that flood insurance take-up increased after the flood events, even though the cost of insurance did not change. Interestingly, Gallagher (2014) further shows that homeowners who were not flooded but were merely exposed to TV coverage of nearby floods, raised their insurance purchases to about one-third of the increase among affected owners. This suggests that flood-risk perception, rather than direct damage or changes in insurance terms alone, may shape financial behavior and generate discounts for perceived in-risk homes. The recent study by Kivedal (2023), which examines the impact of insurance claims related to natural disasters on residential properties in Norway, finds that natural disasters still affect home prices even when insurance fully covers financial losses. This shows that homebuyers also care about non-financial or actual hazard risks, such as displacement, stress, commute disruption, and evacuation, because natural disasters like flood events inflict substantial non-monetary losses that insurance cannot cover, and even then, a uniform insurance policy does not disregard home price adjustments. Therefore, price discounts reflect the perceived hazard risk and intangible costs of homebuyers. This aligns with our findings that even under uniform insurance, homebuyers reasonably incorporate non-financial and behavioral components of risk into property valuations.

4.3 Event study for temporal effect

To assess whether the treatment effect is consistent or varies over time, we estimate the dynamic effects using the Callaway and Sant'Anna (2021) staggered DiD approach, which explicitly accounts for heterogeneous treatment effects across time and across groups that receive the treatment at different periods. This method estimates group-time average treatment effects (ATTs), allowing us to separately identify early and later treated units and to trace how the impact of flood protection evolves over time without the biases that may arise in two-way fixed effects estimators (Goodman-Bacon 2021). For each completion cohort g and sales year t, we estimate a group-time average treatment effect $\mathrm{ATT}(g,t)$ by comparing properties for which a protection was already completed to a comparison group of properties that are never treated in year t.

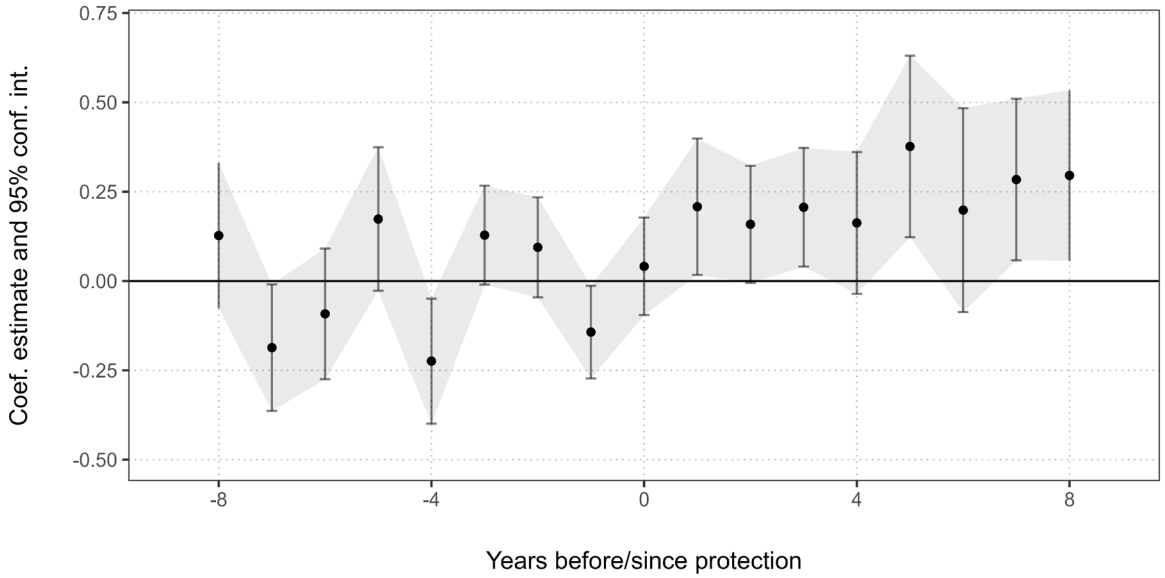
To study the temporal pattern of flood protection capitalization, we reindex these group-time effects relative to the year of completion and construct dynamic effects in event time. Let $\ell = t - g$ denote the number of years relative to protection completion. We then summarize the time profile by averaging $\mathrm{ATT}(g,t)$ across completion cohorts within each event-time bin,

$$\theta_\ell = \mathbb{E}_g[\mathrm{ATT}(g, g+\ell)], \tag{5}$$

where the ℓ value closest but prior to construction is used as reference period. Figure 4 presents the resulting dynamic θ_ℓ estimates. In Panel A, the results show that housing prices rise after the construction of flood protection, and the effect increases over time, with substantially larger impacts in the later post installation periods. Before the flood protection, the house prices fluctuate without a clear pattern, thereby not showing any pre-trends or anticipation effects. Following completion ($\ell \geq 0$), we observe a gradual and persistent increase in prices. The estimated effects strengthen over the first year after completion and remain positive several years out, suggesting that the benefits of reduced flood risk are capitalized into housing values in a sustained rather than purely transitory manner.

Panel B of Figure 4 reports the estimated calendar-time ATTs aggregated across completion cohorts for years $t \in [2012, 2013, \ldots, 2023]$. This complements the event-time dynamics θ_ℓ by showing how the capitalization of flood protections evolves across macroeconomic conditions and different cohorts of completed protective measures. The pattern is broadly consistent with the event-study results: the coefficients remain positive in the post-completion years, with clearer and more precisely estimated effects emerging from 2014 onward. The diminishing standard errors are likely a function of more treated cohorts entering the sample over these years, improving estimation precision. The calendar-year estimates reinforce the interpretation that flood protections generate persistent capitalized benefits in the housing market, rather than short-lived or cohort-specific effects. This temporal decomposition estimator provides a more credible and unbiased illustration of the treatment effects under staggered adoption, reinforcing the results from the previous two-way fixed effects estimations.

Panel A: Dynamic Effects from Callaway and Sant'Anna Estimator



Panel B: Calendar Effects from Callaway and Sant'Anna Estimator

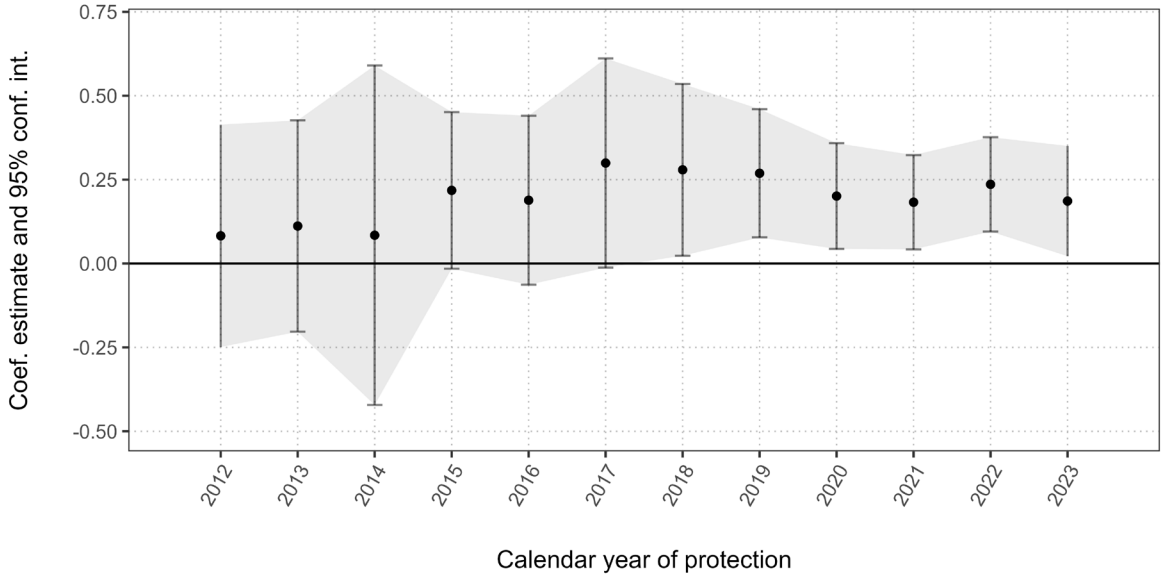


Figure 4: Event Study for Flood Protection Completion

Note: This figure shows the coefficient estimates from an event study using a Callaway and Sant'Anna (2021) estimator. Panel A presents the dynamic effects relative to the treatment year, while Panel B presents the calendar year effects. Coefficient estimates on the vertical axes represent the percentage effect on home prices following the completion of a flood protection within 200 meters of the home downstream in a river. The sample consists of homes sold more than once post January 1, 2010. The models have property fixed effects to capture time-invariant home characteristics and municipality × year fixed effects to capture spatio-temporal development. 95% confidence bands are based on robust standard errors, clustered at the property level. Data sources: Housing transaction data from Ambita AS (2010–2023) and flood hazard data from the Norwegian Water Resources and Energy Directorate (NVE).

4.4 Expert flood risk assessment

To validate our results, we estimate the relation between property prices and flood risk using manual expert flood risk assessments, outlined in Section 2, as a complement to the nationwide GIS-based estimations presented above. These assessments, conducted across

various regions of the country, are available only for selected mapping areas but still cover 134,481 home transactions within those regions. Because the estimated flood hazard is derived from water flow accumulation models applied to 10 × 10 meter raster grids, it may not capture highly localized variations in flood risk. The expert assessments thus serve as a valuable robustness check for the GIS-based flood hazard estimations. Table 8 shows a comparison between the estimated and the expert-assessed flood risk.Table 8: Comparison of Estimated and Expert-Assessed Flood Risk

Flood level	Accuracy	True positive rate	True negative rate
10-year	66.97%	66.04%	67.04%
20-year	67.20%	65.73%	67.29%
50-year	67.84%	72.47%	67.66%
100-year	68.72%	75.24%	68.26%

Note: This table compares model-based estimates of whether a home is in flood with expert-assessed classifications of homes located within the 10-, 20-, 50-, or 100-year flood zones provided through NVE's manual flood-risk mapping. The comparison is restricted to properties located in areas where a human expert has conducted a manual assessment. "Accuracy" measures the overall share of correctly classified homes. "True positive rate" reflects the share of expert-identified at-risk homes that are also identified by the estimated model, while "true negative rate" corresponds to the share of homes deemed not at risk by experts that are correctly classified as such by the model.

To examine the relation between flood risk and low-rise housing, we replicate the analysis from Subsection 3.1, this time using the expert flood risk assessments instead of estimates. These assessments provide classifications for different flood return periods, ranging from 10-year to 100-year flood events. The regression model is specified as follows:

$$\ln(P_{i,t}) = \beta_0 + \beta_1 \text{FloodLevel}_i + \beta_2(\text{FloodLevel}_i \times \text{Lowrise}_i) + X_i\gamma + \delta_{\text{Zip}_i} + \lambda_{\text{Mun}_i \times \text{Year}_t} + \varepsilon_{i,t}, \quad (6)$$

where FloodLevel_i is a binary indicator equal to 1 if the home is located in a specific flood risk zone according to the human expert (i.e., 10-year, 20-year, 50-year, or 100-year flood risk), and $(\text{FloodLevel}_i \times \text{Lowrise}_i)$ is the interaction with low-rise housing. The rest of the equation is identical to that in Equation (2).

The regression results are presented in Table 9. Interestingly, we find a positive relation between flood risk at all levels and sales prices. However, the interaction term for low-rise housing is negative and generally outweighs the positive flood risk effect by approximately two percentage points in absolute terms. This suggests mid-/high-rise homes in flood-prone areas sell for higher prices compared to non-risk homes in the same mapping regions. One possible explanation for this peculiar result is that these homes benefit from the positive

amenities of river proximity without facing the associated flood risk. Further examination in Appendix 2 corroborates this explanation. In contrast, low-rise homes experience a negative price effect when located in flood risk zones, reinforcing the findings from Subsection 3.1. These results indicate that low-rise homes are more vulnerable to price discounts due to their greater exposure to potential flood damage.

Table 9: Manual Flood Risk Areas

	(1)	(2)	(3)	(4)
Sample	Expert assessed	Expert assessed	Expert assessed	Expert assessed
Flood level	10-year	20-year	50-year	100-year
Dependent variable	$\ln(P_{i,t})$	$\ln(P_{i,t})$	$\ln(P_{i,t})$	$\ln(P_{i,t})$
Flood level	0.065*	0.059*	0.082***	0.089***
	(0.038)	(0.034)	(0.031)	(0.028)
Flood level × Low-rise	-0.102*	-0.102**	-0.136***	-0.125***
	(0.058)	(0.042)	(0.042)	(0.037)
Year × Municipality FE	Yes	Yes	Yes	Yes
ZIP code FE	Yes	Yes	Yes	Yes
Property controls	Yes	Yes	Yes	Yes
Location controls	Yes	Yes	Yes	Yes
Observations	134,669	134,669	134,669	134,669
Adjusted R^2	0.666	0.666	0.667	0.667

Note: The coefficients represent the percentage relation with home prices from an OLS regression for different flood types. The sample consists of homes which have been manually assessed for flood risk by a human expert. Property controls include size, age, number of rooms, number of bathrooms, energy label, condition, and home type. Location controls include waterfront, nearby fishing, distance to closest school, distance to public transport, distance to water, and relative altitude within the municipality. The models have nested fixed effects for ZIP code and the interaction between year and municipality. Robust standard errors, clustered at the ZIP code level, are in parentheses. *p<0.1; **p<0.05; ***p<0.01.

5. Conclusions

This study examines how flood risk and flood protection infrastructure affect residential property prices in Norway, leveraging a unique institutional and geographic context. By exploiting the country's uniform insurance premium system and robust legal disclosure requirements, we isolate the economic effects of flood exposure and protective measures on the housing market. Using over 1.4 million housing transactions from 2010 to 2023, we find that low-rise homes located in unprotected flood hazard zones sell at a statistically significant discount of approximately 3.5%. No such discount is observed for mid- and high-rise dwellings, suggesting structural characteristics mediate risk perception and pricing. Importantly, properties located downstream and near completed flood protections enjoy significant price premiums of around 10.7%. The post-protection premium mirrors the pre-protection discount for the same homes that will eventually be treated. This suggests that flood

protections are targeted toward areas with higher initial risk and effectively eliminates the prior price penalty.

Our findings have important implications for a range of stakeholders. For policymakers, they support investment in targeted flood protection infrastructure as a tool to safeguard housing markets in risk-prone areas. Homeowners and real estate developers can use this information to make informed location and design decisions, while insurers and investors gain insight into how physical risk and adaptation measures are priced into assets. More broadly, the results highlight how climate adaptation can generate economic value alongside safety benefits. Future research could explore the broader impacts of flood protections on environmental systems, including their potential to disrupt or enhance biodiversity and ecosystem services that must be balanced in sustainable adaptation planning. As climate risks intensify, understanding how resilience measures affect not only market outcomes, but also ecological systems, is increasingly vital.

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Appendix 1: Propensity score matching

Panel A of Table 10 provides details on the propensity score matching performed for the hedonic regression reported in column (3) in Table 5. The objective of the matching is to make the control group of homes without flood risk comparable to the treatment group of homes exposed to flood risk. This is achieved by matching 124,013 in-risk homes to their 124,013 most similar no-risk counterparts using a k-Nearest Neighbors algorithm with $k = 1$. As shown in Panel B of Table 10, the one-to-one nearest neighbor matching reduces the mean difference in propensity scores for flood hazard exposure between the treatment and control groups to zero. For other selected numerical variables except age, the standardized mean differences are reduced by between 22% and 100% after matching. This suggests that the matched sample achieves greater comparability between the two groups than the full sample.

Table 10: Propensity Score Matching

Panel A: Matching Information			
Treatment variable	Flood hazard	All obs.	1,413,735
Distance metric	Logit of prop. score	All obs. (treated)	124,043
Method	Nearest neighbor	All obs. (control)	1,289,692
Control/treated ratio	1 ($k = 1$)	Matched obs. (treated)	124,013
Caliper	0.01	Matched obs. (control)	124,013

Panel B: Standardized Differences (treated - control)			
Variable	Observations	Standardized mean difference	Percent reduction
Logit of PS	All	0.70	
	Matched	0.00	100 %
Size	All	-0.42	
	Matched	0.02	95 %
Age	All	0.01	
	Matched	-0.04	0 %
Rooms	All	-0.38	
	Matched	0.05	87 %
Bathrooms	All	-0.22	
	Matched	0.02	92 %
Distance to school	All	-0.01	
	Matched	0.01	22 %
Distance to public transport	All	-0.14	
	Matched	0.01	91 %
Distance to water	All	-0.58	
	Matched	-0.03	95 %

Notes: Panel A gives information about the propensity score matching process as well as the number of observations in different groups pre- and post-matching. Matching is done one-to-one by propensity score using a nearest neighbor approach with a caliper of 0.01. Panel B gives the standardized mean differences between homes inside versus outside flood hazard zones, pre- and post-matching, for the numerical variables size, age, number of rooms, number of bathrooms, distance to school and distance to public transport in the same forms they are included in the hedonic regressions (i.e., log-transformed or not). Propensity scores of being in flood

hazard zones are estimated using a logistic regression with the mentioned numerical variables in addition to the categorical property and location controls. Source: Author calculations using Ambita AS housing data, 2010–2023.

Appendix 2: Flood risk at different stories

As the results from previous subsections suggest being located in a flood risk area may be associated with a price premium for mid-/high-rise homes, we further investigate this effect. Intuitively, if the premium stems from amenity values such as water views and proximity to a body of water, without the downside of flood exposure, one would expect the positive effect to be more pronounced for units on higher floors. To test this, we re-estimate our hedonic regressions with interaction terms between flood hazard and floor categories for mid-/high-rise housing, using both the full and propensity score-matched samples.

Table 11: Flood Risk Capitalization for Different Floor Categories

	(1)	(2)	(3)
Sample	Full	PS matched	Border Disc.
Dependent variable	ln(P_{it})	ln(P_{it})	
Flood hazard	-0.029***	-0.037***	-0.020***
	(0.007)	(0.008)	(0.007)
Flood hazard × Ground-floor condo	0.027***	0.031**	0.017*
	(0.010)	(0.011)	(0.009)
Flood hazard × Low-floor condo	0.033***	0.034**	0.021**
	(0.011)	(0.011)	(0.010)
Flood hazard × Mid-floor condo	0.047***	0.053***	0.035**
	(0.014)	(0.014)	(0.014)
Flood hazard × High-floor condo	0.112***	0.137***	0.092***
	(0.028)	(0.029)	(0.028)
Year × Municipality FE	Yes	Yes	Yes
ZIP code FE	Yes	Yes	Yes
Property controls	Yes	Yes	Yes
Location controls	Yes	Yes	Yes
Observations	1,413,735	248,048	674,116
Adjusted R2	0.707	0.741	0.730

Notes: The coefficients represent the percentage relation with home prices from an OLS regression for different data samples. Condo is defined as multi-story condominiums. Ground-floor means located on the first floor of the multi-story building, low-floor means located on the second or third story, mid-floor means fourth to seventh story, and high-floor means eighth story or higher. The matching in column (2) is done one-to-one by propensity score with a caliper of 0.01. The border discontinuity in column (3) uses only homes within 200 meters of a flood hazard area as control group. Property controls include size, age, number of rooms, number of bathrooms, energy label, condition, and home type. Location controls include waterfront, nearby fishing, distance to closest school, distance to public transport, distance to water, and relative altitude within the municipality. The models have nested fixed effects for ZIP code and the interaction between year and municipality. Robust standard errors, clustered at the ZIP code level, are in parentheses. *p<0.1; **p<0.05; ***p<0.01. Source: Author calculations using Ambita AS housing data, 2010-2023.

As shown in column (1) of Table 11, high-floor condominiums in flood risk areas exhibit a significant price premium of over 10%. This effect is robust in the matched sample in column (2), and in the border discontinuity model in column (3), where the non-risk homes used for comparison are more similar to those in hazard zones. In the last specification, we find an overall price discount of 2.0% associated with being located in a flood risk area. However, this is more than offset for high-floor units, which sell for 7.2% more than comparable non-risk homes (9.2% marginal premium minus the 2.0% overall discount). The premium declines with floor level. These findings suggest that, while low-rise homes suffer a price discount in flood risk areas, homes located on higher floors of mid-/high-rise buildings may command a premium from such a location, likely due to higher amenity value. Units on lower floors of mid-/high-rise buildings transact at similar prices to those outside the flood hazard zones.

Appendix 3: Pseudo-panel staggered DiD

We create a pseudo-panel by aggregating data at the municipality–year level while separating homes with and without flood protections into three different cohorts. For each municipality and each year, we have one cohort for homes that will never receive a flood protection, a second cohort for homes that will receive a flood protection in the future, and a final cohort for those homes that have already received a flood protection. This approach allows us to create treatment and control groups at the municipality level rather than at the home level. The treatment group consists of homes with flood protection, while the control group consists of homes without flood protection. This methodology enables us to isolate the causal impact of flood protections on home prices by controlling variations at the municipality level and the different timings of flood protection implementation. For this analysis, we use the following staggered DiD regression model:

$$\ln(P_{c,j,t}) = \beta_0 + \beta_1 \text{Protection}_{c,j} + \beta_2 \text{Post}_{c,j,t} + \beta_3 (\text{Protection}_{c,j} \times \text{Post}_{c,j,t}) + X_{c,j,t}\gamma + \lambda_{\text{Mun}_{c,j} \times \text{Year}_t} + \varepsilon_{c,j,t}, \quad (7)$$

where $\ln(P_{c,j,t})$ is the natural logarithm of the average sales price of homes in cohort c in municipality j at time t. $\text{Protection}_{c,j}$ is binary variable equal to 1 if homes in cohort c in municipality j have or will have a future flood protection within 200 meters, and 0 otherwise. $\text{Post}_{c,j,t}$ is binary variable equal to 1 if time t is after the flood protection for cohort c homes is built in municipality j, and 0 otherwise. $\text{Protection}_{c,j} \times \text{Post}_{cjt}$ is the interaction term that captures the impact of flood protection after the treatment. $X_{c,j,t}$ is a vector of control variables aggregated at the municipality–year level for each cohort. $\lambda_{\text{Mun}_{c,j} \times \text{Year}_t}$ represents municipality and year fixed effects, and $\varepsilon_{c,j,t}$ is error term. We also include interactions with low-rise to evaluate whether the price effects differ for low-rise housing. The estimation excludes cohorts with fewer than 10 transactions and is re-estimated weighting the cohorts by the number of treated homes per municipality. These adjustments reduce the risk that cohorts with only a single or very few sales near flood protections disproportionately influence the findings. The weighting allows us to put emphasis on municipalities with homes receiving flood protections.

The results are presented in Table 12. We find a positive association between homes that have ever received a flood protection and their sales prices. This positive price effect ranges from 7.0% to 9.3%, depending on whether weighting is applied. For low-rise homes, however, we

observe negative price effects that outweigh the positive influence, with price discounts of 12.6% and 11.3%, respectively. These findings suggest while mid-/high-rise homes in areas receiving flood protections may benefit from the amenity value of proximity to a body of water without experiencing notable flood risk, low-rise homes in these areas sell at lower prices compared to similar low-rise homes in non-risky areas. The Protection × Post interaction effect is less clear when aggregating at the municipality–year level. However, the triple interaction with Low-rise is statistically significant at the 5% level in column (2), which focuses on municipalities with a greater number of flood protections. This indicates a positive post-installation price effect for low-rise housing at the municipality level, although no such effect is observed for mid-/high-rise homes in the pseudo-panel approach.

Table 12: Pseudo-Panel Staggered DiD

	(1)	(2)
Sample	Pseudo-panel	Pseudo-panel
Dependent variable	$\ln(P_{it,})$	$\ln(P_{it,})$
Protection	0.070***	0.093***
	(0.024)	(0.023)
Protection × Post	-0.013	-0.031
	(0.039)	(0.034)
Protection × Low-rise	-0.126**	-0.113***
	(0.061)	(0.043)
Protection × Post × Low-rise	0.060	0.100**
	(0.072)	(0.049)
Weighted (# of treated)	No	Yes
Year × Municipality FE	Yes	Yes
Property controls	Yes	Yes
Location controls	Yes	Yes
Observations	6,318	2,168
Adjusted R2	0.891	0.814

Notes: The coefficients represent the percentage effect on home prices from a difference in differences regression for varying specifications. Protection indicates that a home has a flood protection within 200 meters. The sample consists of a pseudo panel aggregated at the municipality level. Cohorts with fewer than 10 transactions are excluded. In column (2), we weight the municipalities by number of treated homes across the entire sample period, giving higher weights to municipalities with more homes receiving flood protections. Property controls include size, age, number of rooms, number of bathrooms, energy label, condition, and home type. Location controls include waterfront, nearby fishing, distance to closest school, distance to public transport, distance to water, and relative altitude within the municipality. The models have fixed effects for the interaction between municipality and year to capture spatio-temporal development. Standard errors are in parentheses. *p<0.1; **p<0.05; ***p<0.01.

Appendix 4: Risk discount for homes that will receive protection

We repeat the analysis from Table 5 for homes that will receive flood protection in the future. These homes will typically be more exposed to flood risk than those in estimated hazard according to the hydrological model, and the coefficient estimates will be more comparable to those for the protection premiums in Table 6. We do indeed find that the pre-protection discounts align more closely with the post-protection premiums, with discounts ranging from 12.2–17.8%.

Table 13: Flood Hazard vs. 200m from Future Protection

	(1)	(2)	(3)	(4)
Sample	Full	Low-rise	PS matched	Bord. Disc.
Dependent variable	ln(P_{it})	ln(P_{it})	ln(P_{it})	ln(P_{it})
Future protection	0.058	-0.072	-0.081	0.019
	(0.099)	(0.123)	(0.073)	(0.093)
Future protection × Low-rise	-0.178***		-0.122*	-0.167***
	(0.043)		(0.068)	(0.043)
Year × Municipality FE	Yes	Yes	Yes	Yes
Zip code FE	Yes	Yes	Yes	Yes
Property controls	Yes	Yes	Yes	Yes
Location controls	Yes	Yes	Yes	Yes
Observations	1,413,735	646,170	248,026	674,116
Adjusted R2	0.707	0.686	0.741	0.730

Note: The coefficients represent the percentage relation with home prices from an OLS regression for low-rise residential real estate. Low-rise is defined as single-family homes, semi-detached homes, row homes, and single-story condominiums. The matching in column (3) is done one-to-one by propensity score with a caliper of 0.01. The border discontinuity in column (4) uses only homes within 200 meters of a flood hazard area as control group. Property controls include size, age, number of rooms, number of bathrooms, energy label, condition, and home type. Location controls include waterfront, nearby fishing, distance to closest school, distance to public transport, distance to water, and relative altitude within the municipality. The models have nested fixed effects for ZIP code and the interaction between year and municipality. Robust standard errors, clustered at the ZIP code level, are in parentheses. *p<0.1; **p<0.05; ***p<0.01.