Bailing Out Homeowners: Disaster Aid and Mortgage Default after Natural Disasters

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Abstract

Natural disasters pose significant challenges to homeowners, often resulting in large-scale government aid. As climate change increases the frequency and severity of these events, the effective disaster relief design becomes increasingly important. I present a structural general equilibrium approach to assess distributional consequences and welfare effects of post-disaster government aid. The model is the first to incorporate natural disaster shocks, that affect housing capital and the utility of housing services, in an incomplete market model with mortgage delinquency and foreclosures. I analyze the welfare effects of governmental disaster aid in a model calibrated to the U.S. in 2000-2020. I find that financial aid reduces private insurance by 10% and increases the housing stock in disaster-prone areas by 4%. Removing financial aid displaces more low-income households after natural disasters but generates the greatest welfare losses for high-income residents in risky regions. Recourse regulation plays a key role in shaping welfare outcomes. The highest welfare gains occur under the current policy design but with a strict recourse regulation, despite widening the insurance gap and further increasing housing in high-risk areas.

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1 Introduction

Over the past three decades, natural disasters have caused economic losses above $2.27 trillion in the U.S. (Smith 2023), with the federal government providing $347 billion in disaster aid through the Disaster Relief Fund during the same period (CBO 2022). U.S. housing is particularly vulnerable to natural disasters, with 1 in 10 U.S. residential properties impacted in 2021 (CoreLogic 2022) and only 42 percent of losses covered by private insurance (Swiss RE 2024)). Since home equity represents a median of 45 percent of homeowners' net worth (U.S. in 2021), property destruction poses a significant threat to household wealth. For mortgage borrowers, disaster-related shocks can lead to financial distress and potential default, particularly for low-income homeowners, though disaster aid can mitigate these effects (Gallagher & Hartley 2017, Kousky et al. 2020). U.S. disaster aid includes financial support, such as grants to affected homeowners, and non-financial measures, like foreclosure moratoria in disaster regions. Federally funded aid acts as a cross-subsidy, with low-risk areas supporting high-risk regions. Aid is proportional to damages, often favoring owners of larger properties, and is funded by all taxpayers, including non-homeowners. Both types of disaster aid create room for moral hazard by discouraging insurance uptake when governmental intervention is anticipated. Despite the urgency of this topic, there is no research on the effective policy design of disaster aid, particularly within a framework that considers mortgage default as a form of implicit insurance against shocks to home equity.

By analyzing the role of government disaster aid in a structural general equilibrium framework, my research aims to inform more effective policy responses in the face of growing physical climate risks. Specifically, I am addressing the following questions: What are the redistributive impacts of existing ex-post disaster aid on homeowners across different income levels and risk exposures? Which policy design best supports affected homeowners while minimizing the negative impacts of public disaster assistance, such as crowding out private insurance coverage and encouraging excessive housing development in disaster-prone areas? I provide a structural general equilibrium approach to address these questions, taking into account the interaction between disaster aid, foreclosure regulation, and private insurance. In an incomplete market framework, I model local housing markets that differ in their exposure to natural disasters. A natural disaster partially destroys housing capital, potentially leaving the homeowner with negative home equity and reducing the utility flow from housing services. Moreover, a natural disaster represents a significant expenditure shock, as homeowners are obliged to invest financial resources into the reconstruction of the damaged property, a process that takes one period to complete. Thus, a natural disaster shock is conceptually a 'double-trigger event', capable of precipitating mortgage defaults.[1] To protect homeowners from the adverse effects of natural disasters, the government provides regional ex-post disaster assistance, which is funded federally. This disaster aid is complementary to voluntary private insurance for homeowners. Since private insurance is only partial, there is room for government intervention. Additionally, agents benefit from implicit insurance through foreclosures and delinquencies, which allow mortgage holders to temporarily suspend payments without immediately facing foreclosure. The effectiveness of this implicit insurance depends on the severity of recourse following foreclosure. I calibrate the model to the U.S. economy and the disaster realizations over the last 20 years. The United States presents a particularly compelling case study due to its frequent encounters with devastating tropical storms, coupled with a substantial proportion of home ownership and a lenient recourse regime. In this framework, I analyze existing disaster aid and conduct the following policy counterfactuals: First, I examine the welfare effect of removing existing disaster aid, considering different recourse regimes. Second, I evaluate the impact of financial aid designs, comparing funding via income vs. housing taxation.

I find that financial aid reduces private insurance by 10% and increases the housing stock in disaster-prone areas by 4%. Removing financial aid displaces more low-income households after natural disasters but generates the greatest welfare losses for high-income residents in risky regions. Overall, welfare changes are modest, with the most significant shifts occurring in high-risk regions. Recourse regulation plays a key role in shaping welfare outcomes. The highest welfare gains occur under the current policy design but with a strict recourse regulation, despite widening the insurance gap and further increasing housing in high-risk areas. Financing disaster aid through a housing tax, rather than income taxation, primarily benefits high-income households.

In addition, I present empirical evidence on the financial responses of households following natural disasters over the past two decades in the United States. An intriguing picture emerges from the data: in the aftermath of natural disasters, delinquency rates spike while foreclosure rates move in the opposite direction. The absence of a direct transition from delinquencies to foreclosures can be attributed, at least in part, to the extensive government assistance provided following extreme weather events. Furthermore, the temporary suspension of mortgage payments may function as a form of quasi-insurance against sudden expenditure shocks. This highlights the critical importance of incorporating delinquencies into the model to accurately capture the observed patterns in mortgage performance after

[1]Households suffering from a combination of both negative equity and affordability shocks are more likely to default Foote et al. (2008). Ganong & Noel (2023) find that 70 percent of defaults are solely by negative life events and a quarter of mortgage defaults are double-trigger defaults.

natural disasters.

As I illustrate with the model, the disaster risk and the level of government support exerts a significant influence on four pivotal decisions made by households: housing tenure, house size, private insurance coverage, and mortgage payment. While government assistance shields homeowners against adverse effects by avoiding default and costly foreclosures, it might lead to an over-consumption of housing in disaster-prone regions and an under-insurance of homeowners. Taking into account their individual exposure to natural disasters and anticipated governmental assistance, households must consider whether to rent or purchase a residence. Homeownership offers additional utility from housing services but also exposes the homeowner to the risks associated with natural disasters. Home purchases are typically financed through long-term mortgages, which the homeowner may default on if unable to meet payment obligations. An agent who ceases making mortgage payments is not foreclosed upon with certainty, resulting in a status of non-performing homeowners. This state of delinquency provides mortgage holders with a form of quasi-insurance against sudden expenditure shocks, enabling them to temporarily suspend in mortgage payments. It allows them to allocate freed-up funds towards rebuilding efforts. However, entering delinquency carries the inherent risk of eventual foreclosure and subsequent eviction from the property. The destruction of a home by a natural disaster alters the incentives for mortgage holders considering delinquency: Given the diminished utility resulting from a destroyed home, foreclosure of a damaged property represents a comparatively smaller loss than eviction from an intact dwelling.

Ex-post governmental intervention mitigates the financial burden of natural disasters on affected homeowners, thereby enhancing the attractiveness of home ownership. This intervention is anticipated to lower mortgage default probabilities, which leads to reduced mortgage rates and an increased demand for homes. However, this heightened demand drives up house prices, thereby diminishing housing affordability. It is notable that disaster aid that is proportional to the house damage exhibit a regressive nature, whereby wealthier households with larger homes receive substantially larger grants. Lastly, disaster assistance affects default incentives: With a foreclosure moratorium in place, temporary nonpayment carries no downside risk for the mortgage holder. Furthermore, financial disaster assistance enables homeowners, who would otherwise be forced to sell their homes and become renters, to remain in their residences. These owners may need to temporarily suspend mortgage payments to finance rebuilding efforts. Consequently, both forms of disaster assistance may result in an increase in delinquencies without a corresponding rise in foreclosures.

The paper closely relates to three strands of literature. First, a literature that studies incomplete market models with mortgage default and foreclosures (Campbell & Cocco (2015), Chatterjee & Eyigungor (2015), Corbae & Quintin (2015), Hannon (2022), Mitman (2016), Kaplan et al. (2020)). My paper is the first to introduce natural disasters and disaster aid in such a setting.

Second, a literature that studies natural disasters in incomplete market models – yet, with a focus on disaster adaptation (Bilal & Känzig (2024), Bilal & Rossi-Hansberg (2023), Fried (2022), Van der Straten (2023)) or post-disaster rebuilding (Fu & Gregory (2019)).[2] Van der Straten (2023) analyses private adaptation incentives of homeowners to climate change in an overlapping-generations framework with financial constraints. However, the analysis is oriented towards a longer-term perspective and does not consider how disaster aid affects mortgage default. Fried (2022) quantifies the impact of disaster aid on (besides others) homeowners' adaptation investment to climate change in a general equilibrium model. The model does not take into account the role of mortgages and mortgage default. With my paper, I aim to fill this gap by integrating the dynamics of mortgage markets, including foreclosure and delinquency processes, and examining the ways in which these interact with disaster aid.

The final strand of literature relevant to my paper is the empirical research that quantifies the immediate impact of extreme weather events on mortgage performance and homeowners (Paxson & Rouse (2008), Gallagher & Hartley (2017), Du et al. (2020), Issler et al. (2020), Calabrese et al. (2021), Biswas et al. (2023)). While the majority of the literature finds only temporary or rather modest effects, these estimates obscure underlying heterogeneities. In particular, vulnerable households with pre-disaster low credit scores and/or low incomes are more significantly affected in their financial situation (Roth Tran (2020), Billings et al. (2022)). Additionally, the crucial role of insurance and governmental assistance in mitigating the consequences of natural disasters is emphasized (Gallagher & Hartley (2017), Kousky et al. (2020)). I contribute to this literature by providing a general equilibrium assessment of ex-post disaster aid.

The paper is organized as follows: I present an outline of the model environment, the calibration strategy and results, followed by the empirical exercise.

2 Model environment

Time is discrete and the total economy is populated by a measure one continuum of households. The model represents two region-types that differ regarding their exposure to natural disasters: a low risk type and a high risk type. In both regions, agents choose to be ei-

[2]More broadly, this paper relates to a growing literature on macro models with climate change and climate policies, such as Acemoglu et al. (2015), Barrage (2020), and Golosov et al. (2014).

ther homeowners or renters on the local housing market. House purchases can be financed by long-term mortgage contracts. Homeowners can default on these mortgages by missing mortgage payments. I explicitly allow for a period of mortgage delinquency in which a mortgage is non-performing but the house is not directly foreclosed. Agents face two sources of uncertainty: a persistent labor productivity shock and a natural disaster shock that temporarily disrupts housing services and requires rebuilding investment. Homeowners can buy one-period private insurance contracts to insure damages caused by natural disasters. Additionally, each region comprises a perfectly competitive final goods producer, a financial intermediary, a rental agency, a real estate construction company, and a rebuilding firm. Labor is perfectly mobile across sectors within a region but households cannot move between regions. The financial intermediary collects deposits from households and supplies secured loans to homeowners. The government maintains a balanced budget, raising labor income taxes and providing transfers and disaster aid to households. The government supports households by providing ex-post disaster assistance through grants and foreclosure moratoria. Foreclosure moratoria limit the ability of banks to foreclose the underlying collateral of non-performing mortgages. Additionally, the government sets the strictness of the recourse regime, which dictates the extent to which a foreclosed homeowner is held liable for outstanding mortgage debt. Figure 1 summarizes the model environment.

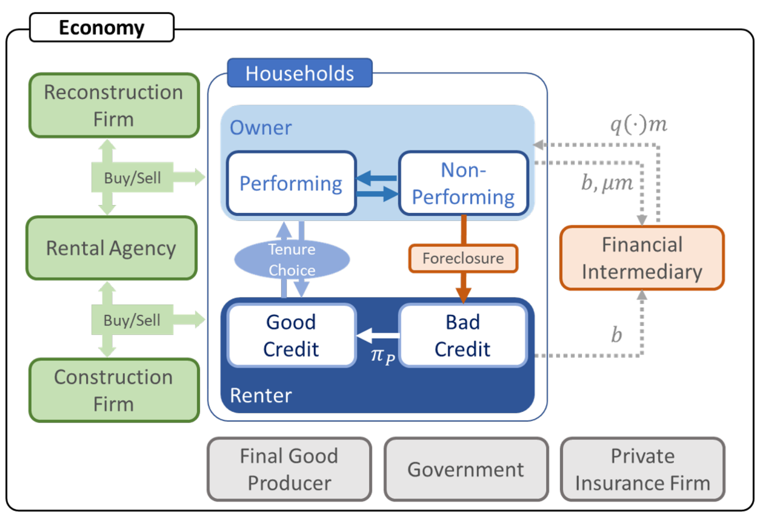


Figure 1: Overview of model environment

The model builds on key features presented in Kaplan et al. (2020), which I extend in several dimensions. First, I include ex-post disaster aid and natural disaster shocks. These differ from standard idiosyncratic house price shocks, as natural disasters represent a wealth shock, an expenditure shock, and a shock to utility flows derived from housing services. Second, I include multiple regions with different disaster exposure to capture cross-region subsidies via disaster aid. Third, I add a private insurance firm to account for the availability of private insurance as an alternative to government aid. Fourth, I explicitly model delinquencies as temporary pauses in mortgage payments without immediate foreclosure. This feature is necessary to replicate empirically observed patterns of rising delinquencies alongside falling foreclosure rates. It is also crucial for capturing the effects of non-financial aid, such as foreclosure moratoria. Fifth, the production side is expanded to include a reconstruction firm specializing in repairing disaster damages. This addition is vital given the timing dynamics of post-disaster rebuilding. Lastly, I incorporate housing market frictions by limiting the probability of a successful home sale. This mechanism is necessary to generate mortgage defaults in the absence of natural disasters, without introducing additional shocks. Unlike Kaplan et al. (2020), my model deos not include a life-cycle structure and, hence, no pay-as-you-go pension scheme. Instead, agents face a constant probability of death $1 - \pi_S$ in each period. Simultaneously, a mass of new agents equal to $1 - \pi_S$ enters the economy as renters, thus maintaining a constant total population. New born agents inherit the liquid wealth of the deceased agents, and previously occupied houses are supplied to the housing market.

2.1 Households

2.1.1 Household Environment

Households are born in region k and cannot move between regions. In every period, a natural disaster shock realizes and destroys a constant share of the housing capital. Aggregate destruction is constant in every period; thus, there is no aggregate risk. An individual household in region k is affected by the destruction with probability θ_k. Individual damages δ of a homeowner living in region k are defined as

$$\delta = \begin{cases} D & \text{with probability } \theta_k \\ 0 & \text{with probability } [1 - \theta_k] \end{cases}$$

In the following, I drop the subscript k for readability.

Preferences Households derive utility from non-durable consumption c and housing services s. The expected lifetime utility of a household is represented by

$$\mathbf{E} \sum_{t=0}^{\infty} [\pi_S \beta]^t \, u(c_t, s_t) \tag{1}$$

where $\beta \in (0,1)$ is the discount factor and π_S the survival probability. Agents utility function is defined as follows

$$u(c,s) = \frac{\left(c^{\alpha} s^{1-\alpha}\right)^{1-\sigma}}{1-\sigma}$$

where α represents the preference weight on non-durable consumption relative to housing services, and $1/\sigma$ gives the intertemporal elasticity of substitution.

Income Households supply inelastically one unit of labor and face idiosyncratic, persistent shocks to labor productivity z which follows an AR(1) process $\log(z') = \rho_z \log(z) + \epsilon'_z$. Agents earn wage w per efficiency unit of supplied labor. Households inherit an initial wealth endowment passed down from deceased households. This initial endowment is drawn from the stationary distribution of liquid savings.

Housing Households choose their housing tenure status ht. In particular, they decide to either rent ($ht = rent$) or own ($ht = rent$) a house, and choose a house size from the corresponding discrete set of rental houses $\mathcal{H}_R = \{h_R^1, ..., h_R^{N_R}\}$ or owner-occupied houses $\mathcal{H}_O = \{h_O^1, ..., h_O^{N_O}\}$. Renters pay a unit price of rent p_r and owners purchase housing units at price $p_h(\delta)$.[3] The owner-occupied housing market is not frictionless. In particular, selling a home is not guaranteed, and agents can only sell with probability π_H. Likewise, prospective home buyers can successfully find a suitable home only with a probability of π_H. Furthermore, housing illiquidity arises due to transaction costs $\epsilon p_h(\delta)$ associated with moving. Every period, homeowners pay a per-period maintenance cost $p_h(\delta)\Delta h$. Housing services s enter the utility function and are proportional to the house size h, but depend on home tenure and the natural disaster shock:

$$s = \begin{cases} \psi_h(1-\delta)h & \text{if } ht = own \\ h & \text{if } ht = rent \end{cases} \tag{2}$$

the parameter $\psi_h > 1$ represents a utility gain from homeownership. Rebuilding after a natural disaster takes time. Hence, the damages caused by the natural disaster reduce contemporaneous housing services for homeowners. Renters do not suffer a reduced utility flow from housing services.[4] In addition, if hit by a natural disaster, homeowners are forced to

[3] Note that the house price depends on realized damages. I assume that agents can only purchase reconstructed homes at price $p_h(\delta = 0)$. However, damages homes are sold at a different price $p_h(\delta > 0)$ to the reconstruction firm.

[4] Agents can move between rental units without incurring moving costs. Therefore, if they experienced disutility from living in a damaged rental unit, they would simply relocate to an intact one. As a result, it is equivalent to assume that renters face no disutility from disasters, while a constant share of rental units remains vacant and under reconstruction.

restore the initial conditions of the house by investing $p_\delta \delta h$. Consequently, a natural disaster can be viewed as both an expense shock and a detrimental impact on the utility derived from homeownership. Additionally, a natural disaster is a shock to housing wealth and can leave agents with negative home equity. Thus, when making housing choices, agents face a trade-off between the utility gains of homeownership and the illiquidity of housing as well as the exposure to natural disaster shocks.

Portfolio choice Agents can hold one-period bonds b and choose next period's liquid savings b' subject to a borrowing limit $b' \geq b_{min}$. Households can finance the purchase of a house with a multi-period mortgage m subject to a collateral constraint $m \leq \lambda p_h(\delta) h$. Mortgages are modeled as infinitely running contracts with decaying mortgages payments μm, where $m' = (1 + r_m - \mu)m$. The per period mortgage payment does not depend on the idiosyncratic characteristics of a borrower. Instead, the mortgage pricing function is borrower-dependent: the household receives the total amount of $q(b', h, m, z)m$ at issuance, and she makes the first mortgage payment in the same period. The present value of a mortgage with size m is then $(1+r_m)m$ and agents own home equity $\eta = p_h(\delta)(1-\delta)h-(1+r_m)m$. Despite the loan-to-value limit, mortgage holders can end up with negative home equity because of a natural disaster shock.

Delinquency and foreclosure A homeowner with mortgage m can choose to either make or miss the mortgage payment μm. Missed mortgage payments alter the outstanding mortgage balance such that $m' = (1 + r_m)m$. Conditional on having missed one mortgage payment, the mortgage stays delinquent with probability $\pi_D(cs, \delta, \mathbf{M})$ or is foreclosed with probability $1 - \pi_D(cs, \delta, \mathbf{M})$. The probability of foreclosure depends on whether the government imposes a foreclosure moratorium for homeowners who where affected by a natural disaster ($\mathbf{M} = 1$). Unless the government imposes a foreclosure moratorium, I assume that mortgages can only stay delinquent for one period. Hence, if a homeowner misses the mortgage payment in two consecutive periods, the house is foreclosed. In case of a foreclosure moratorium, a previously delinquent mortgage is foreclosed with probability π_M. Hence,

$$\pi_D(cs, \delta, \mathbf{M}) = \begin{cases} 1 - \pi_F \pi_M & \text{if } cs = perf, \delta > 0 \text{ and } \mathbf{M} = 1 \\ 1 - \pi_F & \text{if } cs = perf \text{ and } (\delta = 0 \text{ or } \mathbf{M} = 0) \\ 1 - \pi_M & \text{if } cs = del, \delta > 0 \text{ or } \mathbf{M} = 1 \\ 0 & \text{else} \end{cases} \tag{3}$$

In the event of foreclosure, the bank sells the house to use the collateral to cover the outstanding mortgage amount. The bank can only recover $(1-\epsilon_F)p_h(\delta)(1-\delta)h$ of the collateral due to an inefficient foreclosure technology ϵ_F. Home equity after foreclosure is defined as $\tilde{\eta} = (1-\epsilon_F)p_h(\delta)(1-\delta)h - (1+r_m)m$. If the recovered collateral is not sufficient to cover the mortgage amount ($\tilde{\eta} < 0$), the bank can seize non-exempt liquid asset of the agent and garnish future labor income. Liquid assets after foreclosure are then defined as:

$$b_F = \max\{b + \tilde{\eta}, \min\{b_{\text{exemp}}, b\}\} \tag{4}$$

A foreclosed homeowner becomes a renter and is excluded from the mortgage market and the owner-occupied housing market as long as he holds a foreclosure flag in his credit history. For tractability, the household leaves this foreclosure state with a constant probability π_P. A foreclosed homeowner with negative home equity is hold liable via wage garnishment with a probability π_R.[5] In that case, the bank garnishes share $\omega(b, \eta, z)$ of the households' labor income to recover the outstanding mortgage amount in expectation. The amount of negative home equity after foreclosure $\tilde{\eta}$, liquid assets that can be seized $b - b_{\text{exemp}}$ as well as the expected labor income over the wage garnishment period $\bar{y}(z)$ determine the share of income that is garnished.[6]

$$\omega(b, \tilde{\eta}, z) = \max\left\{0, \min\left\{\bar{\omega}, -\frac{\tilde{\eta} + \max\{0, b - b_{\text{exemp}}\}}{\bar{y}(z)}\right\}\right\} \tag{5}$$

with a maximum wage garnishment $\bar{\omega}$.

Public disaster aid Homeowners who stay in their homes after a natural disaster benefit from ex-post disaster assistance through two primary mechanisms: first, homeowners receive damage-proportional grants that reimburse uninsured incurred damages up to a maximum grant $\bar{\tau}_\delta$. Second, the government may impose a foreclosure moratorium for homeowners affected by a natural disaster ($\mathbf{M} = 1$), during which their mortgages are protected from foreclosure. This moratorium extends the period of delinquency and reduces the risk of foreclosure in cases of non-payment.

Private insurance Homeowners can by one-period insurance contracts that cover $\iota \in [0, \bar{\iota}]$ of realized natural disaster damages at unit price p_ι. At the beginning of each period

[5] The parameter π_R can be interpreted as the strictness of the recourse regime. A value of $\pi_R = 0$ implies that defaulted households are not liable for any outstanding mortgage payments after a foreclosure.

[6] The n-period ahead expectation about labor income conditional on labor productivity z_t can be expressed as follows $\mathbf{E}[z_{t+n}|z_t] = z_t^{\rho^n} \frac{1}{2}\sigma_\epsilon^2 \prod_{i=0}^{n} \exp\left(\rho^{n-1-i}\right)$. Hence, the expected income over the wage garnishment period is defined as $\bar{y}(z_t) = \frac{1}{2}\sigma_\epsilon^2 \sum_{n=1}^{\infty}(1-\pi_P)^n z_t^{\rho^n} \prod_{i=0}^{n} \exp\left(\rho^{n-1-i}\right)$.

after observing the realization of idiosyncratic labor productivity, homeowners choose the optimal insurance contract. Regardless of whether a natural disaster hits the individual household, the homeowner pays an insurance premium $p_\iota \iota$. In the event of a natural disaster, the insurance firms pays an insurance claim equal to $\min\{\iota, p_\delta \delta h\}$ in the same period. I can then define the homeowner's liquid asset holdings after the disaster, along with rebuilding expenditures and both public and private insurance payouts/payments:

$$b(\iota, \delta) = b + \frac{1}{1+r}\left[\min\{\iota, p_\delta \delta h\} - \iota p_\iota + \min\{p_\delta \delta h - \iota, \bar{\tau}_\delta\}\right] \tag{6}$$

Budget constraint Agents pay labor income tax τ and housing costs $\kappa(h, \delta, m, ht)$ based on house size h, realized damages δ, mortgage amount m, and their housing tenure status ht. Hence, the budget constraint reads as follows

$$c = \begin{cases} \max\{\underline{y}, (1-\omega(b,\eta,z))(1-\tau)wz\} + (1+r)b - b' - \kappa(h,\delta,m,ht) & \text{Foreclosed Owner} \\ (1-\tau)wz + (1+r)b - b' - \kappa(h,\delta,m,ht) & \text{Renter} \\ (1-\tau)wz + (1+r)b(\iota,\delta) - b' - \kappa(h,\delta,m,ht) & \text{Owner} \end{cases}$$

with

$$\kappa(h,\delta,m,ht) = \begin{cases} p_r h & \text{Renter} \\ \mu m + p_\delta \delta h + p_h(\delta)\Delta h & \text{Owner} \\ \mu m - q(b',h,m,z)m + (1+\Delta+\epsilon)p_h(\delta)h & \text{Buyer} \end{cases}$$

where $\underline{y}$ is subsistence level of income that the government ensures via targeted transfer payments to households under wage garnishment.

2.1.2 Decision problem

In addition to the consumption-saving problem, agents face multiple discrete choices. The choice set of discrete actions depends on both, the credit status cs and the housing tenure status ht of the agents. Relevant state variables at the beginning of a period are liquid savings $b(\iota, \delta)$, the house size h, the mortgage balance m, the realization of the labor productivity shock z, and the realization of the natural disaster shock δ. Figure 2 summarizes the timing and decision problem of a homeowner entering the period with a performing mortgage.

Given the vector of state variables (b, h, m), the realization of the labor productivity shock z, and the begin of period credit status $cs \in \{perf, del\}$, a homeowner ($ht = own$)

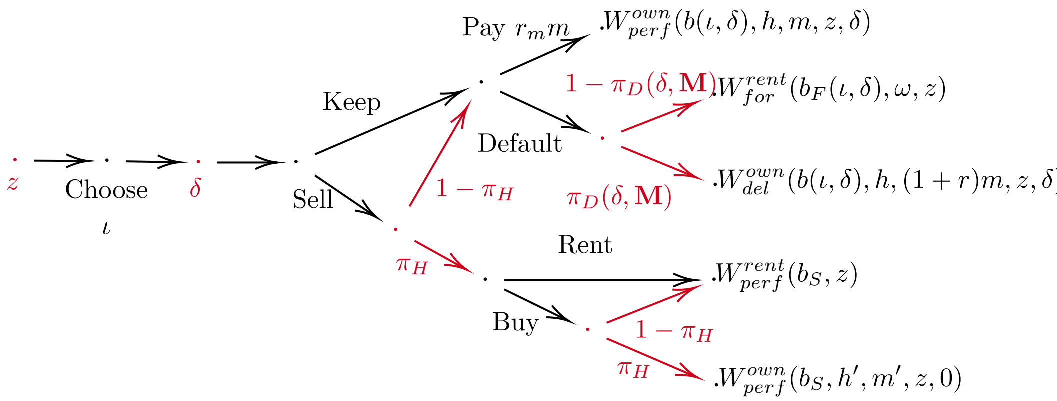


Figure 2: Timing and decisions of a performing homeowner

Note: For simplicity, I omit the state variable k. Exogenous draws are highlighted in red. $\pi_D(\cdot)$ is the probability that a non-performing mortgage stays delinquent and is not foreclosed. π_H is the probability that a listed house is sold/a buyer finds a home. After having sold his house, the agent's liquid bond holdings change by the revenue from the house sale and the proportional moving (out) cost ϵ such that $b_S = b(\iota,\delta) + \frac{1}{1+r}(p_h(\delta)(1-\delta)(1-\epsilon)h - (1+r_m)m)$.

chooses contemporaneous insurance coverage $\iota \in [0, \bar{\iota}]$ to maximize expected life-time utility

$$\max_{\iota} \left(\theta \mathbf{E}\left[V_{cs}^{own}(b(\iota,\delta>0),h,m,z,\delta>0)\right] + (1-\theta)\mathbf{E}\left[V_{cs}^{own}(b(\iota,\delta=0),h,m,z,\delta=0)\right] \right) \tag{7}$$

The value function of a homeowner summarizes two sequential discrete decisions as summarized in Figure 2. After choosing an insurance coverage and observing the realization of the natural disaster shock, the homeowner decides whether to keep her house ($S=0$) or sell the house ($S=1$).

$$\begin{aligned} \mathbf{E}V_{cs}^{own}(b(\iota,\delta),h,m,z,\delta) = \max_{S\in\{0,1\}} \Big\{ &(1-S)\mathbf{E}V_{cs}^{keep}(b(\iota,\delta),h,m,z,\delta) \\ &+ S\mathbf{E}V_{cs}^{sell}(b(\iota,\delta),h,m,z,\delta) \Big\} \end{aligned} \tag{8}$$

If the homeowner decides to keep her house ($S=0$), she then decides whether to make mortgage payments ($D=0$) or to default on her mortgage ($D=1$).

$$\begin{aligned} \mathbf{E}V_{cs}^{keep}(b(\iota,\delta),h,m,z,\delta) = \max_{D\in\{0,1\}} \Big\{ &(1-D)[W_{perf}^{own}(b(\iota,\delta),h,m,z,\delta) + \varepsilon_p] \\ &+ D\big[\pi_D(cs,\delta,\mathbf{M})W_{del}^{own}(b(\iota,\delta),h,m,z,\delta) \\ &+ (1-\pi_D(cs,\delta,\mathbf{M}))W_{for}^{rent}(b_F(\iota,\delta),\omega(b,\eta,z),z) + \varepsilon_d\big]\Big\} \end{aligned} \tag{9}$$

where $\varepsilon_p, \varepsilon_d$ are Type-I extreme value taste shocks with smoothing parameter σ_ε. Since $\mathbf{E}V_{cs}^{keep}(b(\iota,\delta), h, m, z, \delta)$ is the ex-ante value before the realization of the taste shock, there is no need to include the realization of the taste shock as a state variable.[7] The household anticipates that, in the event of default, they may either remain delinquent or face foreclosure.

If, in contrast, the homeowner decides to sell the house ($S = 1$), she finds a suitable buyer with probability π_H. In that case, she can buy a new house ($R = 0$) or become a renter ($R = 1$).[8] Given the market friction, the household finds a suitable home with probability π_H. Otherwise she makes the same decisions as in equation 9.

$$\begin{aligned} \mathbf{E}V_{cs}^{sell}(b(\iota,\delta), h, m, z, \delta) =& (1-\pi_H)V_{cs}^{keep}(b(\iota,\delta), h, m, z, \delta) \\ & + \pi_H \max_{R\in\{0,1\}} \Big\{ RW_{perf}^{rent}(b^S(\iota, h, m, \delta), z) \\ & (1-R)\big[\pi_H W^{buy}(b^S(\iota, h, m, \delta), z) \\ & + (1-\pi_H)W_{perf}^{rent}(b^S(\iota, h, m, \delta), z)\big] \Big\} \end{aligned} \tag{10}$$

If the agent is not successful in finding a suitable buyer, he faces the same decision problem as in equation (9).

A renter with a good credit history (Figure 3, Panel (A)) can either stay in the rental unit ($R = 1$) or become a homeowner ($R = 0$). A renter finds a suitable home with probability π_H. The expected value function can be summarized as

$$\mathbf{E}V_{perf}^{rent}(b, z) = \max_{R\in\{0,1\}} \Big\{ RW_{perf}^{rent}(b, z) + (1-R)\big[\pi_H W^{buy}(b, z) + (1-\pi_H)W_{perf}^{rent}(b, z)\big] \Big\} \tag{11}$$

Finally, a renter with a foreclosure flag (Figure 3, Panel (B)) leaves this state with probability π_P and is no longer excluded from the owner-occupied housing market. His expected lifetime utility is defined as

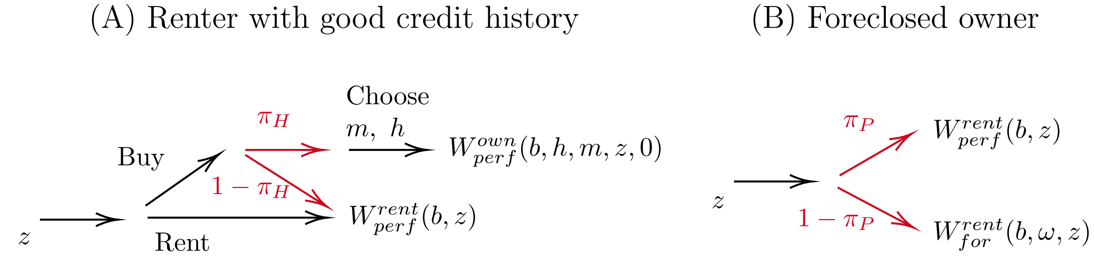
$$\mathbf{E}\left[V_{for}^{rent}(b, \omega, z)\right] = \pi_P W_{perf}^{rent}(b, z) + (1-\pi_P)W_{for}^{rent}(b, \omega, z)$$

Renters choose housing size every period without any frictions. Hence, the current size of their home is not a state variable. Given the discrete choices on tenure and the credit status, households choose consumption c, savings b' and in case of buying house size h and

[7] In case that a mortgage owner cannot afford to stay delinquent, i.e. he would receive a negative consumption stream, he will automatically enter foreclosure. To avoid further complexity, I abstract from this feature in the description of the model.

[8] The option to buy the same house size with a different mortgage amount implicitly allows for re-financing of mortgages in the model.

mortgage m. For a detailed exposition of the full decision problem and the definition of the value functions $W^{own}_{perf}, W^{own}_{del}, W^{rent}_{for}, W^{buy}_{perf}, W^{rent}_{perf}$ see Appendix A.1.



Note: For simplicity, I omit the state variable k. Exogenous draws are highlighted in red. π_P is the probability of leaving the wage garnishment state. π_H is the probability that a listed house is sold/a buyer finds a home.

Figure 3: Timing of Decisions – Renter

2.2 Financial intermediary

There is a representative financial intermediary that acts competitively. The financial intermediary accepts deposits, buys mortgages, and can borrow or lend funds abroad at a given risk-free interest rate r. As there is no default risk on savings and due to perfect competition, the financial intermediary pays the risk-free interest rate on deposits. Mortgages are priced to earn zero profits in expectations on a loan-by-loan basis. The financial intermediary issues $q(b', h, m, z)m$ and receives a stream of decaying mortgage payments μm with $m' = (1 + r_m - \mu)m$. The financial intermediary can observe the portfolio choices of the household b', m, h as well as the labor productivity type z, which affect the future default decisions of the household and thereby the expected return of a mortgage. Define a vector of relevant state variables $x = (cs, b, h, m, z, \delta)$. If the mortgage continues to be performing, $D(x') = 0$, the bank receives mortgage payment $\mu m'$ and the continuation value of the mortgage $q(\cdot)m'$. When the house is sold, $S(x') = 1$, the mortgage is paid off in full. If a household suspends mortgage payments, $D(x') = 1$, and enters delinquency, the bank receives the continuation value $q_{del}(\cdot)m'$. In the event of foreclosure, the bank can recover $F(x)$ with

$$F(x) = \min\left\{(1 + r_m)m, (1 - \epsilon_F)p_h(\delta)(1 - \delta)h + \max(b - b_{exmp}, 0) + \pi_R\omega(x)\bar{y}(z)\right\} \quad (12)$$

To simplify notation, I write $\pi_D(\cdot)$ instead of $\pi_D(perf, \delta, \mathbf{M})$. Further, I define $m' = (1 + r_m - \mu)m$ with $\mu = 0$ in case of default. Thus, mortgage prices are based on the current period payment stream and the expected value in the next period:

$$
\begin{aligned}
q(x)m =& \mu m + \frac{1}{1+r_m}\mathbf{E}\Bigg(S(x')\pi_H(1+r_m)m + [(1-S(x')) + S(x')(1-\pi_H)] \\
& \cdot \Bigg[[1-D(x')]q(x')m' + D(x')\big[\pi_D(\cdot)q_{del}(x')m' + (1-\pi_D(\cdot))F(x')\big]\Bigg]\Bigg)
\end{aligned} \tag{13}
$$

A delinquent homeowner, $cs = del$, can either become re-performing, $D(x) = 0$, miss payments again, $D(x') = 1$, or try to sell the house, $S(x') = 1$, and fully repay the mortgage.

$$
\begin{aligned}
q_{del}(x)m =& \frac{1}{1+r_m}\mathbf{E}\Bigg(S(x')\pi_H(1+r_m)m + [(1-S(x')) + S(x')(1-\pi_H)] \\
& \cdot \Bigg[[1-D(x')]q(x')m' + D(x')\big[\pi_D(\cdot)q_{del}(x')m' + (1-\pi_D(\cdot))F(x')\big]\Bigg)
\end{aligned} \tag{14}
$$

2.3 Housing

The housing sector builds on Kaplan et al. (2020), incorporating a construction firm and a rental agency. The construction firm is necessary to allow for policy-driven variations in housing stock levels across different steady states. Departing from Kaplan et al. (2020), the model introduces a reconstruction agency, which specializes in repairing disaster damages and provides a tractable approach to modeling time-to-rebuild dynamics. Labor is assumed to be perfectly mobile across sectors within a region. For clarity, regional subscripts are omitted in this section.

2.3.1 Construction Sector

In every region, the construction sector is perfectly competitive and produces new owner-occupied housing units using labor N_H and land $\bar{L}$ as input factors based on the following technology

$$
H^{new} = [\Theta N_H]^{\xi} \bar{L}^{1-\xi} \tag{15}
$$

where Θ represents labor productivity. As production takes time, housing units become available in the next period. Land has a fixed supply each period and the government sells the right to use land at a competitive price q_L such that the construction sector makes zero profit in equilibrium. The construction firm solves the following problem

$$
\begin{aligned}
& \max_{N_H} p_h[\Theta N_H]^{\xi}\bar{L}^{1-\xi} - wN_H - q_L\bar{L} \\
\stackrel{\text{in EQ}}{\Longrightarrow}\ & p_h\xi\bar{L}^{1-\xi}[\Theta N_H]^{\xi-1} = w
\end{aligned} \tag{16}
$$

Then, the demand for labor in the construction sector N_H and the total units constructed H^{new} can be defined as follows

$$N_H = \left(\frac{w}{\xi p_h \Theta}\right)^{\frac{1}{\xi-1}} \bar{L} \quad \text{and} \quad H^{new} = \left(\frac{w}{\xi p_h}\right)^{\frac{\xi}{\xi-1}} \Theta^{\frac{1}{1-\xi}} \bar{L} \tag{17}$$

Free entry determines the price for the building permits

$$q_L = w^{\frac{\xi}{\xi-1}} (p_h \Theta)^{\frac{1}{1-\xi}} \left[\xi^{\frac{\xi}{1-\xi}} - \xi^{\frac{1}{1-\xi}}\right] \tag{18}$$

2.3.2 Reconstruction agency

In every region, a reconstruction agency specializes in rebuilding damages caused by natural disasters. Houses that are sold without being rebuilt remain vacant for one period. The agency purchases destroyed units at a discounted price $p_h(\delta > 0)$, rebuilds these units using a linear technology with labor as the only input, and sells the repaired houses in the next period. Additionally, the reconstruction firm sells rebuilding services to homeowners who decide to remain in their damages homes to rebuild. To rebuild a house of size h if vacant (or size o if occupied), the reconstruction agency employs $\Theta\delta h$ ($\Theta\delta o$) units of labor at price w. This gives the following maximization problem:

$$\max_{h,o} \left[-p_h(\delta > 0)(1-\delta)h - \frac{w}{\Theta}\delta h + \frac{1}{1+r}\mathbf{E}p_h'(\delta = 0)h\right] + \left[p_\delta \delta o - \frac{w}{\Theta}\delta o\right]$$

Perfect competition and free entry determine the no arbitrage condition for the price of destroyed units:

$$p_h(\delta > 0) = \frac{1}{1-\delta}\left[\frac{1}{1+r}\mathbf{E}p_h'(\delta = 0) - \delta\frac{w}{\Theta}\right] \quad \text{and} \quad p_\delta = \frac{w}{\Theta} \tag{19}$$

2.3.3 Rental Sector

In all regions, a competitive rental agency owns housing units H_R and buys or sells housing units at the market price $p_h(\delta = 0)$ to rent them out to households at price p_R. The rental agency faces per-period operations costs q_R for each unit rented out. A natural disaster destroys a share $\theta\delta$ of the beginning-of-period housing stock H_R. As there are no moving costs for renters, no renter wants to live in a destroyed house. Therefore, the rental agency sells the destroyed units to the reconstruction firm at price $p_h(\delta > 0)$. The rental agency chooses next period's housing stock H_R' by buying $H_R' - (1-\theta)H_R$ units on the housing market at price $p_h(\delta = 0)$. Additionally, the rental agency makes per unit maintenance investment as the rental housing stock depreciates at a constant rate Δ. The optimization problem can thus be expressed in recursive form.

$$
\begin{aligned}
R(H_R) = &\max_{H_R'} (p_R - q_R - p_h(\delta = 0)\Delta) H_R' - p_h(\delta = 0)(H_R' - (1-\theta)H_R) \\
&+ p_h(\delta > 0)\theta H_R + \frac{1}{1+r} R(H_R')
\end{aligned}
\tag{20}
$$

This gives the following no-arbitrage condition that relates the equilibrium rental rate to operation costs of the rental agency, depreciation by natural disasters as well as current and future house prices.

$$
p_R = q_R + \left[(1+\Delta) - \frac{1-\theta}{1+r}\right] p_h(\delta = 0) - \frac{\theta}{1+r} p_h(\delta > 0) \tag{21}
$$

2.4 Final-Good Sector

In each region, a perfectly-competitive final-good producer operates a constant returns to scale technology $Y_C = \Theta_C N_C$ and uses labor as the only input N_C at cost w to produce non-durable consumption goods. The final-good producer maximizes profit as follows:

$$
\max_{N_C} \Theta_C N_C - w N_C
$$

Hence, with free entry, the equilibrium wage per unit of labor, w, equals the aggregate labor productivity level Θ_C.

2.5 Private insurance firm

A private insurance company operates under perfect competition and sells one-period insurance contracts to households at unit price p_ι. In expectation, the insurance company makes zero profit on a contract-by-contract basis. For each unit of insurance, the insurance company bears intermediation costs q_ι, such as administrative fees. Under the zero-profit condition, the per-unit price of insurance is determined as $p_\iota = \theta(1 + q_\iota)$.

2.6 Government

The government runs a balanced budget: it levies a labor income tax τ, collects revenue from selling land permits q_L, provides post-disaster assistance and redistributes the remaining amount via a lump-sum transfer Γ. Additionally, the government redistributes home equity of deceased agents. Revenue from land permit sales is used locally, while disaster aid is funded across all regions. In the aftermath of a natural disaster, the government supports homeowners by providing damage-based grants up to $\bar{\tau}_\delta$ to affected households. Hence, region-specific lump-sum transfers in region k are defined as follows:

$$\Gamma(k) = \underbrace{\Gamma_G}_{\text{lump-sum transfer to all HHs}} + \underbrace{q_L(k)\bar{L}(k)}_{\text{regional revenue from land permits}} + \underbrace{\int \eta_{i,k} di}_{\text{home equity of deceased agents}} \tag{22}$$

with

$$\begin{aligned}\Gamma_G =& \underbrace{\sum_k \pi_k \int \tau w_k z_{i,k} di}_{\text{labor income tax}} - \underbrace{\sum_k \pi_k \int \min\{\bar{\tau}\delta, p_\delta \delta_{i,k} h_{i,k} - \iota\} di}_{\text{damage-dependent grants}} \\ & - \underbrace{\sum_k \pi_k \int \max\{0, \underline{y} - (1-\omega)(1-\tau) wz\} di}_{\text{social security payments}}\end{aligned} \tag{23}$$

where π_k represents the location-specific population mass with $\sum_k \pi_k = 1$. Additionally, the government determines the strictness of the recourse regime by setting the parameter π_R and can impose a foreclosure moratorium, denoted by $\mathbf{M} = 1$. A foreclosure moratorium temporarily limits banks' ability to foreclose the underlying collateral of non-performing mortgages held by households affected by natural disasters.

2.7 Equilibrium

To ease notation, denote the vector of individual states for homeowners and renters as $\mathbf{x}^h := (cs, b, h, m, z, \delta, k) \in \mathbb{X}^h$ and $\mathbf{x}^r := (cs, b, \omega, z, k) \in \mathbb{X}^r$. Let Ω be the distribution of agents over the state space. Given a risk-free interest rate r and government policies $\mathcal{P} = (\tau, \bar{\tau}_\delta, \pi_R, \mathbf{M})$, a stationary equilibrium consists of value functions $v = \{V^{own}_{perf}(\mathbf{x}^h), V^{own}_{del}(\mathbf{x}^h), V^{rent}_{perf}(\mathbf{x}^r), V^{rent}_{for}(\mathbf{x}^r), W^{own}_{perf}(\mathbf{x}^h), W^{buy}(\mathbf{x}^r), W^{own}_{del}(\mathbf{x}^h), W^{rent}_{perf}(\mathbf{x}^r), W^{rent}_{for}(\mathbf{x}^r)\}$, policy functions $f^* = \{b'^*(\mathbf{x}^h), c^*(\mathbf{x}^h), \iota^*(\mathbf{x}^h), S^*(\mathbf{x}^h), D^*(\mathbf{x}^h), R^*(\mathbf{x}^h), b'^*(\mathbf{x}^r), c^*(\mathbf{x}^r), h^*(\mathbf{x}^r), m^*(\mathbf{x}^r), R^*(\mathbf{x}^r)\}$, an invariant distribution Ω, mortgage pricing functions $q(\mathbf{x}^h), q_{del}(\mathbf{x}^h)$, house pricing functions $p_h(\Omega), p_r(p_h), \tilde{p}_h(p_h)$ such that for all regions k

- **Households Maximization:** Given prices, pricing functions, and policies, the value functions solve the household problem and f^* are associated policy functions.
- **Zero Profit Mortgages:** Given f^* and $\mathcal{P}$, q and q_{del} solve (13) and (14) for any contract traded in equilibrium.

- **Zero Profit Insurance Contracts:** The insurance pricing equation $p_\iota = \theta(1+q_\iota)$ holds for any contract traded in equilibrium.

- **Profit maximization:** Firms in the construction sector maximize profits (16) with associated labor demand $N_H(k)$ and housing construction $H^{new}(k)$. The reconstruction firm employs $N_R(k)$ units of labor to meet reconstruction demand.

- **Labor market clearing:** The labor market clears at wage $w = \Theta_C$, and labor demand in the final good sector is determined residually $N_C(k) = 1 - N_H(k) - N_R(k)$.

- **Rental market clearing:** Given the rental price p^r_{kt} determined by (21), the rental market clears

$$\begin{aligned} H'_R(k) = &\pi_S \Big[\int [R^*(\mathbf{x}^r_i) + (1 - R^*(\mathbf{x}^r_i))(1-\pi_H)] h^*_i(\mathbf{x}^r_i) di \\ &+ \pi_H \int S^*(\mathbf{x}^h_i)[R^*(\mathbf{x}^h_i) + (1 - R^*(\mathbf{x}^h_i))(1-\pi_H)] h^*_i(\mathbf{x}^h_i) \\ &+ (1 - \pi_D(\mathbf{x}^h_i, \mathbf{M})) \int (1 - S^*(\mathbf{x}^h_i)) D^*(\mathbf{x}^h_i) h^*_i(\mathbf{x}^h_i) di \Big] \\ &+ (1-\pi_S) \int R^*(\mathbf{x}^r_i) h^*_i(\mathbf{x}^r_i) di \end{aligned} \tag{24}$$

  where the left-hand-side represents total supply of rental units and the right-hand side total demand of previous renters, households who are successful in selling their homes to become renters, foreclosed homeowners who are forced to become renters, and newborn agents who stay renters.

- **Housing market clearing:** Prices $p_h(\delta)$ clear the regional housing markets such that after all decisions are made the following equality holds

$$\begin{aligned} &H^{sold}(k) + H^{foreclosed}(k) + H^{reconstructed}(k) + (1-\pi_S)H_O(k) + H^{new}(k) \\ =&H^{buy}(k) + [H'_R(k) - (1-\theta)H_R(k)] + \Delta H'_R(k) + \Delta H_O(k) \end{aligned} \tag{25}$$

  The left-hand side equals total inflows into the housing market: undamaged houses sold by previous homeowners (26), undamaged foreclosed homes (27), houses reconstructed from damage in the previous period (28), homes of deceased agents, and newly constructed housing units. The right-hand side represents total outflows from the housing market: housing units purchased by new buyers (29) and the rental agency as well as investment of owners and the rental agency to offset housing deprecation. These terms are defined as follows

$$H^{sold}(k) = \pi_S \pi_H \int S^*(\mathbf{x}_i^h) \mathbb{I}[\delta_i = 0] h_i^*(\mathbf{x}_i^h) di \tag{26}$$

$$\begin{aligned} H^{foreclosed}(k) = &\pi_S \int [S^*(\mathbf{x}_i^h)(1-\pi_H) + (1 - S^*(\mathbf{x}_i^h))] \\ &\cdot D^*(\mathbf{x}_i^h)(1 - \pi_D(\mathbf{x}_i^h, \mathbf{M})) \mathbb{I}[\delta_i = 0] h_i^*(\mathbf{x}_i^h) di \end{aligned} \tag{27}$$

$$\begin{aligned} H^{reconstructed}(k) = &\pi_S \Bigg(\pi_H \int S^*(\mathbf{x}_i^h) \mathbb{I}[\delta_i > 0] h_i^*(\mathbf{x}_i^h) di \\ &+ \int [S^*(\mathbf{x}_i^h)(1-\pi_H) + (1 - S^*(\mathbf{x}_i^h))] \\ &\cdot D^*(\mathbf{x}_i^h)(1 - \pi_D(\mathbf{x}_i^h, \mathbf{M})) \mathbb{I}[\delta_i > 0] h_i^*(\mathbf{x}_i^h) di \Bigg) \end{aligned} \tag{28}$$

$$\begin{aligned} H^{buy}(k) = &\pi_S \pi_H \Bigg(\pi_H \int S^*(\mathbf{x}_i^h)(1 - R^*(\mathbf{x}_i^h)) h_i^*(\mathbf{x}_i^h) di \\ &+ \int (1 - R^*(\mathbf{x}_i^r)) h_i^*(\mathbf{x}_i^r) di \Bigg) \\ &+ (1 - \pi_S) \pi_H \int (1 - R^*(\mathbf{x}_i^r)) h_i^*(\mathbf{x}_i^r) di \end{aligned} \tag{29}$$

- **Final good market clearing:** The final good market clears in every region:

$$\begin{aligned} Y_C(k) = &\int c_i^*(\mathbf{x}_i^h) di + \int c_i^*(\mathbf{x}_i^r) di + q_R(k) H_R(k) + q_I \iota \theta \int \iota_i^*(\mathbf{x}_i^h) di \\ &+ \epsilon \pi_H^2 \int S^*(\mathbf{x}_i^h)(1 - R^*(\mathbf{x}_i^h)) p_h(\Omega) h_i^*(\mathbf{x}_i^h) di \\ &+ \epsilon \pi_H \int (1 - R^*(\mathbf{x}^r)) p_h(\Omega) h_i^*(\mathbf{x}_i^r) di \\ &+ \epsilon_F \int [S^*(\mathbf{x}_i^h)(1-\pi_H) + (1 - S^*(\mathbf{x}_i^h))] \\ &\cdot D^*(\mathbf{x}_i^h)(1 - \pi_D(\mathbf{x}_i^h, \mathbf{M})) h_i^*(\mathbf{x}_i^h) di \end{aligned} \tag{30}$$

where the right-hand side represent non-durable consumption of owners and renters, the operation costs of the rental agency and private insurance firm, the transaction costs of new home purchases by previous owners as well as new home buyers, and the loss from foreclosure.

- **Balanced government budget:** The government budget constraint holds (22), with lump-sum transfers Γ_G adjusting to balance budget.

2.8 Welfare

To compare households welfare across different policy regimes, I use the welfare criterion based on ex-ante expected utility W defined as

$$W = \int V(x) d\Omega \tag{31}$$

I express changes in welfare in consumption equivalence variation. Hence, I find the constant proportional increment of benchmark consumption ε_{CEV} for each state combination under the baseline disaster policy design that yields the same expected utility under an alternative policy scenario. Define $c^*, h^* \left(\tilde{c}, \tilde{h}\right)$ optimal consumption and housing choices under the baseline policy (under a counter-factual policy design). Then, I need to find ε_{CEV} such that the following equation holds:

$$\mathbf{E} \sum_{t=0}^{\infty} \beta^t \pi_S \frac{[(\varepsilon_{CEV} c)^\alpha (\varphi_h (1-\delta) h)^{1-\alpha}]^{1-\sigma}}{1-\sigma} = \mathbf{E} \sum_{t=0}^{\infty} \beta^t \pi_S \frac{\left[(\tilde{c})^\alpha (\varphi_h (1-\delta) \tilde{h})^{1-\alpha}\right]^{1-\sigma}}{1-\sigma} \tag{32}$$

Then, ε_{CEV} is given by

$$\varepsilon_{CEV} = \left(\frac{\tilde{W}}{W^*}\right)^{\frac{1}{\alpha(1-\sigma}} \tag{33}$$

I calculate this measure for the aggregate economy as well as for different income levels and region-specific welfare effects.

3 Calibration and Computation

The model is calibrated to the United States from 2000-2020, with each model period representing half a year. The primary objective is to match aggregate statistics of the U.S. housing market and to capture default behavior following natural disasters, accounting for the institutional framework specific to the U.S. context.

3.1 External calibration

Table 5 in the appendix summarizes all externally calibrated parameters.

Demographics Households die with a constant probability $\pi_D = 0.01$. This implies an average length of working life of 50 years.

Preferences Individual discount future utility flows by $\beta = 0.98$. I assume constant relative risk aversion with an intertemporal elasticity of 1/2 ($\sigma = 2$). Following Mitman

(2016), I set the Cobb-Douglas parameter $\gamma = 0.859$ to match a 14.1 percent share of housing in total consumption.

Income process Following Kaplan et al. (2020), I assume a persistence of labor productivity $\rho^z = 0.97$ and a standard deviation of shocks to labor income $\sigma_{\epsilon^z} = 0.2$. I approximate the income process by a three-state Markov process. Median labor productivity is normalized to one.

Housing To define a housing grid, I categorize rental and owner-occupied housing separately in the AHS, grouping them into four size categories. For each group, I calculate the median market value of homes. Rental unit values are imputed based on owner-occupied homes of the same size. Drawing on housing choices observed in the 2021 American Housing Survey (AHS) (see Figure 9 in Appendix A.2), I assume the housing market is imperfectly segmented, leading to distinct grids for owner-occupied and rental units. The number of grid points and their spacing are determined based on AHS data, while the minimum rental house size, h_{min}, is internally calibrated. Transaction costs for selling a house, ϵ, are set at 10% of the house's value (Chatterjee & Eyigungor 2015), and housing maintenance costs, Δ, which include depreciation and taxes, are set at 2% (Mitman 2016). To calibrate the probability of successfully selling a house, I use the Median Number of Months on Sales Market for Newly Completed Homes reported by the U.S. Census Bureau. Excluding the U.S. housing crisis, the average time-to-sell between 2000 and 2020 is estimated at 3.8 months. Assuming a constant monthly sale probability, this implies a 64% probability of selling a house within one year.

Production As in Kaplan et al. (2020), the construction technology parameter γ_h is set to 0.6 implying a price elasticity of housing supply of 1.5, which is the median value across MSAs estimated by Saiz (2010). I normalize labor productivity to one ($\Theta_H = \Theta_C = 1$).

Financial Instruments and Regulation Agents are restricted to holding non-negative liquid assets, i.e. $\underline{b} = 0$. Following Mitman (2016), I set the annual risk-free rate r at 3 percent and the proportional interest rate wedge $\frac{r_m}{r} - 1$ to 0.33. Mortgage holders can select a loan-to-value (LTV) ratio below the LTV limit of 0.8 (Berger et al. 2018), and repay a constant 10 percent ($\mu = 0.1$) of their outstanding mortgage balance annually. The probability of a non-performing mortgage being foreclosed depends on the occurrence of a disaster and is externally calibrated based on loan-level data from Fannie Mae ($\pi_F = 0.015$). Consistent with Mitman (2016), I set the foreclosure loss parameter, ϵ_F, to 0.22 reflecting the additional loss incurred in a foreclosure, and the probability of a deficiency judgment after foreclosure, π_R, to 0.1. In the event of personal bankruptcy, federal law protects certain amounts of cash and other property. Under Federal Wildcard Exemptions, individuals can shield up to USD 1,825 in cash, plus any unused homestead exemption of up to USD 13,950. Consequently, I define the amount of exempt assets relative to median income as $b_{exemp} = 0.16$. According to the Federal Wage Garnishment Law, up to 15 percent of labor income can be garnished. Similar to the 5-year repayment period under Chapter 13 bankruptcy, agents remain in the wage garnishment state for an average of 5 years, implying a transition probability of $\pi_P = 0.1$.

Natural disasters The model consists of two types of regions ($N_k = 2$) that differ in disaster exposure: low exposure regions and high exposure regions. To identify avergage risk exposure for each region-type, I group U.S. counties based on the Expected Annual Loss Rate (EALR) as defined in the National Risk Index Database.[9] The EALR represents the average proportional economic loss to building infrastructure in dollars resulting from natural hazards each year. This measure combines the annualized frequency of natural disasters with the historical percentage of building value that was destroyed by natural disasters. I sort regions by their EALR and define the cut off loss rate such that the low-risk regions constitute 75 percent of the U.S. population. The regional-specific disaster risk is then the average EALR of all low-risk (high-risk) counties with $EALR_{low} = 0.0004$ (and $EALR_{high} = 0.0023$). Figure 4 provides a map of the classified regions. To identify the average relative housing destruction, I use OpenFEMA data on NFIP claims transactions. These data contains detailed information on the property-level damage amount as well as the actual cash value of an affected property. After trimming the bottom and top one percent, I calculate the average share of property damages relative to the actual cash amount. This gives me an estimate of $\delta = 0.25$. To calculate the share of affected homeowners for each region type, I divide the region-specific EALR by the average share of property damages, and I convert it to a bi-annual frequency by dividing by two. Then, on average 0.45 (0.08) percent of homeowners are affected every period in high-risk (low-risk) regions.

Government The baseline income tax is set to 13.6 percent to match the average income tax paid in the U.S.. In the baseline, the government imposes a foreclosure moratorium for homeowners who are affected by natural disasters ($\mathbf{M} = 1$) and financial disaster aid that covers uninsured damages up to a maximum coverage amount $\bar{\tau}_\delta$. The maximum coverage amount provided for a single disaster under the individual housing assistance by FEMA is USD43,600. Normalizing this by the median household income gives an upper bound on ex-post financial aid of $\bar{\tau}_\delta = 1.28$. In case of a foreclosure moratorium, all homeowners affected by a natural disaster are protected against foreclosures, i.e. $\pi_M = 0$.

Insurance I externally calibrate the insurance wedge using data of the expected Costs and premiums of the NFIP in 2017. Rate-based receipts account for 75 percent of premiums whereas additional charges (reserve fund assessment, surcharges and federal policy fee)

[9]The National Risk Index Database by FEMA can be accessed under `https://www.fema.gov/nri`.

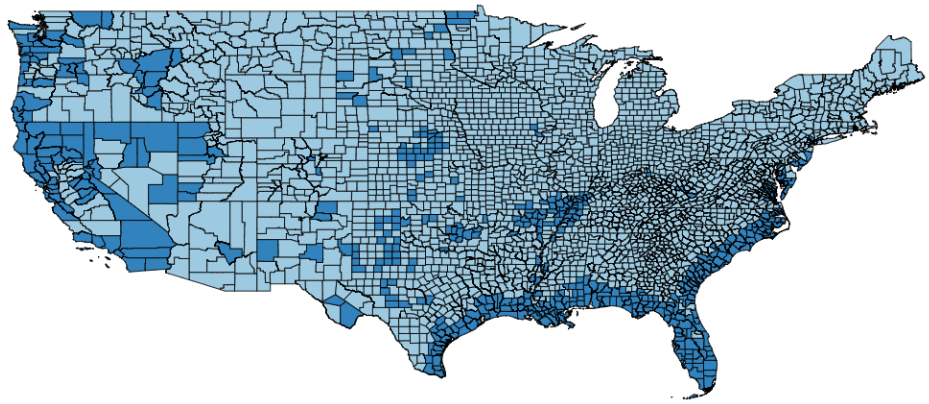


Figure 4: Low and high risk counties in the U.S.

County-specific disaster risk is based on the National Risk Index. Counties with dark-blue coloring are classified as high-risk regions. 25 percent of the total U.S. population lives in these high-risk regions.

amount to 25 percent (CBO 2017). These numbers are in line with expense ratios about 26 percent of homeowner insurance premiums as documented by the Insurance Information Institute (2023). Hence, I set the insurance wedge q_ι equal to 0.33.

3.2 Internal calibration

I calibrate the remaining five parameters $(h_{min}, \psi_h, FC, \bar{L}, q_R)$ jointly to match five aggregate moments. Using the preference for homeownership ψ_h and the minimum house size h_{min}, I target the following moments: the average homeownership rate ($\approx 66\%$, FRED) and the ratio of mean house sizes of renters to homeowners (1.5 according to Chatterjee & Eyigungor (2015)). I target the homeownership rate of low income households ($\approx 46\%$, FRED) with the per-unit costs of operation of the rental agency q_R. The values of land permits $\bar{L}$ are set to reflect the construction sector's relative size in the U.S. ($\approx 5\%$ of total employment, FRED). Lastly, I target the average U.S. delinquency rate with the disutility of default FC. I use loan-level data Fannie Mae Single-Family Mortgage containing the outstanding mortgage amount as well as the length of delinquency. I construct a delinquency rate to align the data with the model, where one period represents one year. Since most delinquencies last less than six months, I adjust for their duration when calculating the target delinquency rate. Specifically, I determine the relative value of mortgages that are delinquent over the course of a year, weighting delinquencies by their length. For each month and region, I calculate the value of mortgages delinquent for 30–90 days, 90–180 days, and more than 180 days. To account for their shorter duration, I scale down delinquencies of 30–90 days by multiplying by 1/2. The delinquency rate is then calculated as the weighted value of delinquent mortgages

Moment	Model	Data
Target Moments		
Homeownership rate (all)	67%	66%
Homeownership rate (low income)	46%	46%
Mean house size (owners/renters)	1.6	1.5
Delinquency rate	1.7%	1.7%
Size of construction sector	2.1%	5.0%
Untarget Moments		
Foreclosure rate	0.02%	0.01%
Liquid wealth / income	0.098	0.064
Average equity ratio	0.87	0.58
Average earnings (owners/renters)	1.8	2.0
Insurance protection gap	58%	58%
Average insurance rate	67%	65%
Homeownership rate (high income)	93%	84%

Table 1: Model v.s. Data

divided by the total value of all active mortgages. Excluding the financial crisis period, this results in an average delinquency rate of 1.7%.

3.3 Computation

The value and policy functions are computed over a predefined grid of liquid bonds and loan-to-value ratios $[0.0, 0.1, 0.2, 0.4, 0.6, 0.8, \lambda]$. For mortgage size, m, and next-period liquid bond holdings, b', I allow for off-grid choices, using linear interpolation of the future value functions to approximate off-grid points. I do not introduce insurance coverage as state variable since liquid bond holds after disaster realization and after insurance payout can be fully characterized by the state vector (b, h, m, z, δ, k). Hence, I solve for value functions over a given grid of liquid assets (and the remaining states h, m, z, δ, k). Based on these value functions, I determine the optimal insurance decision, ι, at the beginning of the period by interpolating the value function with respect to the liquid assets, $b(\iota)$.

3.4 Model fit

The preliminary calibration provides a relatively good model fit for both targeted and untargeted moments while also capturing regional differences qualitatively. The model successfully replicates several key aspects of the U.S. housing and mortgage market. Table 1 summarizes the model's fit against aggregate targeted and untargeted moments.

Targeted moments The model accurately matches both, the aggregate homeownership rate as well as the proportion of low-income households choosing rental units. Similar to a ratio of 1.5 observed in the data, owner-occupied homes in the model are, on average, 1.6 times larger than rental units. Moreover, the model's aggregate delinquency rate closely aligns with the empirical target of 1.7 percent. However, the model underestimates the relative size of the construction sector.

Untargeted moments Homeowners in the model hold relatively large shares of equity in their homes. Compared to a home equity share of 58 percent (FRED, 2000-2020), the model predicts leverage of 22 percent. Nevertheless, the model replicates the low observed foreclosure rate. The predicts a median ratio of liquid assets to income ratio of 0.098, which lies 3.4ppt above the estimates reported in Kaplan & Violante (2014). Additionally, average earnings of owners over renters (1.8 in the model) are close to the ratio 2.0 observed in the data (FRED, 2000-2020). In the model, high income households are more likely to own homes (93 percent) compared to the data (84 percent).

The model aligns well with the extensive and intensive margins of private insurance observed in the data. However, estimates of insurance coverage should be interpreted with caution due to data limitations in the U.S. The aggregate insurance protection gap of 58 percent is based on Swiss RE (2024). I estimate overall insurance coverage in the U.S. as follows: flood insurance coverage is approximately 5 percent, while homeowner insurance coverage is around 95 percent (Fried 2022). To compute total insurance coverage, I weight these peril-specific rates by the historical distribution of property damage from floods and non-flood events, using SHELDUS data (2000–2020).

	Low-risk regions			High-risk regions			
	N	Mean	SE	N	Mean	SE	Difference
GDP (p.c.)	2,543	57.96	15.15	514	55.86	5.28	2.09
Owner costs (with mortgage)	682	1,401	15	142	1,525	42	124***
Owner costs (w/o mortgage)	682	1,154	93	142	1,813	272	659***
Number of rooms	682	5.8	0.02	142	5.3	0.03	-0.5***
Percent with mortgage	679	64.8	0.3	139	60.6	0.8	4.2***
Homeownership rate	682	67.5	0.3	142	65.6	0.7	-1.9***

Table 2: Regional data moments

As documented in Table 2, low- and high-risk regions exhibit significant differences in their housing markets. These differences (summarized in Table 1, primarily based on AHS data) are also qualitatively captured by the model (see Table 2). Since GDP per capita does not differ significantly across regions, I assume the same income processes for both region types. Housing costs are higher in high-risk areas despite people living in smaller homes. Homeownership rates are lower in high-risk regions, yet a higher proportion of residents carry mortgages. Although the model captures these qualitative differences in the housing market, it does not match the quantitative gap in owner costs and size of homes.

	Data	Model
Owner costs (with mortgage)	8.85%	3.36%
Owner costs (w/o mortgage)	57.11%	28.31%
Number of rooms	-8.62%	-0.13%
Percent with mortgage	-6.48%	-6.39%
Homeownership rate	-2.81%	-3.31%

Regional differences are expressed in percentage deviations from the low risk region.

Table 3: Regional differences - Model v.s. Data

4 Results

4.1 Baseline policy

The model enables an analysis of delinquency increases following natural disasters across different income groups (see Figure 5). Consistent with the empirical literature, it predicts a rise in delinquencies after natural disasters, which is most pronounced among low-income households. By design, this rise in delinquencies is not matched by a corresponding increase in foreclosures due to the foreclosure moratorium in place.

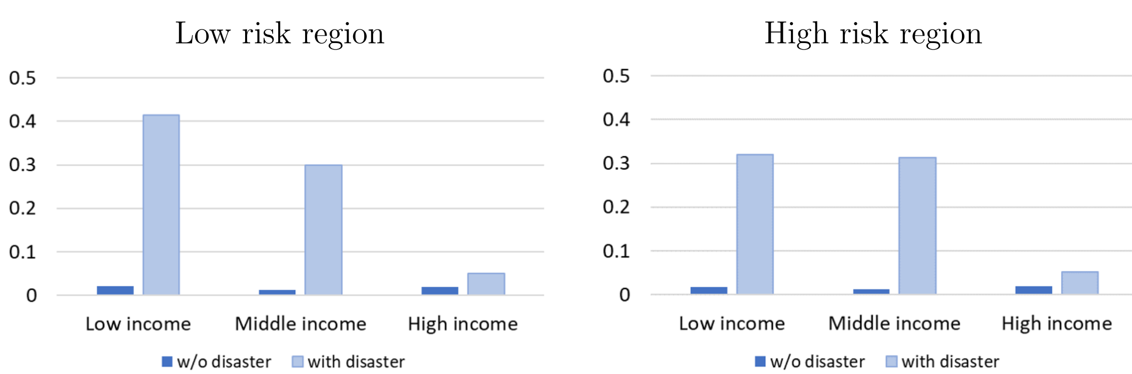


Figure 5: Delinquencies by income and region

4.2 Policy analysis

In this section, I compare the steady-state outcomes of the current federal ex-post disaster aid policy with several alternative scenarios. The first scenario eliminates financial aid

	(1)	(2)	(3)	(4)	(5)	(6)
Insurance gap						
Total	-10.4%	+0.1%	+4.0%	-13.5%	+5.0%	-0.2%
By disaster exposure						
Low risk	-11.1%	+0.0%	-0.6%	-9.2%	+3.2%	-0.0%
High risk	-8.2%	+0.3%	+18.7%	-26.9%	+10.5%	-0.5%
Home ownership						
Total	-1.2%	-0.0%	+0.7%	-0.9%	-0.2%	-0.3%
By disaster exposure						
Low risk	-0.5%	+0.0%	+0.3%	-0.4%	-0.4%	-0.3%
High risk	-3.3%	-0.0%	+2.2%	-2.7%	+0.7%	-0.3%
By income						
Low income	-3.1%	-0.0%	+2.3%	-2.4%	-0.7%	-0.9%
Mid income	-1.3%	-0.0%	+0.6%	-1.0%	-0.1%	-0.3%
High income	-0.1%	-0.0%	+0.1%	-0.1%	+0.1%	-0.0%
Owner-occupied housing stock						
Total	-1.5%	-0.0%	+0.9%	-1.2%	-0.1%	-0.2%
By disaster exposure						
Low risk	-0.7%	-0.0%	+0.8%	-0.2%	-0.1%	-0.2%
High risk	-3.9%	-0.0%	+1.3%	-4.2%	-0.1%	-0.2%

Table 4: Steady Sate Comparison

Note: The columns report percent changes from the baseline steady state for the following policy counterfactuals: (1) Removing financial aid while maintaining foreclosure moratorium; (2) Removing foreclosure moratorium while remaining financial aid; (3) Baseline aid, but strict recourse regime; (4) No aid, lenient recourse; (5) No aid, strict recourse; (6) Baseline aid, financed by housing tax

following a natural disaster while maintaining the foreclosure moratorium. The second scenario retains financial aid but removes the foreclosure moratorium. In the third scenario, disaster aid remains unchanged, but a strict recourse regime is introduced, ensuring that all foreclosed homeowners face recourse with certainty. The fourth scenario eliminates all disaster aid—both financial and non-financial—under the current (lenient) recourse regime. The fifth scenario removes all disaster aid while imposing a strict recourse regime. Finally, the last counterfactual shifts the funding source for disaster aid from a labor tax to a housing tax. Table 4 provides a detailed overview of the percentage changes in the insurance gap, homeownership rates, and aggregate housing stock across all policy counterfactuals.

Counterfactual 1 Removing financial aid leads to a significant reduction in the insurance protection gap, decreasing by more than 10 percent across both high- and low-risk regions. However, the impact on insurance coverage varies by income group. While middle- and high-income households increase their coverage by 50 percent and 150 percent, respectively, low-income households reduce their coverage by 80 percent. Homeownership rates decline overall by 1.2 percent, with a larger drop of 3.3 percent in high-risk regions. Especially among low-income households, homeownership rates decline by 8.6 percent in the high-risk region. Additionally, low-income homeowners opt for smaller homes on average, with a 3.1 percent reduction in home size. Loan-to-value (LTV) ratios increase, particularly for low-income households in high-risk regions (rising by 45 percent) and middle-income households (rising by 15 percent). A significant shift in post-disaster behaviour emerges, as only 65 percent of affected homeowners remain in their homes, compared to 98 percent previously. This trend is primarily driven by low- and middle-income homeowners leaving their homes. Furthermore, the aggregate housing stock in high-risk regions declines by nearly 4 percent, contributing to an overall 1.5 percent reduction in the total housing stock. These findings indicate that financial aid crowds out private insurance and contributes to an increase in risky housing stock.

Counterfactual 2 Removing foreclosure moratoria has minimal effects on the insurance market, as the insurance gap remains virtually unchanged. Similarly, homeownership rates and the stock of owner-occupied housing remain stable, indicating that foreclosure moratoria do not contribute to the crowding out of private insurance or an increase in risky housing. However, low-income households in high-risk regions opt for even lower loan-to-value (LTV) ratios, suggesting a more conservative borrowing approach in the absence of foreclosure protection. Additionally, the removal of foreclosure moratoria leads to a reduction in post-disaster delinquencies, with a more pronounced decrease among high-income households, who now face greater downside risk of default. At the same time, foreclosures increase following natural disasters.

Counterfactual 3 Under the baseline disaster aid policy with a strict recourse regime, the insurance gap widens as households rely less on formal insurance coverage. Instead, individuals increase self-insurance by accumulating higher liquid savings to protect against both natural disasters and income shocks. Homeowners also adopt more conservative borrowing behavior, opting for lower leverage, which in turn leads to a lower average delinquency rate. As a result, mortgage conditions improve, reflecting reduced credit risk. In high-risk regions, low- and middle-income households choose smaller homes, likely as a precautionary measure. However, the overall rise in homeownership rates leads to an expansion of the owner-occupied housing stock.

Counterfactual 4 Under a policy without disaster aid and a lenient recourse regime, the insurance gap decreases even further compared to Scenario (1), with a particularly pronounced reduction in high-risk regions. Homeownership rates decline, especially among low-income households in high-risk areas. In addition, low- and middle-income households in these regions opt for smaller homes. In the absence of governmental support, disaster-induced displacement becomes more widespread across all income groups, with particularly severe impacts on low-income households. Approximately 92 percent of low-income households relocate after a disaster, compared to 40 percent of middle-income households and 4 percent of high-income homeowners.

Counterfactual 5 In the absence of disaster aid but with a strict recourse regime, the insurance gap increases by 5 percent, driven by a 10 percent widening in high-risk regions. Households in high-risk regions respond by increasing their savings, as the strict recourse regime encourages more conservative financial behavior. The average delinquency rate decreases, leading to improvements in mortgage conditions. As a response, high-risk households tend to choose larger leverage. While overall homeownership rates remain largely unchanged, they increase by 0.7 percent in high-risk areas. The housing stock experiences a slight decline of 0.1 percent. Similar to Scenario 4, disaster-induced displacement is very common among low- and middle-income groups, with around 95 percent of low-income households, 52 percent of middle-income households, and 5 percent of high-income households leaving their homes following a disaster.

Counterfactual 6 Shifting the financing of disaster aid from an income tax to a housing tax has only modest effects. The insurance gap slightly decreases, and the housing stock also experiences a small decline. The average house size remains largely unchanged, although it increases slightly for low-income homeowners in low-risk regions. The decrease in housing stock is primarily driven by a reduction in the number of people owning homes, rather than changes in home size.

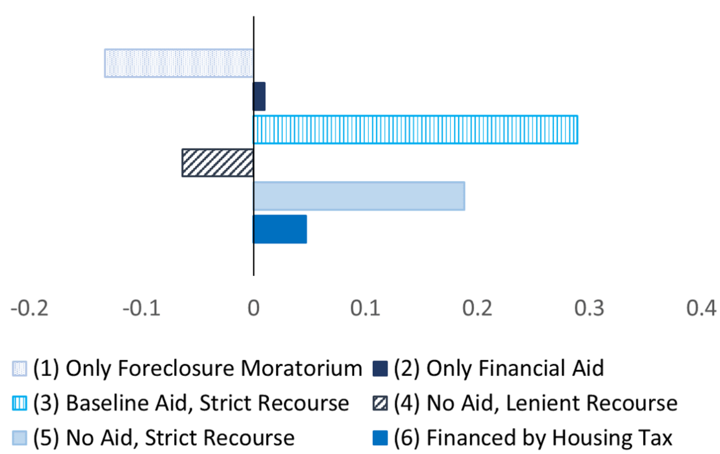
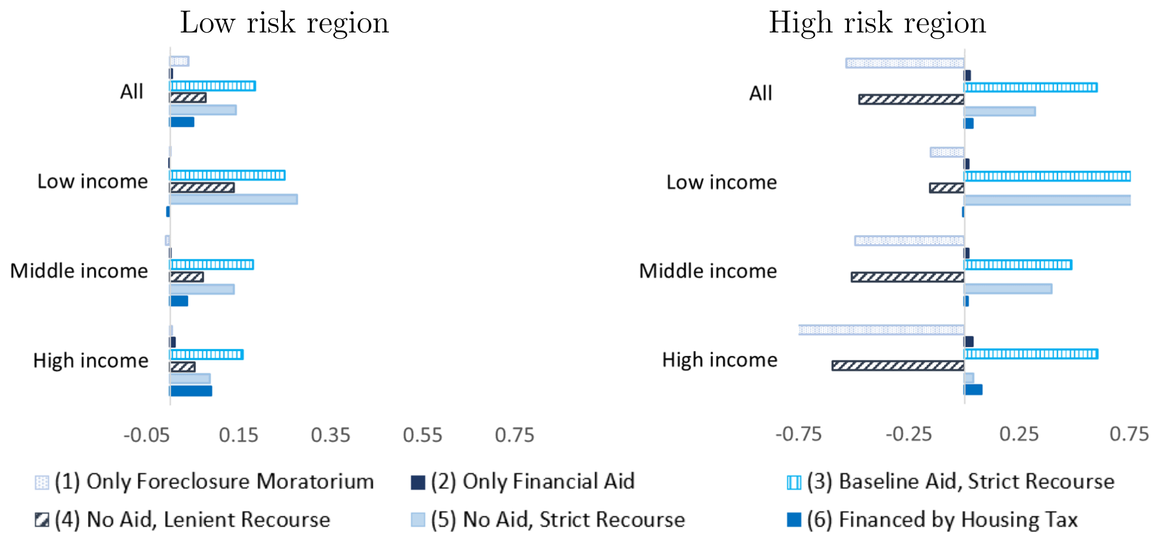


Figure 6: Welfare changes from baseline steady-state to counterfactual policy

Note: Reported welfare changes are percentage changes in average welfare from the baseline steady state to the counterfactual scenario.

Welfare Aggregate welfare changes are summarized in Figure 6. Figure 7 presents wel-



Note: Reported welfare changes are expressed in consumption equivalent variation (in percent) from the baseline steady state to the counterfactual scenario.

Figure 7: Regional differences in welfare changes

fare changes by income group and region across all policy counterfactuals. Overall, welfare changes are modest, with the most significant shifts occurring in high-risk regions. The direction of these welfare changes is heavily influenced by the recourse regime in place. For example, while removing financial aid under the current lenient recourse regime leads to aggregate welfare losses, the same policy change in a strict recourse regime results in welfare gains across both regions and all income groups. Financial aid predominantly benefits high-income households in high-risk regions, who have the highest homeownership rates and the largest homes, making them the primary recipients of financial aid. The policy counterfactual that generates the highest welfare gains is maintaining the current disaster aid while imposing a strict recourse regime. Under this scenario, mortgage rates decrease as banks anticipate that stricter recourse rules will result in higher payouts during foreclosures. Consequently, households at greater risk of default benefit from improved mortgage terms compared to the baseline scenario.

4.3 Additional counterfactuals

Policy Counterfactuals - Means-Tested Transfers: An alternative disaster aid regime implements means-tested transfers, prioritizing support for lower-income households affected by natural disasters.

Policy Counterfactuals - Mandatory Insurance Requirement: Under this counterfactual, all homeowners in disaster-prone areas are required to carry insurance. This policy change aims to reduce uninsured losses, but may impact household budgets and overall affordability of homeownership in higher-risk regions.

5 Empirics

In this section, I provide empirical evidence on responses on mortgage performance to natural disasters in the United States from 2000 to 2020.

I use the *Spatial Hazard Events and Losses Database for the US* (SHELDUS) that provides estimated monthly county-level USD damages caused by a wide range of natural disasters, including geophysical and hydrological perils. The *Fannie Mae Single-Family Mortgage Performance Dataset* provides monthly mortgage-level performance data since 2000 including information of the Metropolitan Statistical Area (MSA) of the properties' location. The final sample is a month-MSA-state panel ranging from 2000 to 2020 including around 100,000 observations and 409 different MSAs. To construct a delinquency measure $Delinquency_{mst}$ and a foreclosure measure $Foreclosure_{mst}$, I aggregate the monthly loan-level data to the MSA-state level.

$$\begin{aligned} Delinquency_{mst+h} &= \frac{\text{value of delinquent mortgages in MSA } m \text{ and state } s \text{ at time } t+h}{\text{total value of mortgages in } m \text{ and state } s \text{ at time } t-1} \\ Foreclosure_{mst+h} &= \frac{\text{value of properties foreclosed in } m \text{ and state } s \text{ at time } t+h}{\text{total value of mortgages in } m \text{ and state } s \text{ at time } t-1} \end{aligned} \tag{34}$$

To examine size-dependent responses, I group natural disasters based on the realized USD damages, defining disasters as small (S)/medium-sized (M) if damages are within the 95th and 99th percentiles and large (L) if above the 99th percentile. I define the dummy variable $D^i_{ms,t}$ that equal one if in MSA m and state s at time t a disaster of size $i \in \{S, M, L\}$ occured. Then, I estimate impulse response functions by running local projections as proposed by Jordà (2005).

$$\Delta_h Y_{ms,t+h} = \beta^S_h D^S_{ms,t} + \beta^M_h D^M_{ms,t} + \beta^L_h D^L_{ms,t} + \alpha^h_{ms} + \alpha^h_t + \epsilon_{m,t+h} \tag{35}$$

with $\Delta_h Y_{mst+h} = Y_{mst+h} - Y_{mst-1}$ and $Y_{mst+h} \in \{Delinquency_{mst+h}, Foreclosure_{mst+h}\}$. Conditional on the location, the actual realization of natural disasters can be seen as an exogenous variation. Therefore, I include region fixed effects (α_m) to account for region-specific exposure to natural disasters as well as MSA-specific regulations for disaster mitigation. Additionally, sorting of households into disaster-prone areas and differences in industry-structure might be correlated with damages and financial performances but should be covered by the fixed effects.Time fixed effects account for aggregate movements in house prices and increase in delinquencies during the great financial crisis.

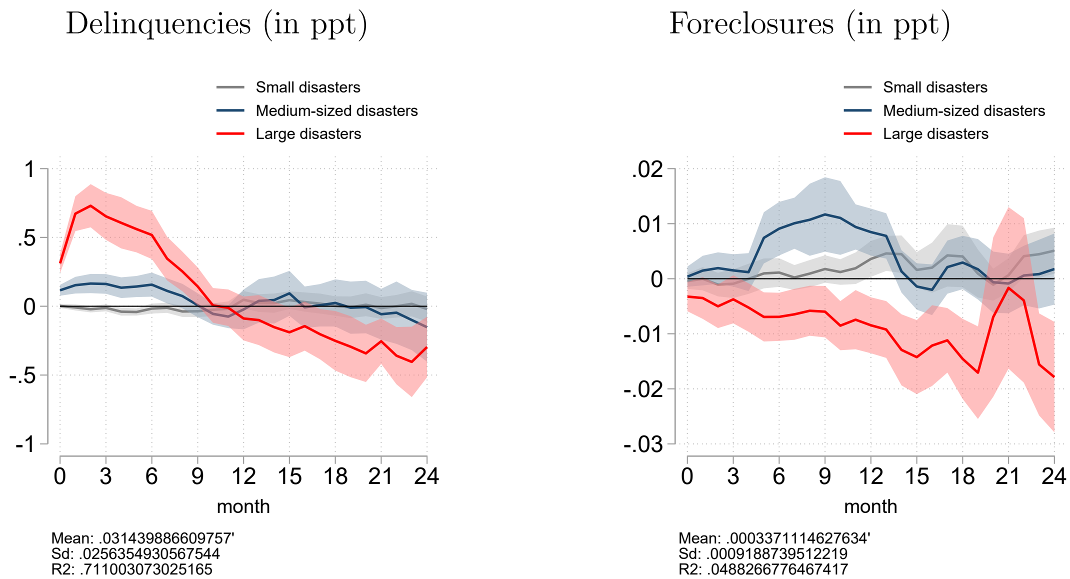


Figure 8: Impulse Response Functions
Shaded areas are 90 percent confidence bands. Standard errors are clustered on msa-level

Figure 8 depicts the impulse response functions of mortgage delinquencies and foreclosure rates following a natural disaster. Notably, households do not exhibit a discernible response to small disasters on average, but delinquencies surge after medium-scale and large disasters upon impact. However, this effect is transient. For large disasters, there is even a negative impact on delinquencies after one year. In contrast, foreclosure rates display a delayed response, increasing within the first 15 months following a medium-sized disaster, but fewer homes face foreclosure after large disasters. Hence, for large-scale natural disasters, the rise in delinquencies is not matched with a proportional rise in foreclosures.

Given that large disasters often trigger a federal disaster declaration and free up extensive financial assistance[10], I incorporate an additional specification including a dummy variable indicating federally declared disasters (see Figure 10). Interestingly, the impulse response functions of delinquency rates remain unchanged. However, the response of foreclosure rates to large disasters no longer exhibits a significant negative trend, suggesting that government assistance prompted by federal disaster declarations may alleviate foreclosure rates. Furthermore, the temporary suspension of mortgage payments may function as a form of quasi-insurance against sudden expenditure shocks. This highlights the critical importance

[10]In the U.S., disaster assistance from the Federal Emergency Management Agency (FEMA) supports homeowners through grants from the Individuals and Households Program (IHP) and Small Business Administration (SBA) loans, supplemented by aid from the National Flood Insurance Program (NFIP).

of incorporating delinquencies into the model to accurately capture the observed patterns in mortgage performance after natural disasters.

6 Conclusion

To conclude, I have developed a structural general equilibrium model to investigate the interplay between disaster aid and mortgage default. Within an incomplete market framework, my model illustrates the dual impact of natural disaster shocks—destroying housing capital and diminishing housing service utility—and the role of delinquencies, where mortgage payments are temporarily paused without leading to foreclosures. I find that financial aid reduces private insurance by 10% and increases the housing stock in disaster-prone areas by 4%. Removing financial aid displaces more low-income households after natural disasters but generates the greatest welfare losses for high-income residents in risky regions. Overall, welfare changes are modest, with the most significant shifts occurring in high-risk regions. Recourse regulation plays a key role in shaping welfare outcomes. The highest welfare gains occur under the current policy design but with a strict recourse regulation, despite widening the insurance gap and further increasing housing in high-risk areas.

Additionally, I offer empirical evidence of the financial behavior of households in the wake of natural disasters in the U.S. over the last twenty years. The data reveals a significant pattern: delinquency rates surge post-disaster, while foreclosure rates decline.

An important extension would be to analyze transition dynamics, as disaster policy reforms could improve welfare in the long run but may negatively impact current homeowners. Examining welfare effects across income groups and risk levels during the transition would offer valuable insights. Additionally, projecting a climate-induced shift in natural disaster distribution—such as increased frequency and severity—may indicate whether current policy mixes are sufficient or if new combinations, like housing taxes or mandatory insurance, are necessary to address the evolving risk landscape.

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A Appendix

A.1 Full definition of household decision problem

Consider the decision problem of agents after the realization of the labor productivity shock, the insurance coverage decision, and the realization of the natural disaster. I abstract from the insurance coverage choice as a state variable as this choice only affect liquid assets. Hence, liquid assets $b(\iota, \delta)$ can be interpreted as liquid assets after having paid insurance premia and potentially having received insurance claims and government aid. For simplicity, I write $b \equiv b(\iota, \delta)$.

A homeowner who decides to stay performing solves the following problem

$$\begin{aligned} W^{own}_{perf}(b, h, m, z, \delta) =& \max_{b'} u(c, \psi_h h) + \beta \pi_S \mathbf{E} V^{own}_{perf}(b', h, m', z', \delta') \\ \text{s.t. } c =& (1-\tau) wz + (1+r)b - b' - p_\delta \delta h - p_h(\delta)\Delta h - \mu m + \Gamma \\ & b' \geq b_{min} \\ & m' = (1 + r_m - \mu) m \end{aligned}$$

where τ is a labor income tax and Γ are governmental transfer payments. A delinquent homeowner faces the same choices as a performing homeowner but does not make any mortgage payments:

$$\begin{aligned} W^{own}_{del}(b, h, m, z, \delta) =& \max_{b'} u(c, \psi_h h) + \beta \pi_S \mathbf{E} V^{own}_{del}(b', h, m', z', \delta') \\ \text{s.t. } c =& (1-\tau) wz + (1+r)b - b' - p_\delta \delta h - p_h(\delta)\Delta h + \Gamma \\ & b' \geq b_{min} \\ & m' = (1 + r_m) m \end{aligned}$$

A household who decides to buy a new house chooses the optimal house size h from the discrete set of houses $\mathcal{H}$, a corresponding mortgage m subject to a loan-to-value limit λ, and savings in liquid bonds b':

$$W^{buy}_{perf}(b, z) = \max_{h \in \mathcal{H}_O} \left\{ W^{buy, h^1_O}_{perf}(b, z), ..., W^{buy, h^{N_O}_O}_{perf}(b, z) \right\}$$

with

$$\begin{aligned} W^{buy,h}_{perf}(b, z) =& \max_{m, b'} u(c, \psi_h h) + \beta \pi_S \mathbf{E} V^{own}_{perf}(b', h, m', z', \delta', k) \\ \text{s.t. } c =& (1-\tau) wz + (1+r)b - b' + q(b', h, m, z) m - \mu m + \Gamma - p_h(\delta)(1 + \epsilon + \Delta) h \\ & b' \geq b_{min} \\ & m \leq \lambda p_h(\delta) h \end{aligned}$$

A renter who stays a renter chooses liquid savings b' and the optimal size of the rental unit $h_R \in \mathcal{H}_R$:

$$W^{rent}_{new}(b,z,k) = \max_{h_R \in \mathcal{H}_R} \{W^{rent}_{perf}(b,h_{R_1},z,k), W^{rent}_{perf}(b,h_{R_2},z,k), ...\}$$

with

$$\begin{aligned} W^{rent,h_R}_{perf}(b,z) = & \max_{b'} u(c,h_R) + \beta\pi_S \mathbf{E} V^{rent}_{perf}(b',z') \\ & \text{s.t. } c = (1-\tau)wz + (1+r)b - b' - p_r h_R + \Gamma \\ & \quad b' \geq b_{min} \end{aligned}$$

A renter with a bad credit history chooses liquid savings b' and the size of the rental unit h_R:

$$W^{rent}_{for}(b,\omega,z) = \max_{h_R \in \mathcal{H}_R} \{W^{rent,h^1_R}_{for}(b,\omega,z), ..., W^{rent,h^{N_R}_R}_{for}(b,\omega,z)\}$$

with

$$\begin{aligned} W^{rent,h_R}_{for}(b,\omega,z) = & \max_{b'} u(c,h_R) + \beta\pi_S \mathbf{E} V^{rent}_{for}(b',\omega,z') \\ & \text{s.t. } c = \max\{\underline{y}, (1-\tau)(1-\omega)wz\} + (1+r)b - b' - p_r h_R + \Gamma \\ & \quad b' \geq b_{min} \end{aligned}$$

A.2 Calibration

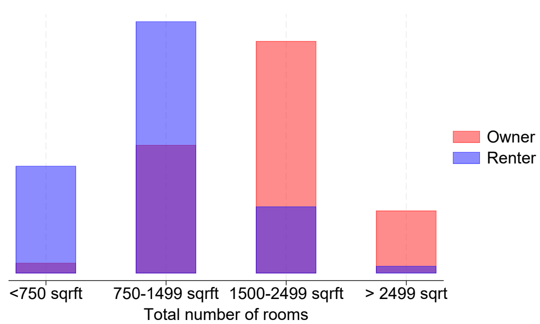

Figure 9: Segmentation of housing market (AHS, 2021)

	Parameter	Value	Source/Details
Utility			
β	Discounting	0.98	6-month frequency
α	Consumption share	0.859	Mitman (2016)
σ	CRRA parameter	2	Standard assumption
π_S	Survival probability	0.99	Life expectancy of 50 years
σ_ϵ	Variance of taste shock	0.05	
Income process			
ρ_z	Autocorrelation	0.97	Kaplan et al. (2020)
σ_z	Standard deviation	0.2	Kaplan et al. (2020)
Financial markets			
$\underline{b}$	Budget constraint	0	No uncollateralized borrowing
π_F	Probability of foreclosure	0.015	Own estimation
ϵ_F	Inefficiency of foreclosure	0.22	Kaplan et al. (2020)
$\bar{\omega}$	Maximum wage garnishment	0.15	Federal Wage Garnishment Law
π_P	Leaving garnishment stage	0.1	Avg. duration of 5 yrs (Chapter 13)
π_R	Probability of recourse	0.1	Mitman (2016)
r	Risk free rate	0.015	Mitman (2016) in 6-month frequency
r_m	Intermediation wedge	0.33	Mitman (2016)
λ	LTV limit	0.8	Berger et al. (2018)
b_{exemp}	Asset exemptions	0.16	U.S. wild card exemptions
Housing			
ϵ	Proportional transaction costs	0.1	Chatterjee & Eyigungor (2015)
N^{H_R}	Number of grid points	3	AHS (2021)
N^{H_O}	Number of grid points	3	AHS (2021)
$\Delta_{\mathcal{H}}$	Normalized grid points	$[1, 1.3, 2.1, 3.2]$	AHS (2021)
ν	Efficiency of rebuilding	1.0	Same labor productivity across sectors
Production			
Θ	Labor productivity	1	Normalize total output to one
ξ	Labor share of production	0.6	Kaplan et al. (2020)
Government			
τ_0	Baseline income tax	0.136	Average income tax paid in the US
$\bar{\tau}_\delta$	Maximum disaster aid	1.26	Maximum grants as reported by FEMA
Natural disasters			
δ	Share of destruction	0.25	NFIP claims transactions
θ	Probability of damages	[0.0008, 0.0045]	Based on the National Risk Index
Private insurance			
q_ι	Administrative fees	0.33	Expense ratios of policy claims

Table 5: External Calibration of Parameters

A.3 Empirical Results

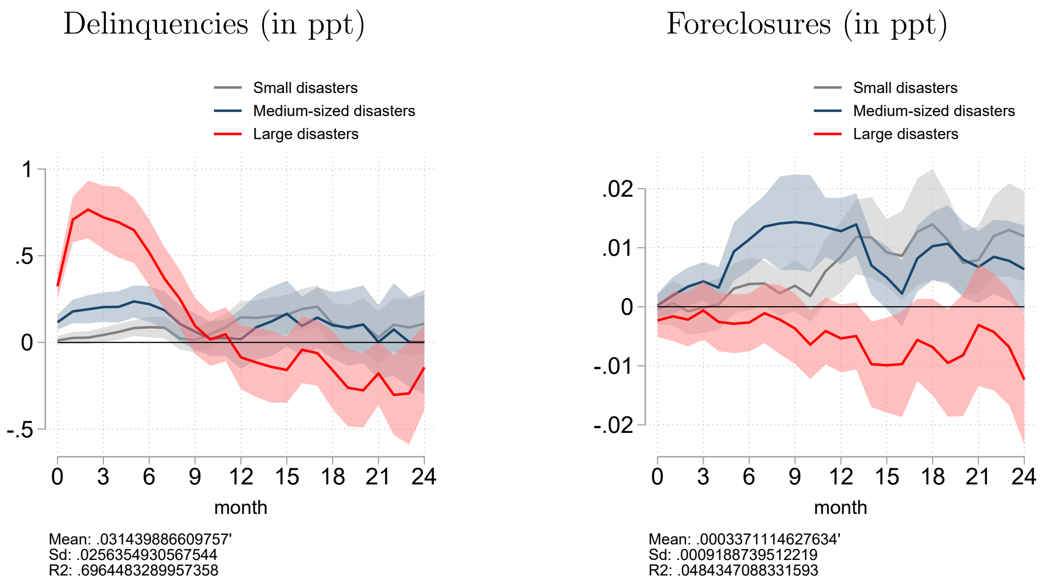

Figure 10: Impulse response functions (including a dummy for disaster declarations)
Shaded areas are 90 percent confidence bands. Standard errors are clustered on msa-level