Heterogeneous insurers and aggregate climate fluctuations

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Extended abstract

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Abstract

Property insurers in the U.S. provide over $15 trillion in multi-peril insurance coverage annually to homeowners. The insurance industry is under stress due to natural disasters that cause record-level claim payouts, driving several insurers to exit or lower coverage in disaster-prone areas. While such exits limit insurers' financial exposure to climate shocks, they make communities more vulnerable to climate disasters. Society faces the challenge of jointly maintaining economic stability, by offering disaster insurance, and financial stability, by minimizing insolvency and related fire sale risks. This balancing act requires an understanding of how the supply of disaster insurance, disaster realizations, and market volatility co-move in the economy.

In this paper, I examine how the *distribution* of insurer size affects the co-movement between disaster insurance supply, disaster realizations, and market volatility. I develop a macroeconomic heterogeneous agent model in which insurers are individually exposed to disaster shocks but connected in asset markets through fire sale spillovers. Furthermore, I provide complementary empirical analyses that aim to establish the relevance of insurer heterogeneity in disaster insurance and corporate bond markets.

I argue that insurer heterogeneity is critical to reconcile climate-driven aggregate fluctuations in insurance and financial markets. The key intuition is that the *distribution* of insurer size matters for: 1) how sensitive individual insurers are to climate shocks, affecting aggregate insurance contraction following disasters, 2) insurance pricing efficiencies through economies of scale, and 3) the magnitude of fire sale spillover risks due to concentration in asset markets.

Broadly, the research objective is to understand the insurance market conditions that maximize the long-run supply of disaster insurance when insurers are individually fragile through their exposure to climate risk and jointly connected in asset markets. The output of this research can be highly relevant to insurers, policy makers and central banks for whom climate-driven insolvency risks and market volatility are high on the agenda.

1 Motivation

Property insurers in the U.S. provide over $15 trillion in multi-peril insurance coverage annually to homeowners (Jeziorski and Ramnath, 2021). The insurance industry is under stress due to natural disasters that cause record-level claim payouts[1], driving several insurers to exit or lower coverage in disaster-prone areas (Sastry et al., 2023). While such exits limit insurers' financial exposure to climate shocks, they make communities more vulnerable to climate disasters. As global warming continues, society faces the challenge of jointly maintaining economic stability, by offering disaster insurance, and financial stability, by minimizing insolvency and related fire sale risks.[2] This balancing act requires an understanding of how the supply of disaster insurance, disaster realizations, and market volatility co-move in the economy.

In this paper, I examine how the *distribution* of insurer size affects the co-movement between disaster insurance supply, disaster realizations, and market volatility. I argue that insurer heterogeneity is critical to reconcile these climate-driven aggregate fluctuations. The key intuition is that the *distribution* of insurer size matters for: 1) how sensitive individual insurers are to climate shocks, affecting aggregate insurance contraction following disasters, 2) insurance pricing efficiencies through economies of scale, and 3) the magnitude of fire sale spillover risks due to concentration in asset markets, which reduces liquidity. An economy with larger insurers on average is better insulated against idiosyncratic climate shocks and prices risks more efficiently, but creates illiquidity in asset markets, which increases fire sale spillover risks. The *distribution* of insurer size thus introduces trade-offs for economic and financial stability.

My paper has three main contributions. First, I aim to jointly explain the economic and financial stability implications of disaster insurance. Koijen and Yogo (2022) and Ellul et al. (2022) study the financial stability implications of life insurers' product and investment decisions in an equilibrium framework. To the best of my knowledge, no paper thus far has investigated the joint behavior of insurers in product and financial markets in a climate setting. In Koijen and Yogo (2022) and Ellul et al. (2022), life insurers are exposed to systematic (market) risk, while I consider idiosyncratic climate risk as in Fried (2022), which, although imperfectly, can be diversified by selling more policies in different geographies.[3] Larger insurers are better able to diversify idiosyncratic climate risk, yet such diversification benefits do not apply to market risk that affects a life insurer's entire

[1] Insured losses from natural disasters amounted to $140bn in 2024 (MunichRE, 2025).

[2] Fire sales can occur when insurers' liquidity needs for paying out claims or maintaining capital ratios drive insurers to sell assets below their intrinsic values.

[3] Full diversification of climate risk is unrealistic since climate shocks tend to be spatially correlated.

portfolio. This setup introduces novel dynamics and makes the distribution of insurer size relevant. Second, existing studies investigating the financial stability implications of insurers' product and market decisions tend to feature a representative intermediary. I fill this gap in the literature by developing a disaster insurance equilibrium model in which heterogeneous insurers are individually exposed to disaster shocks but connected in asset markets through fire sale spillovers. Third, existing models that feature disaster insurance tend to assume an exogenous and fixed supply of disaster insurance (Fried, 2022), while disaster insurance supply in practice co-moves with disaster realizations. To fill this gap, I allow for disaster insurance supply to co-move with disaster realizations. As a starting point, I construct several novel empirical analyses that test the intuition and mechanisms embedded in the model.

Consider an economy in which insurers of heterogeneous size offer disaster insurance to households. Households experience climate shocks, posing a form of idiosyncratic risk to insurers that they cannot perfectly diversify. To motivate the relevance of insurer heterogeneity, I elaborate on three channels.

First, larger insurers, through their ability to diversify climate risk geographically, are better insulated against idiosyncratic climate shocks than smaller insurers. To understand the resulting implications for aggregate insurance supply, I introduce the concept marginal propensity to insure (MPI). MPI captures the sensitivity of the quantity of sold insurance policies to changes in insurer net worth. Smaller insurers operate closer to binding constraints, are more vulnerable to idiosyncratic climate shocks and their insurance decisions are more responsive to changes in net worth. Hence, MPI decreases in insurer net worth. The overall economy-wide MPI critically depends on both the size distribution of insurers and insurer-level MPI and therefore matters for how insurance supply changes in response to disaster shocks.

Second, insurer size predicts pricing granularity: the ability of insurers to distinguish between low- and high-risk policyholders. An insurer's investment in granular pricing technologies is more likely to have a positive net present value (NPV) when the insurer can spread the investment over a larger base of policies. A larger insurer is thus more likely to undertake such an investment.[4] Risk-based pricing of climate risks is required to compensate insurers on average for climate losses and matters for how financially fragile insurers are to climate change. Pricing granularity furthermore reduces adverse selection issues and it provides the incentives to policyholders to adapt to climate change (Wagner, 2022). Boomhower et al. (2024) confirm both empirically and theoretically that

[4]Another argument for why pricing granularity increases in insurer size is that a Bayesian insurer can reduce pricing errors more when the number of claims it learns from is larger.

the insurers with the largest market share adopt and use more sophisticated risk information in wildfire insurance markets. The distribution of insurer size, through the capacity of individual insurers to price risks accurately, therefore determines whether insurers are adequately compensated for climate losses on average.

Third, scale at the insurer level drives market concentration under a constant supply of insurance. Since insurers invest their proceeds from their operations in asset markets, I hypothesize that concentration in the product market leads to ownership concentration in asset markets to which insurers have shared exposures. Ownership concentration in the bond market is associated with lower liquidity and increased volatility (Huang et al., 2024; Li and Yu, 2022).[5] Insurers sell off assets to meet claim pay outs following disasters. When the asset market in which insurers operate is less liquid, sales will put more downward pressure on asset prices. Since insurers are subject to regulatory capital constraints, such downward price pressure could enforce other insurers to also sell assets to meet minimum reserves. Hence, insurer concentration in disaster insurance markets could increase fire sale spillover risks and affects financial fragility. Insurance companies hold a large fraction (≈40%) of the corporate bond market (Koijen and Yogo, 2023). Moreover, insurers are responsible for 62% of corporate bond trading in the secondary market (Kubitza, 2021). Studying how fire-sale spillover risks vary with insurer concentration in the corporate bond market is therefore a natural starting point.

In sum, this paper aims to investigate the role of insurer heterogeneity for the trade-off between the economic stability benefits that disaster insurance markets provide and aggregate insolvency and fire sale risks in financial markets. Broadly, the research objective is to understand the economic conditions that maximize the long-run supply of disaster insurance when insurers are individually fragile through their exposure to climate risk and jointly connected in asset markets. To answer this question, I first construct several novel empirical analyses that aim to establish the relevance of insurer heterogeneity in disaster insurance and corporate bond markets. Moreover, I develop a macroeconomic heterogeneous agent model. The main purpose of the model is to investigate how the hypothesized channels unfold in equilibrium.

[5] Li and Yu (2022) observe a significant level of concentration in the corporate bond market, with a median of just 47 investors for U.S. investment-grade bonds and find that bonds with lower investor concentration are more liquid. During periods of financial stress, bonds with less concentrated investor bases experience more substantial price drops on impact but subsequently recover more rapidly. Relatedly, Huang et al. (2024) find that more concentrated mutual fund ownership is associated with higher volatility of corporate bonds.

2 Related literature

This paper relates to different strands of the literature. First, I contribute to the literature studying how insurers affect financial stability. This literature studies insurers' joint behavior in product and asset markets, investigating how insurer liabilities affect trading behavior in asset markets under regulatory capital constraints. For example, Ellul et al. (2022) show that life insurers, through the sale of variable annuities, driving them to invest in illiquid corporate bonds, can contribute to system-wide fire sale risk. Koijen and Yogo (2022) show how financial frictions and market power drive the fragility of variable annuity markets, exposing insurers to significant risks during economic shocks. Chodorow-Reich et al. (2021) show that life insurers act as insulators during periods with transitory dislocations in market prices but not during crises. Knox and Sørensen (2024) develop a theory that connects insurance prices, insurance companies' investment behavior, and equilibrium asset prices. Jung et al. (2023) develop an approach to estimate climate beta for insurers using stock returns. To the best of my knowledge, no paper has investigated insurers' joint behavior in product and asset markets in an equilibrium framework that features climate change. I fill this gap by developing a model where insurers are individually exposed to disaster shocks but connected in asset markets through fire sale spillovers.

Second, my paper relates to the literature studying how heterogeneity between financial intermediaries affects the macroeconomy. While existing models typically feature a representative insurer, I contribute to the literature by allowing for heterogeneity in insurer size. I hypothesize that insurer heterogeneity is important to reconcile aggregate fluctuations in insurance supply, disasters, and market volatility. In a banking context, Coimbra and Rey (2024) develop a dynamic macroeconomic model and highlight a tension between economic and financial stability that arises from the risk-shifting behavior of the cross-section of financial intermediaries. Relatedly, Jamilov and Monacelli (2023) study how bank heterogeneity affects the macroeconomy. Goldstein et al. (2024) show that bank heterogeneity reduces financial fragility. While Goldstein et al. (2024) look at different sources of systematic risk, I look at a single source of undiversifiable idiosyncratic risk. Moreover, while Coimbra and Rey (2024) and Goldstein et al. (2024) define heterogeneity in terms of differences in risk-taking and exposures across banks, I look at heterogeneity in insurer size. Furthermore, the model of Goldstein et al. (2024) does not take a stance on what happens to aggregate credit supply when banks become more heterogeneous. In my setup, I allow for time-varying availability of disaster insurance, thereby affecting economic stability. In doing so, I relax the assumption of a fixed and exogenous supply of insurance in existing climate models that feature

insurance (Fried, 2022).

Third, my paper relates to the literature on the pricing of climate risks in insurance markets. This literature studies how insurers price climate risks, the implications for policyholder behavior, and how regulations can distort efficient pricing of climate risks. Oh et al. (2022) find that insurance rates charged on properties decouple from their underlying risks, with insurers cross-subsidizing high friction states by raising rates in low friction states. Boomhower et al. (2024) documents significant heterogeneity in insurers' pricing strategies in the U.S. market for wildfire risk insurance. Insurers with a lower market share have less granular pricing strategies and primarily sell insurance to high-risk policyholders. Van der Straten (2023) finds that disaster insurance reduces adaptation. Sastry et al. (2023) find that following increased physical climate risks, highly rated insurers are replaced by lower-rated insurers. Sastry et al. (2024) find that climate under-insurance is driven both by responsive borrowers reacting to rising premiums and behavioral inertia. Blonz et al. (2024) find that households with subprime credit pay 30% more for home insurance than individuals with super-prime credit. Ge et al. (2024) find that higher premiums increase the probability of mortgage delinquency. Fried (2022) finds that the availability of disaster aid reduces adaptation through moral hazard. Wagner (2022) finds that the willingness to pay for flood risk is remarkably low. I contribute to this literature by investigating how insurer market concentration affects the pricing of climate risks and the resulting implications for financial stability. Importantly, in a model extension, I allow policyholders to contract adaptation investments through insurance rates. Policyholders can lower insurance rates by investing more in adaptation, which reduces the damage upon disaster arrivals. Kousky (2019) highlight the potential of using insurance premiums as an incentive for risk reduction. However, there is no evidence quantifying the importance of this channel. My empirical analyses and model contribute to this question.

Lastly, I contribute to the literature studying how the operating conditions of insurers affect their investment behavior in asset markets. Ge et al. (2024) find that insurers that become more constrained due to climate shocks shift towards safer bonds. Chen et al. (2020) study how operating risk from underwriting insurance policies affects insurers' risk-taking behavior in their portfolio investments. I contribute to this literature by modeling the fire sale spillover risks in corporate bond markets as a function of market concentration in the insurance sector.

3 Methods and output

I split my analysis into two parts. I first develop several empirical analyses to establish the relevance of insurer size heterogeneity in climate insurance markets. Specifically, I analyze: 1) how changes in disaster insurance supply following disasters vary by insurer concentration, 2) how the efficiency of pricing climate risks in insurance markets varies by insurer concentration, 3) how regional adaptation by households and firms to climate changes varies by insurer concentration, and 4) how concentration in product markets affects concentration in corporate bond markets and fire sale spillover risks. The outcomes of these analyses serve as stylized facts and the parameter estimates inform the inputs of the heterogeneous agent model, which forms the second part of my analysis.

3.1 Empirical analyses

I now proceed by explaining how I aim to construct the four empirical analyses. First, I investigate how changes in disaster insurance supply following disasters vary by insurer concentration. The hypothesis is that larger insurers are better insulated against idiosyncratic disaster shocks and, hence, their supply is less sensitive to local shocks. This analysis regresses the change in the log number of insurers in a state on disaster losses interacted by the average size of the insurer in this state. The analysis is conducted at the state-quarter level. I cannot use premiums as a dependent variable since premiums can be driven by both coverage and rate changes, while I am interested in the effect of disasters on the supply of insurance and how this relationship varies with insurer concentration. Although imperfect, the change in the number of active insurers in the market parsimoniously captures changes in insurance supply. I define an insurer's size as its total volume of premiums earned. I furthermore propose a difference-in-differences (DiD) design to compare changes in insurance supply between states struck by disasters with a concentrated insurance market (treatment), states struck by disasters without a concentrated insurance market, and states not struck by disasters (control).

I obtain insurer regional product-level premiums and losses at the quarterly frequency from National Association of Insurance Commissioners (NAIC) in the United States. To construct a measure of state-level climate disasters, I rely on two sources. First, I rely on the Spatial Hazard Events and Losses Database for the United States (SHELDUS), which offers monetary estimates of damages caused by every natural hazard event, including wildfires, hurricanes, tornadoes, and so on. The data available to me are aggregates at the state-quarter level. Insurers that offer property insurance

are exposed to such disasters. Second, I rely on EarthStat, which provides information on regional crop yields, and the ERA5-Land dataset, which provides granular information on local temperatures. Extreme heat reduces crop yields and creates losses for insurers who offer crop insurance. To construct a regional measure of climate-induced crop yield variation, I follow Hsiao et al. (2024) by relating crop yields to local temperature shocks.

Second, I investigate how the efficiency of pricing climate risks in insurance markets varies by insurer scale. While I do not observe the pricing behavior of insurers directly, I propose to infer whether insurers have priced climate risks accurately based on realized insurance losses. I argue that the sensitivity of an insurer's profitability to disasters depends on its ability to price disaster risks adequately. Adequate pricing of disaster risks ensures that the premiums earned by insurers on average compensate for climate losses. I can test the hypothesis that pricing granularity increases with insurer scale by testing how the sensitivity of an insurer's profitability to disasters varies by scale and time in the market. I regress an insurer's operating ratio, defined as incurred claims divided by earned premiums, on incurred disaster losses interacted with insurer scale. A key challenge will be to address reverse causality[6], for which quasi-experimental approaches such as DiD are relevant.

I calculate incurred disaster losses as the monetary loss from disasters multiplied by the insurer market share in the regional property insurance market. The regression is performed at the insurer-region-quarter level. Scale is the volume of premiums written in a product line across all regions and is defined at the insurer-product-quarter level. Since an insurer's losses can result from both incorrect pricing and realizations of tail risk, I need to control for aggregate disaster loss realizations. Controlling for total regional disaster losses allows me to assess how an individual insurer's sensitivity to disaster losses varies by scale while keeping ex-post aggregate disaster losses constant.[7] I also include the variable market share of the insurer in the regression to ensure that differing sensitivities to climate change are not driven by the ability to charge higher markups through market power.

Third, I investigate how regional adaptation varies with the level of insurer concentration in this region. Evidence of this channel would be consistent with a channel in which efficient insurance rates provide stronger incentives for adaptation. I measure regional adaptation by examining the relationship between the severity and frequency of climate losses which requires a time-series on the intensity of climate events and associated damage amounts in dollars. The data structure on

[6]Indeed, insurer size could induce pricing efficiencies, but pricing efficiencies could also help the insurer grow.
[7]Alternatively, the inclusion of state-quarter fixed effects fulfills the same purpose.

regional crop yields, extreme temperatures and insurer premium distributions allows me to infer adaptation. I regress regional crop yields on regional extreme temperature incidents interacted with time dummies and an indicator for whether the region has a concentrated insurance market. Evidence of adaptation over time requires the effect of extreme temperatures on yields to decrease over time. The interaction with insurance market concentration allows me to investigate how adaptation varies with the efficiency of insurance rates as incentives for adaptation. Importantly, I aim to control for variables that likely co-vary with adaptation and insurance supply, such as credit constraints.

Fourth, I investigate how insurer concentration affects the transmission of climate shocks in corporate bond markets. Specifically, I investigate how concentration in the product market affects concentration in the corporate bond market. The existing literature shows that bond ownership concentration correlates negatively with the liquidity of the bond (Huang et al., 2024; Li and Yu, 2022). Next, I analyze how climate shocks affect portfolio holdings and move equilibrium prices in corporate bond markets. Importantly, I investigate how this relationship varies with insurer concentration in the product market. I use corporate bond holdings from Thomson Reuters eMaxx and corporate bond returns from TRACE.

To strengthen the credibility of the analyses, I propose using two instruments. As a source of exogenous variation in market power, I could use other insurers' acquisitions and spinoffs as events. This instrument is relevant for the analysis on how changes in insurance supply following disasters vary with insurer scale. Moreover, I could instrument an insurer's regional premium growth by using an insurer's premium growth in the same product line in other regions. Premium growth in another region helps the insurer to learn about the risk and arguably price the same risk in another region better. Under the assumption that regional premium growth does not directly affect operating losses in another region, this allows for causally estimating the effect of insurer growth on the sensitivity to climate losses. This instrument is relevant for assessing how the efficiency of pricing climate risks in insurance markets varies by insurer scale.

3.2 Model

Insurer size heterogeneity introduces trade-offs for economic and financial stability. Using empirical analysis only, it is challenging to understand the sign of the different trade-offs and the implications for aggregate climate-driven fluctuations. The main purpose of the model is to investigate how the trade-offs unfold in equilibrium.

I aim to develop a dynamic heterogeneous agent model in an incomplete markets economy that

features idiosyncratic climate shocks. I adapt an Bewley-Huggett-Aiyagari (BHA) model. Fried (2022) uses the model to study household adaptation in response to idiosyncratic climate shocks. Furthermore, Jamilov and Monacelli (2023) use the model to study how bank heterogeneity affects the business cycle. My model closely builds on the model by Jamilov and Monacelli (2023). The main adjustments I make compared to previous work are introducing heterogeneous insurers[8] and a corporate bond market in which insurers invest. Introducing idiosyncratic climate shocks next to idiosyncratic labor shocks is relatively new and I borrow this setup from Fried (2022).

The economy hosts three types of agents: a continuum of heterogeneous insurers, a representative final good firm and a representative household. Time is discrete and infinite.

Insurers offer disaster insurance to households who experience disaster shocks. There are no other forms of insurance. Insurers cannot perfectly diversify their idiosyncratic climate risk exposure.[9] Insurers earn premiums from the insurance sold to households which they can invest in the corporate bond of a representative firm. Insurers operate under a regulatory risk-based capital constraint that enforces them to hold reserves. These reserves ensure that insurers can pay out claims in case of severe disaster losses or market draw-downs. Insurers decide each period on their insurance supply and how much to invest in the corporate bond. At the end of each period, insurers collect interest payments on the bond. In addition, insurers pay out claims from the disaster realizations that have occurred. If claims exceed the sum of the prior period reserves and current period earnings, insurers must liquidate part of their corporate bond holdings. Importantly, since the asset is illiquid, selling causes downward pressure on the bond price. This also affects other insurers who, due to lowering asset values, may also need to sell to comply with the regulatory constraint of the next period. The degree of bond illiquidity increases in market concentration. In equilibrium, the insurers whose premiums exceed claims buy the bonds from the selling insurers. A result is that a new equilibrium price of the bond emerges which affects insurers' next period asset values.

The model eliminates scale invariance: the decisions of insurers depend on insurer-specific net worth. I introduce the notion of MPI, which captures the sensitivity of the quantity of sold insurance policies to changes in insurer net worth. Larger insurers are better insulated against idiosyncratic climate shocks as they have a more diversified portfolio. An economy populated by primarily large insurers has a low average MPI.

[8] I do not simultaneously allow for heterogeneous households as this would create dimensionality problems.

[9] While larger insurers could reduce their exposure to climate risk through revenue or geographic diversification, climate shocks tend to be spatially correlated, making full climate risk diversification unrealistic.

I capture the granularity of pricing with a parameter that captures their efficiency of insurance. This parameter endogenously increases with scale: larger insurers identify better opportunities than smaller insurers. While a simplification, it allows for parsimoniously capturing pricing efficiencies in the model.

Households provide labor to firms and earn wages. Each period, the consumer forms beliefs about the probability of a climate shock occurring in the next period and decides on how much to consume and invest in a risk-free bond. Households consume the representative final good produced by firms in the economy. Productivity shocks affect wages earned and disaster shocks destroy a portion of households' wealth, increasing the marginal utility on consumption. While investing in a single risk-free asset is possible, I introduce a borrowing constraint such that households are imperfectly able to smooth consumption. Importantly, the degree to which households buy disaster insurance affects their wealth sensitivity to disasters. Disaster shocks affect consumption levels, firm profits and indirectly firms' ability to repay the bond. Insurers are therefore exposed to climate losses through sold insurance policies and their holdings in the corporate bond.

The representative final good firm uses labor and capital as inputs. Each period, the firm decides on how much labor to hire in the current period and how much to invest in capital for future production. It obtains financing through the corporate bond, which is issued in the first period. At the end of each period, the firm earns revenue, pays out wages and fulfills the periodic coupon and interest payment.

I aim to construct a recursive competitive equilibrium, which consists of the dynamics of the insurer size distribution, the insurer value and policy functions, policy functions for the household, such that, given a vector of aggregate pricing functions, a range of conditions hold.[10] I resort to dynamic programming techniques to solve the model numerically. Important steps in this process include discretizing the distribution of insurer size and idiosyncratic labor and climate shocks.

I next describe the outputs from the model. First, I aim to describe how the insurer policy function for disaster insurance supply varies with insurer net worth and idiosyncratic climate risk. Insurance supply is expected to be increasing in insurer net worth. Of primary interest is understanding how insurance supply varies in response to idiosyncratic climate risk for different distributions of insurer net worth. I can quantitatively examine how disaster insurance contraction following disasters varies under the actual and assumed counterfactual distributions of insurer net worth.

[10]Based on the existing literature, these conditions include: 1) the value and policy functions of all agents solve their respective decision problems; 2) the insurance distribution is consistent with the agents' optimization; 3) prices are determined by the first-order conditions; and 4) all markets clear.

A second output from the model is studying the co-movement between aggregate disaster insurance supply, insurer net worth, the value of the bond, total output in the economy and disaster realizations. The BHA model introduces ex-post insurer heterogeneity since insurers experience different idiosyncratic shocks even when insurers are ex-ante similar. In counterfactuals, I introduce ex-ante heterogeneity in the size distribution to understand how these aggregate fluctuations change.

Although the baseline model captures the main trade-offs behind economic and financial stability, I aim to extend the model in various ways. First, I allow for dynamic adaptation in response to insurance premia. Policyholders can contract adaptation investments through insurance rates. In this extension, households not only decide on consumption and savings, but also their investment into adaptation. Investment into adaptation reduces losses upon disaster realizations. It therefore also lowers insurance contraction following disasters, with the effect varying depending on insurers' individual MPI. An insurer's pricing granularity, which increases with scale, affects the insurers' ability to differentiate between low- and high-risk policyholders and therefore the feasibility of contracting adaptation.

Second, I relax the assumption of perfect competition and allow for market power. Market power allows large insurers to charge premiums above the actuarial fair price. While it provides insurers cushion to disasters, it makes policyholders more credit constrained, reducing their ability to adapt to climate change. Whether market power in disaster insurance markets improves financial stability is therefore ambiguous.

Third, I consider that regulators impose additional climate-related capital constraints on insurers to limit their exposure to natural disasters, which is currently a topic of discussion among central banks (Authority, 2021). While such capital constraints could reduce insolvency and fire sale risks, it likely disincentivizes insurers to offer disaster insurance and invest more in corporate bonds. Whether such additional capital constraints reduce financial stability risks is uncertain since it also depends on how much consumption is affected by disasters, which affects firm output and corporate bond returns.

Fourth, I allow for insurers' pricing strategies to not only depend on scale, but also through the disaster realizations it has experienced in the past. Specifically, I allow insurers to learn from past damages in a Bayesian framework. One argument for why insurer size predicts pricing granularity is that the insurer has a larger base of policies to learn from. Letting an insurer's pricing decision to be a function of historical losses allows me to differentiate between a learning channel and an

economies of scale channel that increases investments into pricing technology.

3.3 Practical value of the project

The output of this research can be highly relevant to insurers, policy makers and central banks for whom climate-driven insolvency risks and market volatility are high on the agenda.

The research is practically relevant to insurance companies as it provides them deeper insight into the origins of system-wide climate-driven financial fragility. In particular, it evaluates how insurer fragility is affected directly by climate disasters and indirectly through fire sale spillovers. The research furthermore challenges smaller insurers on whether they should compete in disaster-prone insurance markets. Smaller insurers' high sensitivity to idiosyncratic climate shocks and lack of granularity in pricing climate risk could weaken the stability of those insurers. They are more likely to service market segments that are adversely selected, which Boomhower et al. (2024) refer to as 'the winner's curse'. Smaller insurers who lack pricing granularity might fail to realize they are primarily selling insurance to low-risk types. Inaccurate pricing of climate risks in addition has adverse consequences for the broader market since a lack of risk-based pricing reduces incentives to adapt to climate change and furthermore prevents more sophisticated insurers to charge margins that adequately insulate them against climate risk. Showing how the sensitivity of insurers' performance to disasters varies across the size distribution informs important discussions at insurance companies.

This paper furthermore aims to equip central bankers with novel insights on the effects of additional climate-related capital constraints. Such capital constraints could reduce short-run financial fragility since it limits disaster insurance supply conditional on reserves. The long-run effects are however unclear since such capital regulation could threaten long-run bond returns through reduced consumption and production resulting from under-insurance to disasters. My model allows for investigating these dynamics.

Lastly, this paper is practically relevant to competition regulators. One aim of this paper is to understand the optimal level of market concentration that maximizes long-run disaster insurance supply while preserving financial stability. Traditional competition regulation limits how much market power individual insurers can enjoy. A possible outcome of this paper is that traditional competition regulation increases the financial fragility from climate change and inhibits insurers from learning about climate change.

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