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**Application for the NBER PhD Student Workshop on Climate Finance**

To whom it may concern,

I am a PhD Candidate in Economics at BI Norwegian Business School and an economist at Norges Bank's Monetary Policy Department. My research explores how climate and petroleum-related issues affect individual-level economic outcomes using micro data. More broadly, my interests include applied macroeconomics, climate economics, insurance markets, labor economics, and monetary policy.

I am applying to the PhD Student Workshop on Climate Finance, taking place in Cambridge, MA, on October 9, 2025. Enclosed are my CV and a preliminary draft of my single-author paper titled *One Price Fits All? Quantifying Implicit Cross-Subsidization in Norway's Natural Damage Insurance Scheme*, which I submit for consideration. I would greatly welcome the opportunity to receive feedback from faculty and peers in the workshop setting. As the paper is still in an early stage, such feedback would be especially valuable, both on the current approach and on potential directions going forward.

I confirm that I meet the stated requirement of having a complete draft of at least one research paper on climate finance. This requirement is met by *Weathering the Storm: The Effects of Natural Disasters on Households under Universal Insurance*, which I am scheduled to present at the main NBER Climate Finance Conference on October 10.

I expect to complete my PhD by the end of 2025. My primary advisor is Professor Ragnar Torvik, who is available to serve as a reference. He can be reached at ragnar.torvik@ntnu.no or by phone at +47 988 24 721.

Please do not hesitate to contact me if you require any further information.

Sincerely,
Caroline Espegren

# Caroline Espegren



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- Academically strong; reliable, precise, and results-oriented
- Proficient communicator; focused on clarity and impact
- *Research Interests:* Applied Macroeconomics, Climate Economics, Insurance Markets, Labor Economics, Monetary Policy

## Education

**BI Norwegian Business School, Ph.D. in Economics** **Aug 2020 – today**

- Title: *Essays in Economic Resilience: Petroleum Displacement, Climate Shocks and Insurance Markets*
- Working Papers:
  - *Lost in transition? Earnings losses of displaced petroleum workers*, CAMP Working Paper Series 06/2022
  - *Weathering the Storm: The Effects of Natural Disasters on Households under Universal Insurance*
  - *Quantifying Implicit Subsidies in Norway's Natural Damage Insurance Scheme*
- Completed all required PhD coursework (61 ECTS)
- Teaching Assistant in GRA6631 Economic Policy, GRA6639 Business Cycles and Monetary Policy, and GRA6665 Environment and Sustainable Development.

**Norwegian University of Science and Technology, Master of Science in Economics** **Aug 2010 – Dec 2015**

- Specialization in macroeconomics and econometrics
- Master Thesis: *"Monetary policy in commodity exporting countries"*, grade: A
- GPA: A, 4.9/5.0

**The Norwegian School of Theology, Intercultural Communication** **Aug 2009 – June 2010**

- One-year programme, specializing in international development, humanitarian aid, and Chinese culture
- GPA: A, 4.7/5.0

**Kristelig Gymnasium, High School** **Aug 2006 – June 2009**

- General studies with specialization in advanced mathematics, physics, and economics
- GPA: 5.6/6.0

## Work Experience

**Senior Economist, Monetary Policy Department, Norges Bank** **Aug 2015 - today**

- Worked in various parts of the department: monitoring and analyzing international economic developments, developing policy models, and contributing to speechwriting, including the 2019 Annual Address
- Analyzed the macroeconomic consequences of new technology, resulting in two blog posts
- Engaged in recruitment and marketing strategies towards students. I was in charge of Norges Bank's annual case competition 2019, and a part of Norges Bank Teaching Initiative, where we gave lectures on macroeconomics and monetary policy for undergraduate students

**Summer Intern & Master Thesis Student, Monetary Policy Dep., Norges Bank** **2013 – 2015**

- 2015: Master Thesis Student: Developed core sections of my thesis during this summer position
- 2014: Updated source data for the indicator for external price impulses to imported consumer goods (IPK)
- 2013: Worked on expanding Norges Bank's trading partner aggregate to include two additional countries

**Teaching Assistant, Norwegian University of Science and Technology** **2013 – 2015**

- In macroeconomics and econometrics, courses with up to 120 undergraduate and 40 graduate students.

**Volunteer in Microfinance, Alliance Microfinance AS (Norwegian NGO)** **Aug 2013 – May 2014**

- I spent almost a year in Guayaquil, Ecuador, working at a local bank that provided microfinance services. I contributed to initiatives to boost loan-repayment rates and customer loyalty, including designing and conducting a client survey.

**Summer Intern, The Norwegian Water Resources and Energy Directorate (NVE)** **June 2012 - July 2012**

- I interviewed Norwegian energy providers regarding the introduction of smart meters (AMS) in Norway. Summarized and reported the qualitative findings in two internal reports.

**Part-time, Christiania Belysning** **Sep 2008 – June 2011**

## Invited Seminars and Conferences

NYU Stern Summer Climate Finance Conference; **2025**
CEPR Climate Change and the Environment Symposium 2025;
Conference "Applied Macroeconomics in a Changing World" by Bank of Canada, Bank of Italy and CAMP/BI;
NBER Climate Finance Conference

Fagkonferansen, Norges Bank **2024**

## Positions of Responsibility

| | |
|---|---|
| Member of PhD Students Committee, The E-axes Forum | **July 2025 - today** |
| Member of Finance Committee, Mission Alliance (Norwegian NGO) | **Nov 2024 - today** |
| Chair of Student Organization, Econnect NTNU | **Jan 2012 - April 2013** |
| Member of Student Organization, Econnect NTNU | **Feb 2011 - Jan 2012** |
| Vice Chair of Student Council, Kristelig Gymnasium | **Jan 2008 - Jan 2009** |

## Media (in Norwegian)

*Ekstremvær kan skape den neste finanskrisen*, DN-innlegg, 02.07.2025
*Økonomene må snakke så folk forstår dem*, DN-innlegg, 16.02.2025
*Når ulikhet former demokratiet*, DN-innlegg, 23.10.2024
*Digitalisering og ny teknologi kan gi lavere renter*, Intervju med e24.no, 03.02.2019

## Other

**Citizenships:** Norwegian, Polish
**Maiden Name:** Lesiewicz
**Marital Status:** Married, three children
**Languages:** Norwegian (native – dominant), Polish (native – heritage), English (fluent), Spanish (basic)
**Programming:** Stata, Python (Jupyter Notebook, Spyder), Dynare, LaTeX, git (Github), Excel and Office
**Interests:** Family and friends, running, writing and knitting

# One Price Fits All? Quantifying Implicit Cross Subsidization in Norway's Natural Damage Insurance Scheme*

Caroline Espegren[a,b]

[a]BI Norwegian Business School
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August 7, 2025

*Preliminary draft. Please do not circulate.*

**Abstract**

This paper quantifies implicit subsidies in Norway's natural disaster insurance scheme, where a uniform premium is charged regardless of location-specific risk. Using individual property data, hazard zone maps, and municipal insurance payouts, I estimate loss ratios inside and outside high-risk areas. The results show that uniform pricing leads to substantial redistribution, implicitly subsidizing high-risk properties. Focusing on flood risk, I find that the actuarially fair premium in flood-exposed zones would be 14–20 times higher than in non-flood zones. Extensions to other hazard types are planned. The findings contribute to broader discussions on the design of climate risk insurance.

**JEL classification**:
**Keywords**: Climate Economics, Insurance Markets, Natural Disasters

*I would like to thank Parinitha Sastry, Steffen Andersen, Christian Brinch, Ragnar Torvik, Gisle J. Natvik, Espen R. Moen, Fabian Harang and Hans Martin Espegren for valuable brainstorming and useful comments. I would also like to thank Norges Bank for granting the project access to relevant micro data. I am especially grateful to Kasper Roszbach and Magnus Gulbrandsen for their assistance with the data application process, and to Haakon Solheim and Bjørn Helge Vatne for their support and information sharing. The views expressed in this paper are those of the author only and should not be attributed to Norges Bank. All mistakes are my own.

# 1 Introduction

Norway's natural damage insurance scheme is universal, with uniform pricing applied regardless of a property's exposure to climate-related risks. While this system promotes collective responsibility, it also results in cross-subsidization: homeowners in high-risk areas effectively receive an implicit subsidy, whereas those in low-risk areas pay premiums that exceed their actuarially fair levels.[1] As climate change increases the frequency and severity of weather-related hazards, the magnitude of these implicit subsidies may grow over time, with potential implications for the housing market, household resilience and financial stability.

In this paper, I quantify the magnitude of implicit subsidies by comparing the insurance premiums currently paid by households to the actuarially fair premiums that would accurately reflect location-specific climate risk. The analysis is guided by two central questions. First, to what extent are properties in high-risk areas subsidized under the existing system, as measured by the gap between the uniform premiums paid and the risk-adjusted premiums implied by actuarial calculations? Second, how might projected increases in extreme weather events driven by climate change alter the scale of these subsidies over time?

To study implicit subsidies in the current insurance scheme, I use a dataset covering all residential properties in Norway. For each property, I calculate the insured value using standardized valuation tables applied in the national insurance scheme. I then combine this data with hazard zone maps from the Norwegian Water Resources and Energy Directorate (NVE) to determine, at the individual property level, whether a property is located inside a designated risk zone for natural hazards such as flooding, landslides (including quick clay), or storm surges.

To estimate expected losses, I use municipality-level data on historical insurance payouts for natural hazards, covering the period from 1980 to 2024. Because this payout data is only available at the municipal level, I aggregate the property-level dataset accordingly. For each municipality, I compute the share of total insured value located within mapped risk zones. By exploiting variation in this exposure measure, I estimate zone-specific loss ratios – defined as expected losses relative to

[1] Actuarially fair pricing refers to premiums set strictly according to expected losses, reflecting the true underlying risk of the property without cross-subsidization.

insured value – for properties inside and outside flood zones.

Under actuarial fairness, the uniform premium should reflect the national average loss ratio. By comparing the estimated loss ratios across zones to this uniform premium, I assess whether properties in low-risk areas implicitly subsidize those in high-risk areas. Moreover, the difference in zone-specific loss ratios provides a direct measure of the imbalance embedded in the uniform pricing scheme.

So far, the analysis has focused exclusively on flooding, which is one of the most costly and spatially mappable hazard types. Specifically, flood-related events account for 32.3 percent of total insurance payouts (see Table 1). Although storm damage represents an even larger share (47.9 percent), it is less geographically predictable given the current availability of hazard maps. Flood risk, by contrast, can be systematically identified using official flood zone designations, making it a natural starting point for this type of spatial analysis. While the current analysis focuses on flooding, the same approach can be extended to other hazards, such as landslides or storm surges. Still, flood risk alone accounts for a substantial share of aggregate losses, and therefore offers valuable insight into the broader structure of climate-related insurance imbalances.

The results show that, under actuarially fair pricing, the average flood premium for high-risk properties would be 14–20 times higher than for non-exposed areas. For a typical home in a flood risk area insured for 5 million NOK (approx. 480,000 USD), this implies an annual flood premium of nearly 2,000 NOK (190 USD), compared to around 150 NOK (14 USD) under the current uniform flood rate. This sizable gap illustrates the extent to which the current system redistributes costs, with lower-risk households contributing more than their expected share to cover flood-related losses in high-risk zones.

Understanding and quantifying implicit subsidies in a natural damage insurance scheme with uniform pricing is important for several reasons. First, if households in vulnerable regions do not receive accurate financial signals of their underlying risk, they may underinvest in mitigation measures and make location choices that increase their long-term exposure to climate hazards. Second, implicit subsidies can distort the pricing of risk in housing markets, potentially leading to overvaluation of properties in high-risk areas. Over time, this may have implications for the stability of the financial system, particularly if large-scale repricing occurs abruptly

as the impacts of climate change intensify. Such abrupt adjustments may amplify vulnerabilities in banks' mortgage portfolios. Finally, estimating the magnitude and distribution of these subsidies can support policymakers in designing insurance reforms, targeting risk-reduction efforts, and shaping land-use policy.

This analysis also relates to an ongoing policy dialogue on the design of natural disaster insurance systems under increasing climate risks. In Europe, and particularly within the EU, there is growing interest in exploring more coordinated approaches across national schemes, including proposals for an EU-level public-private reinsurance mechanism to improve coverage and risk pooling. While institutional contexts vary, insights from the Norwegian case may offer useful perspective on the trade-offs between distributive fairness, efficiency, and risk signaling in broader insurance policy discussions.

Moreover, this paper contributes to a broader literature on the pricing of homeowners' insurance, an area that is gaining increased attention in light of growing climate-related losses. Sen and Tenekedjieva (2021) examine the role of rate regulation and show that insurance premiums are clearly shaped by different regulatory regimes across U.S. states, resulting in persistent cross-subsidies and pricing distortions. Boomhower, Fowlie, Gellman, and Plantinga (2024) investigate the role of asymmetric information and find that firms relying on coarser wildfire risk models are exposed to severe adverse selection, due to their informational disadvantage relative to insurers with more sophisticated, granular data. This highlights how unequal access to risk information can shape market outcomes. Mulder and Kousky (2023) analyze the early effects of introducing risk-based pricing in the U.S. National Flood Insurance Program (NFIP). They find that despite the use of improved risk models, pricing differentials between high- and low-risk areas have narrowed, largely because households and regulators continue to rely on outdated flood maps, limiting the effectiveness of the new pricing system.

The remainder of the paper is structured as follows. Section 2 discusses the insurance of catastrophic risk more generally, with a particular focus on the Norwegian scheme. Section 3 presents the data and descriptive statistics. Section 4 outlines the research design and estimation strategy. Section 5 presents the main results, and Section 6 concludes.

# 2 Insuring Catastrophic Risk

Insurance markets are built on the idea of risk pooling. By collecting small premiums from many individuals, insurers provide financial protection against rare but costly events, thus converting unpredictable losses into predictable costs. As Friedman and Savage (1948) noted, insurance offers 'gains from certainty': even when premiums are equal to expected losses – that is, actuarially fair and excluding administrative costs or profit – risk-averse individuals prefer paying a known cost to avoid uncertain, potentially ruinous losses.

A central question in insurance theory is what makes a risk insurable. Rejda, McNamara, and Rabel (2022), a widely used undergraduate textbook on risk management and insurance, outlines a set of criteria that defines when a risk is insurable through private markets. A risk should (1) involve a large number of exposure units, (2) be accidental and unintentional, (3) determinable and measurable, (4) not be catastrophic in nature, (5) have a calculable chance of loss, and (6) allow for economically feasible premiums. When these conditions are met, actuarially fair pricing in theory implies that each policyholder pays a premium equal to their expected loss.

However, catastrophic risks such as those associated with natural disasters challenge several of these foundational assumptions because they often result in highly correlated losses, violating the assumption of independence across risks that underpins actuarial pooling. In particular, the fourth criterion of Rejda et al. (2022), that the loss should not be catastrophic, is clearly strained in this context. As a result, such risks are often considered difficult, or even impossible, to insure privately, and are therefore commonly referred to as 'uninsurable risks'.

This concern is no longer merely theoretical. As extreme weather events become more frequent and severe, insurance markets are coming under pressure. In some regions, insurers have raised premiums and deductibles sharply, or withdrawn from high-risk areas altogether. This trend has triggered broader policy debates about the future of catastrophe coverage. For instance, The Economist (2024) (April 2025, Global warming is coming for your home) highlights how climate change is making home insurance inaccessible for many households, while Kaufman, Kishan, and Lopez (2024) reports on parts of the world increasingly viewed as effectively

uninsurable. These developments illustrate how climate change may render key risks uninsurable not in principle, but in practice.

Yet this view is not universal. Jaffee and Russell (1997) argues that there is nothing inherent to catastrophe risk that prevents the operation of private insurance markets. While the damage from such events may be substantial, they are typically infrequent, geographically localized, and uncorrelated with global asset prices. This makes them, at least in principle, diversifiable.

Still, the scale and simultaneity of losses from disasters introduce a structural friction: a temporal mismatch between steady premium inflows and large, irregular outflows. Insurers may collect premiums for years before a single catastrophic event triggers massive payouts. Jaffee and Russell (1997) contends that standard explanations for market failure, such as adverse selection, probability uncertainty, and extreme aggregate risk, do not fully explain the challenge. Instead, the core difficulty lies in this intertemporal structure.

Managing this structural challenge requires access to global risk-sharing mechanisms. Reinsurance (i.e., insurance for insurers) allows primary insurers to transfer portions of their risk portfolios to global reinsurers. This reduces their exposure to extreme losses and helps maintain solvency after large-scale disasters. Reinsurance thus plays a critical role in enabling insurance markets for catastrophic risks. Other strategies to manage catastrophic risk include geographic diversification and financial instruments like catastrophe bonds.

However, these mechanisms have come under increasing strain. As climate-related disasters become more frequent and severe, reinsurance has become more expensive globally. Keys and Mulder (2024) document that average U.S. home insurance premiums rose by 33 percent between 2020 and 2023, with much of this increase attributed to rising reinsurance costs. Consider, for instance, a local insurer whose customer base is concentrated in a flood-prone area. Without reinsurance, a single event affecting many policyholders could deplete the insurer's reserves. Reinsurance spreads this risk across global markets, assuming that not all regions are affected at once. Yet in recent years, more regions have been hit simultaneously, eroding the assumption of spatial diversification and driving up the cost of reinsurance.

Keys and Mulder (2024) show also that U.S. home insurance premiums have

become more sensitive to local hazard risk. This reflects risk-based pricing enabled by detailed insurer data and modeling tools, and highlights a key asymmetry: insurers often possess far more granular information about hazard exposure than policyholders do. Unlike the classic setting of adverse selection (Rothschild and Stiglitz (1978), Akerlof (1978)) where consumers hold private information, catastrophe insurance often reverses the asymmetry: insurers have superior access to probabilistic models, hazard maps, and historical claims data. Information asymmetry strengthens the economic case for risk-based pricing, given that insurers are better positioned to assess actual risk exposure, though it may come at the cost of perceived transparency for households if the rationale for increasing prices is not evident or credible to policyholders.

Households, particularly those in high-risk areas, are already adjusting their insurance behavior in response to higher premiums. Ge, Johnson, and Tzur-Ilan (2025) document that higher insurance costs increase mortgage delinquency risk, particularly among debt-constrained households. They also find increased rates of early mortgage prepayment and migration to lower-risk areas. These patterns suggest that insurance pricing may actively drive climate-induced relocation. Moreover, Sastry, Sen, Tenekedjieva, and Scharlemann (2024) find that willingness to pay for coverage is constrained by financial limitations. Many households underinsure their homes, covering only a portion of the full replacement value. If prices continue to rise at current rates, the authors estimate that up to 30 percent of U.S. households will have to significantly reduce their coverage.

The fact that insurance against natural disasters is increasingly becoming inaccessible in practice, either because rising risk assessments drive premiums beyond what households can afford, or because insurers withdraw from high-risk areas altogether, raises a core policy dilemma: if society values broad access to coverage, what can be done when actuarially fair premiums become unaffordable? One approach is uniform pricing with cross-subsidies, as in Norway. Another is the development of public-private reinsurance mechanisms to preserve affordability while maintaining risk signals – an approach increasingly advocated within the EU (EIOPA & ECB, 2024).

In sum, the central challenge in catastrophe insurance is not merely assessing risk accurately but designing institutions capable of managing it over time. Where

traditional insurance structures fall short, hybrid models that blend market principles with social protections may offer a more resilient response to climate-related risks. This is a challenge that will only grow more pressing in the years ahead.

## 2.1 The Norwegian Natural Damage Insurance Scheme

The setup of insurance models for natural disasters varies internationally and can be broadly categorized into three types (The Norwegian Ministry of Agriculture and Food, 2014): countries without state compensation schemes where private insurance coverage dominates (UK, Sweden, USA), countries with compensation or insurance schemes involving state participation or regulation (France, Spain, Iceland, Switzerland), and countries with schemes under development with government involvement (Denmark, Finland, Netherlands, Taiwan). Standard insurance schemes are the most common approach to compensation for natural disasters. Some countries do not have fixed compensation schemes for losses due to natural disasters, and may only provide ad hoc support following major events. Against this backdrop, the Norwegian model stands out as a distinctive and comprehensive approach. Losses from natural disasters are covered through a combination of mandatory private insurance and a supplementary state compensation scheme. This dual structure is considered unique in an international context.

In Norway, the natural disaster insurance scheme is structured such that any property insured against fire is automatically covered for natural perils, including floods, landslides, and storms. In practice, this means that anyone who purchases fire insurance, typically through a standard homeowners insurance policy, automatically receives coverage for natural disasters. Since nearly all Norwegian homeowners hold such insurance, and most properties are insured for their full replacement value, coverage is, for all practical purposes, universal.

The system is organized through the Norwegian Natural Perils Pool, which coordinates among private insurers. Each insurer settles claims with its own customers, and the pool subsequently redistributes losses among members based on their market share, measured by total fire insurance sums (i.e., insured values). The uniform premium is set annually to ensure long-term balance between total inflows and outflows – that is, to be actuarially fair at the national level. Excess

revenues accumulate as natural damage capital within each company, and this capital is used to offset future losses.

A defining feature of the system is its use of a uniform premium rate. The same percentage of the fire insurance value is charged regardless of the property's location or risk level. This is known as the solidarity principle, and it represents a deliberate departure from actuarial pricing norms. Since 2012, the natural disaster insurance premium has remained between 0.065 and 0.08 per mille of the insured fire value (The Norwegian Ministry of Justice and Public Security, 2019). For a typical house insured for 5 million NOK (approx. 480,000 USD), the annual natural damage premium would therefore be around 350 NOK (approx. 33 USD).

Several arguments have historically been advanced in favor of maintaining a uniform rate (The Norwegian Ministry of Justice and Public Security, 2024). First, a key motivation at the time of the system's design was administrative simplicity. A differentiated pricing model based on localized natural hazard risk was considered technically demanding and costly to implement, especially in light of the limited availability of detailed risk data. Even today, while statistical and modeling tools have improved, risk projections remain uncertain, particularly in the context of climate change. This complicates the ability to forecast where and how natural disasters will occur in the future. A premium structure heavily reliant on historical loss data may therefore give a misleading signal about future risk.

Second, there are concerns about the fairness and feasibility of fully risk-based pricing. In high-risk areas, actuarially fair premiums could become expensive for households, potentially excluding them from the insurance market altogether. In early policy discussions, it was noted that such pricing could undermine the goal of ensuring broad access to affordable coverage. By spreading costs across all policyholders, the system avoids placing disproportionate financial burden on those who happen to live in risk-prone areas, particularly in cases where the choice of location is constrained by socioeconomic or historical factors.

Third, it has been argued that because natural disasters can occur with little warning and affect large areas, no region can be considered entirely safe. The original commissions behind the Norwegian insurance model emphasized that risk is to some extent ubiquitous and stochastic in nature, and that spreading the cost of rare, large-scale events across all insured parties promotes equity and social

cohesion.

Finally, the system has been designed to complement, rather than replace, public responsibility for long-term risk mitigation. While private insurers bear the financial cost of insured damages, land-use planning and infrastructure investments remain central to reducing overall exposure.

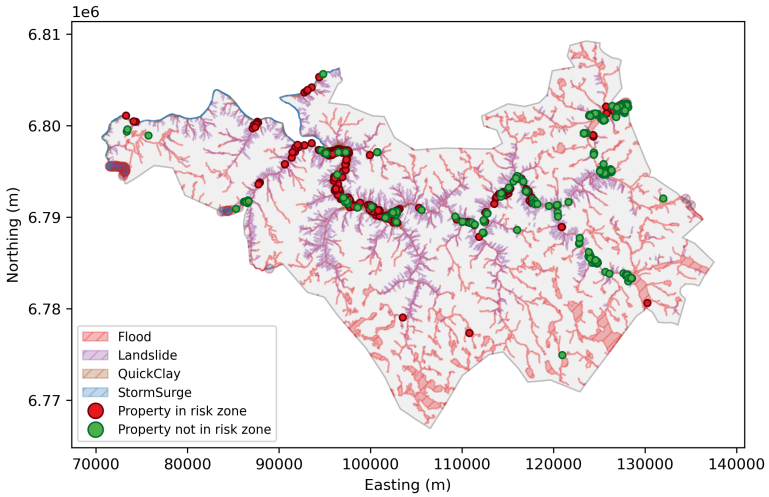
Despite its strengths in maintaining universal coverage, the system has faced criticism. The solidarity principle reduces incentives for households to invest in risk-reducing measures, and may encourage inefficient location choices. Moreover, it weakens the economic signals needed to guide adaptation and prevention. Still, these critiques have not led to reform of the fundamental principle of uniform pricing model, as its underlying principles have so far remained outside the scope of past policy reviews.

In sum, Norway offers an example of how uniform pricing and risk pooling can ensure widespread coverage, albeit with trade-offs in terms of efficiency and risk signaling.

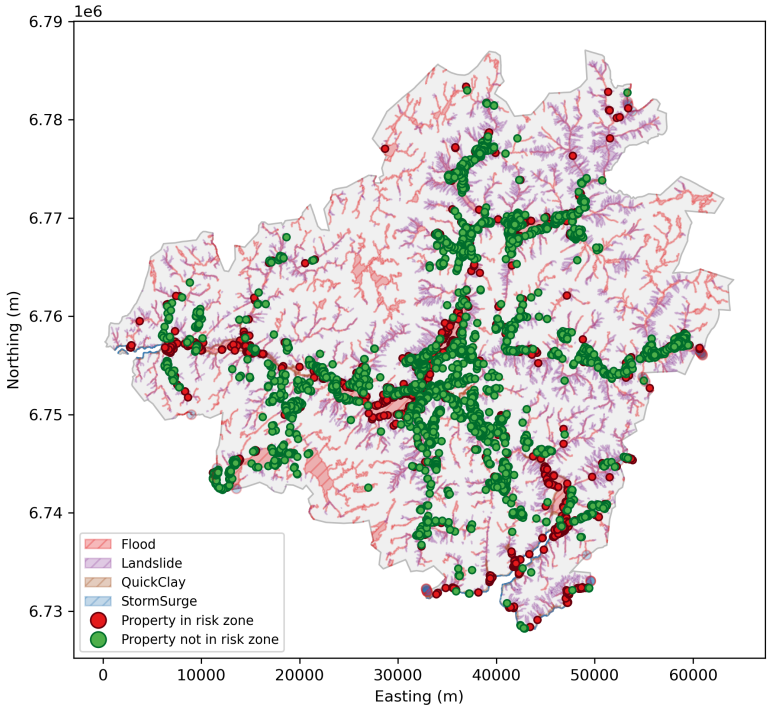
# 3 Data and Descriptive Statistics

This analysis combines detailed microdata on residential properties with spatial risk exposure and aggregated insurance payout data at the municipal level. The property dataset, sourced from Eiendomsverdi, covers all 2.6 million private residential dwellings in Norway as of 2024, including both primary residences and secondary homes. It also contains information on estimated market value, size, and other key characteristics. Using data from the Norwegian Mapping Authority, each property is assigned precise geographic coordinates, which allows for spatial analysis of exposure to natural hazards.

To determine whether a property is located in a high-risk zone, I combine this geospatial information with official hazard zone maps from the Norwegian Water Resources and Energy Directorate (NVE). These maps define risk zones for flooding, landslides (including quick clay areas), and storm surges. By overlaying property locations with these zones, I identify which properties are exposed to each type of hazard. Figure 1 illustrates two municipalities: Lærdal (Figure a), which has the highest proportion of total insured value located inside a flood zone (65 percent),




**(a)** The Municipality of Lærdal (approx. 2200 inhabitants)




**(b)** The municipality of Voss (approx. 16 500 inhabitants)

**Figure 1:** Hazard maps with overlaid property locations, distinguishing between properties inside and outside the risk zones, for the municipalities of Lærdal (a) and Voss (b).

*Note:* All spatial coordinates refer to the EUREF89 / UTM Zone 33N coordinate reference system (EPSG:25833).

and Voss (Figure b), which has a notably lower proportion of around 9 percent.

To calculate the insured value of each property, I apply standardized valuation tables provided by the Norwegian Natural Perils Pool (Norsk Naturskadepool)[2]. These tables are used by non-life insurance companies and property firms to estimate and update the replacement value of buildings, contents, and equipment in line with cost developments. They specify typical construction costs per square meter in different regions of the country. To calculate the insured value, I multiply the size of the property by a building-type-specific square meter cost and apply a location factor to account for regional variation in construction costs.

Historical loss data is sourced from Finance Norway, which provides a complete record of insurance payouts for natural perils across all Norwegian municipalities from 1980 to 2024. The dataset includes the number of claims, the type of affected property, the total compensation amount (including both paid and reserved payouts), and the specific cause of damage, such as storm, flood, or landslide. The ability to distinguish losses by hazard type is particularly important for this analysis. When focusing on flooding, I use the subset of payouts caused by flood events to calculate municipal-level loss ratios.

Since the payout data is only available at the municipality level, I aggregate the property-level dataset accordingly. For each municipality, I calculate the share of total insured residential value located within designated flood zones. A national overview is presented in Figure 2, which maps this share across all municipalities in Norway.

[2]The standardized valuation tables can be found here.

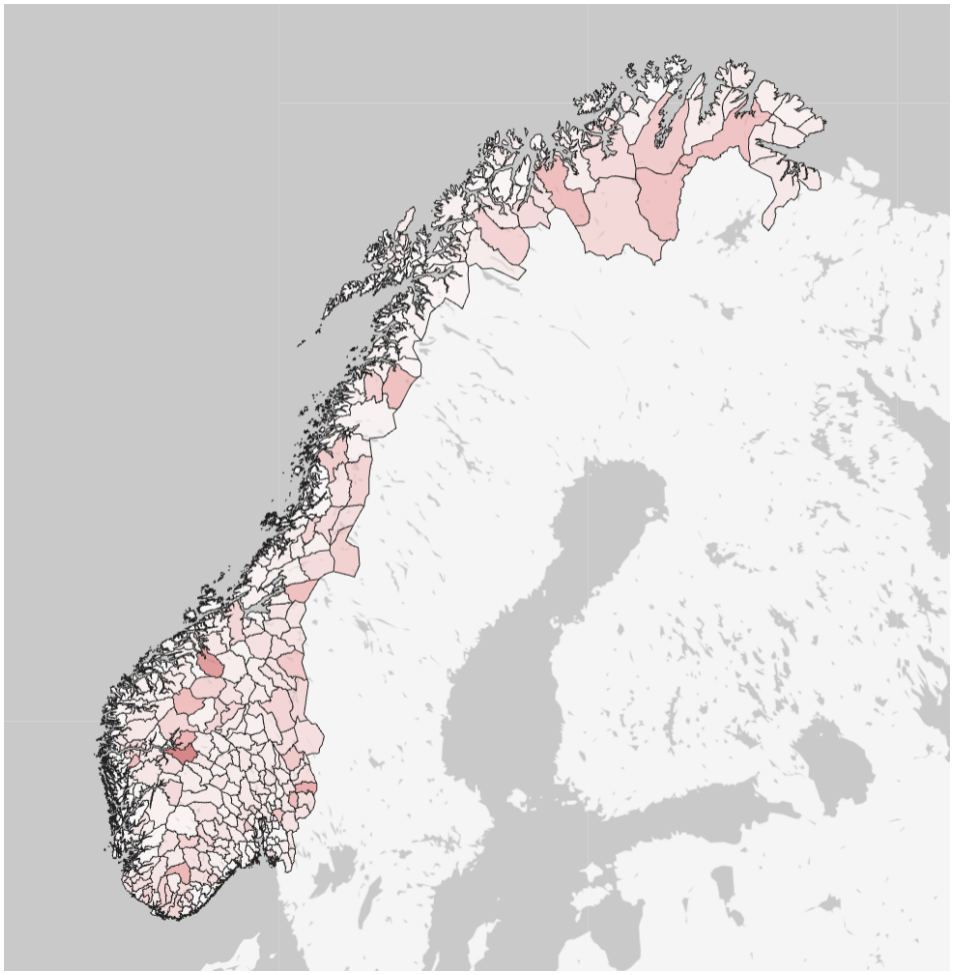


**Figure 2:** Share of insured residential property value located in mapped flood zones, by municipality. Darker red shades indicate higher exposure (0–65 %).

*Note:* Municipality boundaries are based on illustrative data from GeoNorge.

Table 1 summarizes the number of claims and payout volumes for each hazard type. Storm is the most frequent and costly cause of damage, followed by flood and landslides. In total, flood-related events account for roughly one-third of all payouts. Although rare, storm surges have also caused significant losses in monetary terms. Events such as earthquakes, tsunamis, and meteorite impacts are extremely rare and account for a negligible share of the total.

The combination of property-level exposure and municipality-level insurance losses allows for a unique analysis of the link between physical hazard exposure

**Table 1:** Insurance Payouts by Natural Hazard Type, 1980–2024

| Hazard Type | Number of Claims | Share (%) | Payouts (2024 MNOK) |
|---|---|---|---|
| Storm | 308,601 | 47.9 | 19,088.3 |
| Flood | 65,786 | 32.3 | 11,553.6 |
| Landslide | 16,035 | 15.3 | 4,920.3 |
| Storm surge | 19,299 | 4.5 | 1,871.1 |
| Other | 1,256 | 0.0 | 22.1 |

and observed insurance payouts over time. This forms the basis for the empirical identification of loss ratios in flood-exposed versus non-exposed areas.

# 4 Research Design

## 4.1 Definitions

In Norway, natural damage insurance is priced at a single, uniform rate. This rate is chosen to be actuarially fair at the national level, meaning that total premium income should equal total expected losses.

In practice, natural damage insurance is priced as a proportion of the insured value. Let $\rho$ be the premium rate per kroner of insured value (the loss ratio), and let $\sum_i S_i$ be the total insured value across all municipalities. If $X_i$ is the random variable representing the insurance loss in municipality $i$, then the uniform premium rate $\rho$ can be interpreted as the expected national loss ratio, i.e. the average expected claim per krone of insured value across all municipalities:

$$\rho = \frac{\mathbb{E}[\sum_i X_i]}{\sum_i S_i}$$

Using hazard maps, I identify the precise geographic location of all residential properties in Norway and determine whether each property falls within a designated risk zone. For each property, I calculate the insured value, allowing me to compute the total insured value within and outside the risk zone for each municipality. For each municipality $i$, let $S_i^r$ denote the total insured value of properties located

inside the risk zone, and $S_i^n$ the total outside the risk zone, so that the total insured value in the municipality is $S_i = S_i^r + S_i^n$. I then define the municipality-level share of exposure in risk zones as

$$f_i = \frac{S_i^r}{S_i},$$

Since both premiums and expected losses scale proportionally with insured value, $f_i$ serves as the appropriate weight when averaging per-krone loss rates across the two zones.

At the national level, let $\rho^r$ be the average loss ratio within the risk zones, and $\rho^n$ the corresponding outside risk zones. Under the assumption that expected loss per krone is constant within each zone, the expected loss ratio in municipality $i$ can be expressed as a weighted average:

$$\rho_i = f_i \, \rho^r + (1 - f_i) \, \rho^n.$$

Aggregating across all municipalities, the national loss ratio becomes:

$$\rho = \frac{\sum_i S_i^r}{\sum_i S_i} \, \rho^r + \frac{\sum_i S_i^n}{\sum_i S_i} \, \rho^n.$$

The national rate is simply assumed to be a weighted average of the within-zone loss ratios, where the weights correspond to each zone's share of total insured value.

## 4.2 From Definitions to Estimation

Let $\bar{X}_i$ denote the average insurance payout in municipality $i$, computed over the full sample period. Under the assumption that this sample average approximates the expected annual loss, I treat $\bar{X}_i \approx \mathbb{E}[X_i]$, where $X_i$ is the annual loss in municipality $i$.

Given that the total insured value in municipality $i$ is $S_i = S_i^r + S_i^n$, actuarial fairness implies that expected payouts equal expected premiums:

$$\bar{X}_i = \rho_i S_i$$

Dividing both sides by $S_i$ yields an empirical estimate of the expected loss ratio:

$$l_i \equiv \frac{\bar{X}_i}{S_i} = \rho_i = f_i\,\rho^r + (1 - f_i)\,\rho^n$$

where $f_i$ is the share of total insured value located in risk zone, as defined above. The variable $l_i$ thus serves as an empirical proxy for the expected loss ratio in municipality $i$. Interpreting $\bar{X}_i$ as the expected loss and assuming that $\rho^r$ and $\rho^n$ are constant across municipalities, I estimate the relationship using a linear regression of $l_i$ on the share of insured value located in the risk zone, $f_i$:

$$l_i = \beta_0 + \beta_1\,f_i + \varepsilon_i, \qquad \beta_0 = \rho^n, \quad \beta_1 = \rho^r - \rho^n.$$

where $\varepsilon_i$ captures idiosyncratic deviations. Cross-municipality variation in $f_i$ thus identifies the differential loss rate $\rho^r - \rho^n$, which reflects the magnitude of the implicit subsidy embedded in uniform pricing.

## 4.3 Estimation Strategy

The baseline specification is an ordinary least squares (OLS) regression, where the dependent variable is the loss ratio at the municipality level, defined as average historical payouts divided by the total insured value. This is regressed on the share of insured value located in mapped flood zones within each municipality.

Under the assumptions laid out in the previous section, this regression provides an empirical strategy for identifying the average loss ratio inside and outside flood zones, $\rho^r$ and $\rho^n$, based on variation in risk exposure across municipalities. The intercept $\beta_0$ captures the average loss ratio in non-flood areas $\rho^n$, while the slope, $\beta_1$ identifies the differential loss rate in flood zones, $\rho^r - \rho^n$.

Diagnostic tests (e.g. Breusch–Pagan) indicate that residual variance is not constant across municipalities. To account for this, I compute HC3 robust standard errors, which adjust for heteroskedasticity without altering point estimates.

The municipality Lærdal with largest share of insured value located in flood zone, see Figure 1, shows extreme influence, both in terms of leverage and Cook's distance. Although I explore how results change when dropping this observation, it reflects real exposure and is not a data error. I therefore complement OLS with

robust regression using Huber's M-estimator, which automatically downweights high-influence observations while preserving the rest of the data. This method is implemented via iteratively reweighted least squares (IRLS), and is an approach that offers a compromise between bias and efficiency.

Next, I assess the presence of spatial dependence. Using a queen-contiguity spatial weights matrix, I compute Moran's $I$ statistic for the OLS residuals. The result indicates statistically significant positive spatial autocorrelation. That is, municipalities with high residuals tend to cluster geographically, violating the assumption of independently distributed errors.

To address this, I estimate two types of spatial regression models. The first is the Spatial Error Model (SEM), which accounts for spatial autocorrelation in the unobserved error component. The model is defined as

$$\mathbf{y} = \mathbf{X}\beta + \mathbf{u}, \qquad \mathbf{u} = \lambda \mathbf{W}\mathbf{u} + \varepsilon,$$

where $\mathbf{W}$ is the spatial weights matrix, $\lambda$ measures the degree of spatial autocorrelation in the error term, and $\varepsilon$ is i.i.d. noise. The second is the Spatial Autoregressive Model (SAR), which allows for direct spillovers in the dependent variable across space:

$$\mathbf{y} = \alpha \mathbf{W}\mathbf{y} + \mathbf{X}\beta + \varepsilon,$$

where $\alpha$ captures spatial dependence in the outcome variable itself.

Both models are estimated using maximum likelihood, and standard errors are computed using HC3 corrections after transforming the regression equations accordingly. From a theoretical perspective, the SEM is particularly well-suited to this context, as it allows for unobserved spatially correlated factors, such as geology or infrastructure quality, to influence losses through the error structure. In contrast, the SAR model would be appropriate if the dependent variable (i.e., insurance payouts relative to insured value) in one municipality directly affected the same outcome in neighboring areas. This would require spatial dependence in the outcome itself. However, in this setting, spatial correlation is more plausibly located in the explanatory variable (i.e., the share of insured value located in flood zones).

In sum, the estimation strategy progresses from a simple OLS specification

toward increasingly robust and spatially aware models. This layered approach allows for careful assessment of the empirical relationship between mapped natural hazard exposure and observed insurance losses.

# 5 Results (Preliminary)

To estimate the actuarially fair premium for flood risk, I compute the average national loss ratio for flood-related insurance payouts. This is done by dividing the total historical flood payouts by the total insured value across all municipalities:

$$\rho^{\text{flood}} = \frac{\sum_i X_i^{\text{flood}}}{\sum_i S_i}$$

This expression yields the national expected loss per krone of insured value due to flooding, which represents the actuarially fair premium for flood damages under a uniform pricing system. Empirically, I find that this value is approximately 0.03 per mille. This estimate makes intuitive sense, given that floods account for about 30 percent of all historical insurance payouts, see Table 1, while the total uniform premium across all natural perils is around 0.08 per mille. Of the approximately 2.6 million homes in Norway, about 193,500 (roughly 7.4 percent) fall within a designated flood risk area.

## 5.1 Primary Regression Specifications

In the baseline OLS model (1), the average loss ratio outside flood zones, $\rho^n$, is estimated at 0.0232 per mille, while the differential effect for flood zones, $\rho^f - \rho^n$, is 0.409. This implies a loss ratio, and thus a premium, in flood zones of approximately 0.432 per mille, notably higher than the uniform flood premium and over 18 times higher than in non-flood zones. The results are robust to heteroskedasticity-robust standard errors (model 2) and to excluding the outlier municipality of Lærdal (models 3). Although Lærdal has a disproportionate influence on the estimates due to a high share of insured value in flood zone, it is not a data error. As such, it is retained in the main specification, while exclusion serves as a robustness check. To address sensitivity to outliers, models (4) and (5) use robust linear estimation

(RLM) with Huber T weighting, showing smaller coefficients but still a significant effect.

**Table 2:** Regression Results (All coefficients in ‰)

| Model | $\beta_0 = \rho^n$ | $\beta_1 = \rho^f - \rho^n$ | Implied $\rho^f$ | Obs | $R^2$ |
|---|---|---|---|---|---|
| (1) OLS | 0.02322** (0.00785) | 0.409*** (0.0774) | 0.432 | 357 | 0.073 |
| (2) OLS (HC3) | 0.02322** (0.00736) | 0.409** (0.125) | 0.432 | 357 | 0.073 |
| (3) OLS (HC3) ex Lærdal | 0.01843** (0.00694) | 0.500*** (0.133) | 0.518 | 356 | 0.085 |
| (4) RLM Huber T | 0.01350*** (0.00173) | 0.257*** (0.0170) | 0.271 | 357 | – |
| (5) RLM Huber T (boot) | 0.01350*** (0.00214) | 0.257*** (0.0536) | 0.271 | 357 | – |

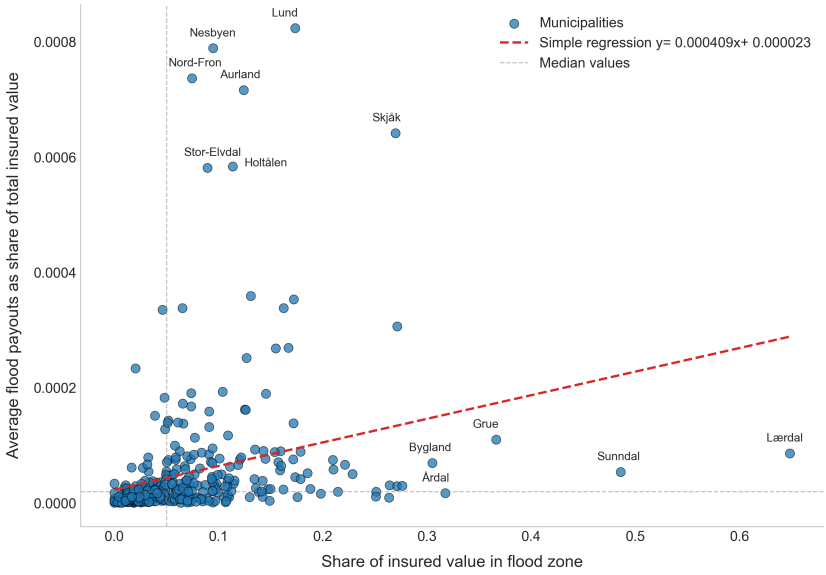
*Notes:* All coefficients and standard errors are reported in ‰ (per thousand NOK of insured value). Standard errors in parentheses. Significance levels: $^{*}p < 0.05$, $^{**}p < 0.01$, $^{***}p < 0.001$.

I also estimate a log-normal specification where the dependent variable is the logarithm of the loss ratio. The results confirm a strong positive relationship between flood exposure and payouts. Although the coefficients are not directly comparable to the main estimates, they reinforce the conclusion that loss risk increases with mapped flood exposure. The log-normal model also yields a higher $R^2$, which may reflect a better fit to the skewed distribution of the loss ratio.

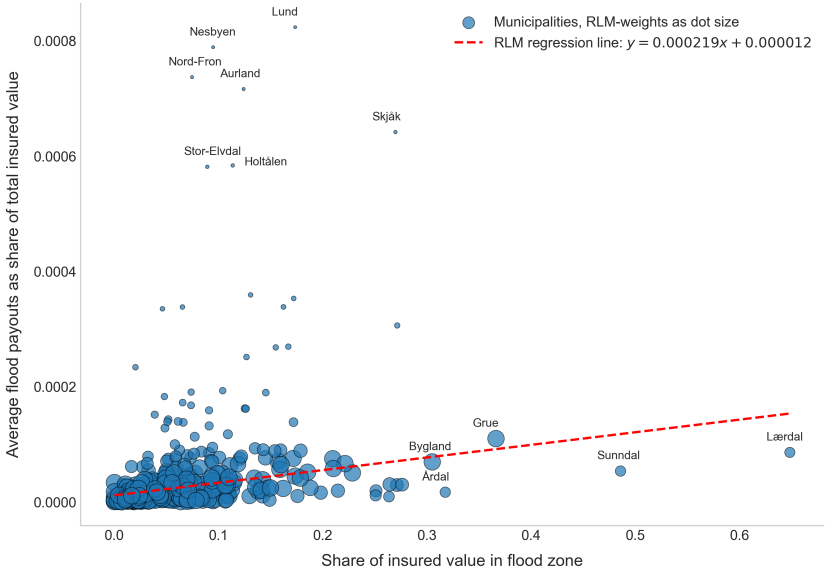
**Table 3:** Log-normal Regression (Robust SE)

| | $\beta_0$ | $\beta_1$ |
|---|---|---|
| | −10.21*** | 1.92*** |
| | (0.42) | (0.35) |
| Obs | 357 | |
| Pseudo $R^2$ | 0.234 | |

*Notes:* Dependent variable is $\log(l_i)$, the log loss ratio. Standard errors are HC3 robust. Coefficients indicate log-point changes; interpretation differs from the level-based models above. Significance levels: $^{*}p < 0.05$, $^{**}p < 0.01$, $^{***}p < 0.001$.




**(a)** Simple OLS




**(b)** Robust Linear Model (RLM)

**Figure 3:** Comparison of regression methods. Panel (a) shows a simple OLS fit between calculated loss ratios and flood zone exposure. Panel (b) presents results from a robust linear model (Huber estimator).

## 5.2 Spatial dependence

To test for spatial autocorrelation in the regression residuals, I compute Moran's I using a queen-contiguity spatial weights matrix. I find significant spatial dependence: the Moran's I statistic for the OLS residuals is 0.1251 (p-value = 0.004), suggesting that model errors are spatially clustered. In particular, municipalities with higher-than-predicted payouts tend to be located near other municipalities with similar patterns.

To account for spatial dependence in the regression residuals, I estimate a spatial error model (SEM), which captures unobserved spatially correlated factors through the error term. In this specification, the spatial autocorrelation parameter is estimated at $\lambda = 0.051$, and both coefficients remain significant: $\rho^n = 0.0267$ and $\rho^f - \rho^n = 0.363$, see Table 4. This suggests a persistent and economically meaningful difference in loss rates between flood and non-flood zones, even after accounting for spatial structure. Moreoever, the SEM specification effectively removes spatial autocorrelation in the residuals: Moran's I drops from 0.1251 in the OLS model to $-0.0003$ with a p-value of 0.40, indicating that the spatial error correction captures the omitted spatial structure.

**Table 4:** Spatial Error Model (SEM) Regression (‰ units)

| | $\beta_0 = \rho^n$ | $\beta_1 = \rho^f - \rho^n$ | Implied $\rho^f$ |
|---|---|---|---|
| | $0.0267^{***}$ | $0.363^{***}$ | 0.3897 |
| | (0.00827) | (0.134) | – |
| Spatial parameter $\lambda$ | | 0.051 | |
| Moran's $I$ (residuals) | | $-0.0003$ | |
| Obs | | 357 | |
| Pseudo $R^2$ | | 0.162 | |

*Notes:* All coefficients and standard errors are reported in ‰ (per thousand NOK of insured value). Heteroskedasticity-robust standard errors in parentheses. Significance levels: $^{*}p < 0.05$, $^{**}p < 0.01$, $^{***}p < 0.001$. Moran's $I$ computed on spatially filtered residuals.

For robustness, I also estimate a spatial autoregressive model (SAR), which allows for direct spillovers across neighboring municipalities. While the coefficients are similar, the SAR model is less theoretically appropriate in this context, as there is little reason to expect that insurance payouts in one municipality would causally

affect those in adjacent areas. For this reason, I focus on the SEM as the preferred specification.

While point estimates vary across specifications, the qualitative conclusion remains: flood-exposed municipalities face substantially higher realized loss ratios than other areas.

## 5.3 Magnitude of Implicit Subsidies

Table 5 summarizes the estimated ratio of loss ratios between flood and non-flood zones across all model specifications. These values provide a natural measure of the magnitude of the implicit cross-subsidy embedded in the uniform pricing regime. Across models, the implied risk in flood zones is consistently higher, but the estimates vary across specifications.

**Table 5:** Relative Loss Ratio Across Models ($\rho^f/\rho^n$)

| Model | $\frac{\rho^f}{\rho^n}$ |
|---|---|
| (1) OLS baseline | 18.61 |
| (2) OLS (HC3) | 18.61 |
| (3) OLS (HC3) drop Lærdal | 28.13 |
| (4) RLM Huber T | 20.02 |
| (5) RLM Huber T (boot) | 20.02 |
| (6) Log-normal (back-transformed) | 10.05 |
| (7) SEM | 14.60 |

*Notes:* Table shows the implied ratio of average loss ratios in flood vs. non-flood zones, $\rho^f/\rho^n$, from each model specification. The log-normal estimate is derived from back-transforming the coefficients using $\rho^n = \exp(\beta_0 + \sigma^2/2)$ and computing $\rho^f$ via marginal effect. SEM is estimated by maximum likelihood with HC3 robust standard errors.

In the baseline OLS model, the average loss ratio in flood zones is estimated to be about 18 times higher than in non-flood zones. Excluding the outlier municipality of Lærdal (model 3) increases this ratio substantially, to 28.13. Lærdal has an unusually high share of insured value located in flood zones, but only moderate

realized losses. Its position at the far right of the distribution, see Figure 3, flattens the estimated regression slope, thereby pulling down the implied flood-zone loss ratio. When Lærdal is excluded, the slope steepens, leading to a much larger estimated difference in expected losses between flood and non-flood areas.

Robust linear models (models 4 and 5) yield estimates very similar to baseline OLS. This suggests that Lærdal, despite having high leverage due to its extreme flood-zone exposure, does not have an unusually large residual and is therefore not strongly downweighted in the RLM estimation. However, the RLM procedure does downweight several other municipalities with large residuals relative to the regression trend, such as Lund, Nesbyen, Aurland, and Skjåk, which helps limit their influence on the slope estimate, see Figure 3. Overall, most municipalities conform to the central trend, which explains the similarity between the OLS and RLM results.

In contrast, the spatial error model (SEM, model 6) produces a lower ratio of 14.60. This is because it adjusts for spatial autocorrelation in the error term, recognizing that geographically proximate municipalities often share unobserved characteristics that jointly influence both flood exposure and losses. By absorbing these shared effects into the spatial error term, the SEM model attributes less of the variation in loss ratios directly to flood zone exposure.

The log-normal specification offers a complementary perspective by modeling the logarithm of the loss ratio. To interpret the results on the original scale, I compute the expected loss ratio in non-flood zones as $\rho^n = \exp(\beta_0 + \sigma^2/2) = 0.02508$ per mille, where $\sigma^2$ is the residual variance. The marginal effect of full flood exposure is then $\beta_1 \cdot \rho^n = 0.22695$, implying an expected flood-zone loss ratio of $\rho^f = 0.25203$ per mille. This yields a relative ratio of $\rho^f/\rho^n \approx 10.05$. While this estimate is lower than those from OLS or RLM models, it still suggests a tenfold increase in risk for flood-exposed properties.

Across model specifications, the estimated loss ratio in flood zones is consistently much higher than in non-flood areas. Based on the spatial error model (SEM) reported in Table 4, the average loss ratio in flood zones is approximately 0.39 per mille, compared to 0.027 per mille in non-flood zones. For reference, the current uniform national premium for natural damage insurance is 0.08 per mille, of which about 0.03 per mille is allocated to flood risk. Using the SEM estimates,

a risk-based premium for a property located in a flood zone would be 0.39 per mille – more than 13 times higher than the current uniform flood premium. For a typical home insured for 5 million NOK (approx. 480,000 USD), this would imply an annual flood-related premium of nearly 1,950 NOK (approx. 187 USD), compared to about 150 NOK (approx. 14 USD) today. In contrast, the implied premium for homes outside mapped flood zones would be around 135 NOK (approx. 13 USD), reflecting their much lower expected loss. These figures underscore the magnitude of the implicit cross-subsidy embedded in the current pricing system, where properties in low-risk areas effectively subsidize those in high-risk zones.

# 6 Conclusion

This paper sheds light on the implicit cross-subsidization embedded in Norway's natural damage insurance scheme, where a uniform premium is charged regardless of location-specific risk. Using detailed data on property-level exposure and municipal-level insurance payouts, the analysis shows that actuarially fair premiums in flood-exposed areas would be between 14 and 20 times higher than in non-flood zones. This implies a substantial implicit transfer from low-risk to high-risk households, one that is not reflected in current pricing signals.

These findings have broader implications. As climate change increases the frequency and severity of natural hazards, the magnitude of these implicit subsidies is likely to grow. Without reform, the current system weakens important signals that households need to assess and respond to climate-related risk. It may also distort housing market incentives, encouraging overinvestment in vulnerable areas and increasing long-term exposure for both households and financial institutions.

From a policy perspective, this analysis highlights important trade-offs between solidarity and efficiency in climate insurance design. While uniform pricing ensures broad access and simplicity, it may undermine resilience if it weakens incentives for mitigation or masks risk differentials. Future reforms could explore hybrid approaches that preserve core solidarity principles while introducing partial risk-based pricing or targeted incentives for adaptation.

The findings also contribute to ongoing policy discussions on how to design climate risk insurance under rising hazard exposure. Within Europe, interest is

growing in more coordinated approaches, including proposals for EU-level public–private reinsurance. While institutional contexts differ, the Norwegian case offers relevant insight into the trade-offs between distributive fairness, efficiency, and risk signaling.

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