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Are Bank Bailouts Welfare Improving?

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Abstract

The financial sector bailouts seen during the Great Recession generated substantial opposition and controversy. We assess the welfare benefits of government-funded emergency support to the financial sector, taking into account its effects on risk-taking incentives. In our quantitative general equilibrium model, the financial crisis probability depends on financial intermediaries' balance sheet choices, influenced by capital adequacy constraints and ex ante known emergency support provisions. These policy tools interact to make financial sector bailouts welfare improving when capital adequacy constraints are consistent with the current Basel III regulation, but potentially welfare decreasing with looser capital adequacy regulation existing before the Great Recession.

Topics: Financial system regulations and policies; Financial institutions; Financial stability
JEL codes: E44, D62, G01, E32

1 Introduction

The global financial crisis of 2008–2009 significantly disrupted financial markets and macroeconomic activity around the world, prompting unprecedented fiscal and monetary support measures aimed at alleviating the financial system stress. Publicly funded bailouts[1] of commercial financial institutions during the onset of the Great Financial Crisis generated substantial objections and social discontent.[2] Staggering immediate outlays and uncertain returns led to concerns whether the expected societal benefits of supporting distressed financial institutions justified their costs. In retrospect, the bailouts helped contain the extent of failures and dislocations in the financial markets and the broader economy.[3] Moreover, the bailouts turned out to be less costly for the public finances than initially feared, as government agencies realized capital gains on private assets acquired at fire sale prices.[4] Despite positive aspects, a longer-term concern remains if public interventions have created an expectation of implicit public guarantees for the liabilities of private financial institutions. Such expectations may increase future financial risks by incentivizing higher levels of leverage and risk taking. These concerns are likely alleviated to some extent by tighter financial regulation and supervision measures introduced as part of the Basel III initiative after the Great Financial Crisis. However, it is also possible that enhanced bailout expectations at least partially undermined the beneficial impact of tighter regulatory measures. Using a carefully calibrated structural model, we examine if financial bailouts during banking crises are welfare beneficial once their impact on risk taking and the crisis probability is considered. Our analysis shows that generous government support during a crisis is welfare improving, provided capital adequacy regulation is sufficiently tight.

[1] In line with the literature, we refer to financial sector emergency support measures as financial bailouts or bank bailouts.

[2] The article "Occupy Wall Street, Tea Party Movements Both Born of Bank Bailouts" argues that both protest movements emerged in response to bailouts. See https://www.foxbusiness.com/markets/occupy-wall-street-tea-party-movements-both-born-of-bank-bailouts.

[3] Twelve of the 13 most important U.S. financial firms were at the brink of failure in 2008, according to remarks made by Federal Reserve Chairman Ben Bernanke to an investigative panel.

[4] As of February 18, 2021, Bailout Tracker online project estimates a profit of $110 billion on $634 billion of bailout outflows. See projects.propublica.org/bailout/ for detailed information.

The rarity of widespread financial crises, the unobserved nature of bailout expectations, and cross-country differences in financial regulation make it nearly impossible to assess the welfare benefits of bailouts with purely empirical evidence. The alternative route we take is to build a well-calibrated macroeconomic model in which financial institutions can adjust the riskiness of their asset and liability positions in response to expected future bailouts. These adjustments in balance sheet positions of financial institutions increase their default probability, making widespread bank crises more probable. Bank crises are costly from a societal point of view, and government support alleviates crises costs. More specifically, in our general equilibrium model, which builds on Stein (2012), private banks invest in risky assets while issuing liquid callable deposits and less liquid time deposits. Callable liabilities are calibrated to match the amount of uninsured demand deposits and short-term liabilities on the balance sheets of U.S. depository institutions. The fragile nature of these liabilities creates the risk of premature withdrawals leading to occasional bank runs and asset fire sales. As in real life, it is never optimal in our model to eliminate the callable liabilities, as they provide valued liquidity services to households. The model is carefully calibrated to match key features of the U.S. economy and its financial sector, including the historical prevalence of severe financial crises and their estimated costs. As discussed in the literature review section, most existing studies of bank defaults, fire sale events, and financial bailouts use more stylized models. This makes it difficult for policymakers to quantify the likely costs and benefits of government interventions.

In our model, the financial crisis probability depends on financial intermediaries' balance sheet choices, influenced by two policy tools: capital adequacy regulation and ex ante anticipated bailouts. We find that these tools interact in a non-linear way to make bailouts welfare improving when capital adequacy constraints are consistent with Basel III regulation, but likely welfare decreasing when capital adequacy constraints are at lower levels seen before the Great Recession. Moreover, tighter capital adequacy constraints introduced by the Basel III reform are themselves highly welfare beneficial. They contribute to greater financial stability and significantly increase household wealth. Since future financial crises and bailouts are likely unavoidable, policymakers and regulators play an instrumental role in preserving and enforcing tighter capital adequacy requirements introduced in response to the Great Financial Crisis.

The paper is organized as follows. Section 2 discusses related literature. Section 3 describes our model. This is followed by Section 4, devoted to the calibration of the model. Section 5 presents results from the benchmark model as well as from a version of our model with exogenous distress probability. We conclude in section 6.

2 Context and related literature

The Great Financial Crisis has shown that bank runs and associated fire sales of assets remain a relevant concern for policymakers. While deposit insurance practically eliminated bank panics associated with rapid household deposit withdrawals, new types of short-term liabilities, prevalent among financial institutions, have become a source of financial fragility.

Financial crises associated with bank runs were quite common in the United States before deposit insurance was introduced (Figure 1). The dashed red spikes mark the financial crises. Economic downturns often accompanied these crisis episodes (Figure 1, solid line).

After a long quiet period without crises, the change in the composition of short-term funding from retail to wholesale (Figure 2) has created another fragile type of funding, as was evident during the 2008–09 financial crisis. Gorton and Metrick (2012) documented how securitized wholesale funding emerged as a new source of financial fragility. As the signs of financial sector distress mounted, financial institutions and corporations started to run on distressed intermediaries, rapidly withdrawing their funds or increasing their collateral requirements. Figure 3 illustrates how the costs of repurchase (repo) refinancing grew from almost zero in July 2007 to 46 percent haircuts by January 2009.[5] In response to

[5] Gorton (2012) provides a detailed discussion of the relationship between bank funding and financial crises.

these dramatic developments, central banks and other government institutions across the world stepped in with unprecedented support measures. These measures included publicly funded emergency loans to private financial institutions, equity injections, and asset return guarantees extended to private investment entities acquiring assets of distressed financial institutions. Notably, the bailout support coverage was not universal, as some financial institutions were not rescued.

As with any insurance, implicit or explicit public support guarantees create an incentive to take on higher than prudent amounts of financial risks. Poole (2008) succinctly describes the problem, namely that "bailouts unavoidably increase inappropriate risk taking." Despite this conclusion, he states that the Federal Reserve Bank's emergency support measures during financial crises are essential, as they help to avoid much higher costs of financial market disruptions and dislocations. He advocates transparent and systematic support facilities rather than ad hoc case-by-case bailouts. Shortly after Poole's article was published, the Federal Reserve facilitated JPMorgan Chase's acquisition of Bear Stearns in March 2008. Then, in the fall of 2008, the Federal Reserve assisted with the acquisition of Washington Mutual and the rescue of AIG while letting Lehman Brothers fail. Given that many of the emergency measures undertaken in 2008 and 2009 were improvised and unconventional, the question remains if they created an expectation of future government interventions, promoting imprudent risk taking and elevating the chances of future financial crises. Tighter financial regulation likely alleviated these concerns to some extent. The Basel III (BIS 2011) international framework developed in response to the Great Financial Crisis requires additional capital buffers and liquidity provisions to reduce the probability of future crises. However, the experience shows that ever-present financial engineering (Coskun 2011) and deregulation lobbying efforts often lead to the erosion of regulatory safeguards and controls. In December 2018, the Former Federal Reserve Chair, Janet Yellen, voiced her concerns that there could be another financial crisis because banking regulators have seen reductions in their authority to address panics amid the current push to deregulate

(Yellen 2018). The recently adopted "Economic Growth, Regulatory Relief, and Consumer Protection Act" (U.S. Congress 2018) is an example of such a financial deregulation push in the United States. Münnich (2016) discusses the lack of fundamental change in British and German financial regulation following the 2008 credit crunch. In addition, the high levels of government, corporate, and household debt and elevated housing prices in many countries prompted warnings by the Bank for International Settlements (Borio 2018) that the global economy faces the risk of another financial crisis. A recent spurt in public debt accumulation during the ongoing COVID pandemic made this problem more acute. Even in the absence of regulatory erosion, it is possible that enhanced bailout expectations undermine the effectiveness of tighter regulation.

There are many challenges for reliably assessing the impact of bailouts on risk taking and the probability of future crises. First, the widespread banking crises and bailouts are relatively rare events, making it challenging to establish a cause-and-effect link between them or to assess changes in crisis probabilities. Second, the private expectations of future bailouts are unobservable, which makes it hard to ascertain if changes in risk-taking behavior of financial institutions are driven by past bailouts or by other factors, such as the current credit or business cycle conditions. Nevertheless, Hett and Schmitt (2017) use firm-specific credit spreads and equity returns to assess the effects of 2008 bailouts on expectations of future bailouts in the U.S. They find that bailout expectations peaked in reaction to government interventions following the failure of Lehman Brothers in September 2008 and returned to pre-crisis levels following the initiation of the U.S. Dodd-Frank financial regulation act in 2010. While the decline in measured bailout expectations is consistent with the new regulation being effective at containing risks, it could also reflect the general stabilization in the financial markets after the worst phase of the financial crunch had passed by 2010.

Dam and Koetter (2012) analyzed all observed capital preservation measures and distressed exits in the German banking industry during 1995–2006. Using regional political differences, they identified that the stronger expectations of bank bailouts in a particular region due to political factors lead to increased risk taking and a higher probability of defaults. These empirical studies give support to the idea that bailouts are likely to increase risk taking by financial institutions. They, however, have a limited ability to determine if the welfare benefits of systematic bailouts outweigh their costs. Structural theoretical models with bank runs and bailouts can help in this respect.

There exist many excellent theoretical studies of the welfare benefits of bank bailouts. They, however, are often too stylized to give a quantitative assessment and focus instead on general theoretical predictions from a dynamic model, often with just two- or three-period horizons. A few examples of such papers are Keister (2015), Gorton and Huang (2004), Farhi and Tirole (2012), and Diamond and Rajan (2002, 2012), who all study the effects of bailouts in various versions of the Diamond and Dybvig (1983) three-period model.

Several papers consider bailouts in infinite-horizon models, which are more suitable for quantitative assessments. They, however, often are stylized along some other dimensions, thus limiting their quantitative insights for policymakers. For example, the model by Chari and Kehoe (2016) analyzes bailouts in a model in which there is neither physical capital nor any other physical links between periods. Bianchi (2016) abstracts from financial institutions and analyzes bailouts that relax borrowing constraints of all firms in the economy while also restricting households from holding debt instruments. Gertler et al. (2012) develop a model in which banks have access to debt and equity financing from households. However, the absence of bank defaults in their model makes it hard to link their credit policy recommendations to bank bailout policies.

Angeloni and Faia (2013) provide a tractable quantitative model in which the probability of a banking crisis depends on banks' leverage choices. The absence of asset fire sales and the exogenously fixed costs of banking crises in their model make it difficult to assess the welfare benefits of bailouts reliably.

Collard et al. (2017) provide a quantitative model with monetary policy and regulations, in which the optimal policy implies no risk taking. This model feature makes it difficult to generalize their optimal policy results to problems where some amount of financial risk taking is socially desirable.

We view our framework as complementary to recent quantitative, general-equilibrium models analyzing the welfare benefits of capital adequacy requirements, including Begenau and Landvoigt (2021), Begenau (2020), Nguyen (2014), Canzoneri et al. (2020), Davydiuk (2018), and Elenev et al. (2021). These authors built rich quantitative models which are well suited for analyzing the welfare implications of capital requirements over the business cycle. Our modeling framework is different in two main respects. First, we focus on explicitly defined bailout insurance arrangements active only during systemic bank crises with widespread bank defaults. In contrast, in most of the papers mentioned above, bailouts are implicitly defined as a part of universal deposit insurance available in all periods.[6] Second, panic asset liquidations with deep fire sale discounts, as seen during the Great Financial Crisis, serve as important shock propagation vehicles in our model but not in the above-listed studies.

More specifically, our paper augments the stylized model of Stein (2012) and uses it to analyze the effects of bank bailouts on the endogenously determined probability of banking crises. The model is carefully calibrated to match a) key macroeconomic moments of the U.S. economy and its financial sector, b) the financial crisis costs, and c) the frequency of severe financial crises in the historical U.S. data. Our framework has a rich financial structure that makes it suitable for analyzing bailout policies. First, the model features banks that issue callable short-term liabilities (in addition to other liabilities) that can be withdrawn on demand. When short-term liabilities are withdrawn prematurely, banks are forced to sell claims to their illiquid assets at fire sale prices. In the calibrated model, banks issue too much short-term debt relative to the socially optimal level, leaving the financial system vulnerable to costly financial crises. Moreover, the output costs of financial panics

[6] The exception is Nguyen (2014), who assumes random bailout eligibility for regulated banks. Begenau and Landvoigt (2021) allow for randomized bailouts of unregulated shadow banks in addition to universal deposit coverage of regulated banks.

are increasing endogenously in the amount of short-term liabilities on the balance sheets of financial institutions, as in Stein (2012). Most importantly, the financial crisis probability is linked to the balance sheet positions of financial institutions, and some positive amount of risk taking is always desirable. When policies change, banks optimally adjust their asset and liability positions, thus creating feedback from policies to crisis probabilities. Policy tools available in this model include a systematic, publicly funded bailout support framework activated during financial panics and asset fire sales. The bailout support is provided as a return guarantee for buyers of assets purchased from bailout-eligible banks. Importantly, we allow for lottery-like randomness in bailout eligibility criteria to create some ex ante uncertainty for individual banks concerning ex post bailout outcomes.

3 A model of bank runs and fire sales

The model has five decision makers: banks, patient investor firms, producers, households, and the government. The core of the model is the financial sector that admits bank runs and fire sales of assets. It consists of two types of intermediaries: banks and patient investors. Output producers require external financing and obtain funds from these financial intermediaries. We follow Stein (2012) and abstract from financing frictions between good producers and their financial intermediaries. Instead producers are directly and exclusively controlled by either banks or patient investors, depending on their source of funding. Banks and patient investors collect investment returns from their producer firms and use proceeds to pay deposit returns, bond returns, and equity returns to the households.

The resolution of uncertainty and the timing of events play an important role in generating bank runs and asset fire sales in our model. Figure 4 provides a visual guide for the sequence of events in a generic period of this economy. Production and asset return payments take place at the beginning of period t, right after the current aggregate labour productivity z_t is realized. After the settlement of liabilities issued in the previous period

$t-1$, all pre-existing financial intermediaries are dissolved. Instead, equal measures of identical new banks and identical new patient investor firms (PIs) are created. Immediately after their establishment, new banks and patient investor firms raise capital from the households. These two intermediaries differ regarding the types of liabilities they issue and the timing of their investments into illiquid assets of good producers. Focusing on the timing of investments, banks finance producers that have up-front capital financing needs in each period, while patient investors specialize in financing projects that can delay their illiquid capital acquisitions till later in the period.[7] Thus, banks immediately make irreversible investments into illiquid productive assets, while patient investors can wait for fire sale opportunities before investing into illiquid capital.

Banks' investments are funded by issuing bank equity and two kinds of debt instruments: 1) term liabilities, which we further call *bonds*; and 2) callable liabilities, which we further refer to as *callable deposits*. The bonds issued in period t may not be withdrawn early and must be held to maturity, which happens after production takes place at the beginning of next period $t+1$. In contrast, callable deposits may be withdrawn early. The decision to withdraw callable deposits is tied to an aggregate public signal, named the *financial distress signal*. The realized value of the distress signal is revealed in each period after banks raise funds from households and invest them into illiquid assets. With probability p_t, the distress signal is one (i.e. affirmative), indicating that all bank-financed investment projects might lose a fraction $(1-\lambda)$ of their total output (a severe financial crisis state). This signal prompts households to withdraw all of their callable deposits, i.e. run on banks, in order to avoid potential losses. The premature deposit withdrawals force banks to liquidate their assets at fire sale prices. The presence of patient investors is crucial for the existence of fire sales, allowing banks to raise funds when deposits are withdrawn prematurely. Specifically, banks can sell ownership rights of their illiquid investments to patient investors. As described

[7] As explained in Stein (2012, page 68), in a model without endogenous defaults, this assumption of full specialization and full separation between banks and patient investors is made without loss of generality. In our model with endogenous bank defaults, it affects the default probabilities and thus has an impact on our calibrated parameter values.

further below, the government in our model may partially insure patient investors' returns against the event that the acquired bank-financed projects suffer an output loss in a severe financial crisis.

As explained in section 3.4, we endogenize the likelihood of a bank run by assuming that the probability of a positive distress signal p_t in any given period is equal to the default probability which is common across banks.

The rest of this section describes the decisions of various agents in the economy conditional on an aggregate state $S_t = \{W_t, z_t\}$. The endogenous state variable W_t is the total wealth of the representative household to be divided between consumption and investments in period t. This wealth is realized after asset returns and wages are paid to the representative household at the beginning of period t. To simplify notation, we will assume that a period t subscript on any variable X_t represents the dependence of this variable on the current aggregate state $S_t = \{W_t, z_t\}$. We will also often use $X_{t+1|\psi_t}$ notation to represent the realization of a variable at the beginning of period $t+1$, conditional on a period t financial distress state ψ_t, i.e. $X\left(W_{t+1}, z_{t+1}|\psi_t\right)$. There are three possible financial distress states indexed by $\psi_t \in \{1,2,3\}$. State $\psi_t = 1$ is the most likely *normal times* state. This state realizes whenever the distress signal is zero, revealing that no financial distress is happening in the current period t. States $\psi_t = \{2,3\}$ are *bank-run* states. States 2 and 3 are preceded by a positive financial distress signal that realizes with the endogenous probability p_t and triggers a bank run by informing all agents that only states $\psi_t = 2$ or $\psi_t = 3$ are possible in the current period. The actual period t crisis state $\psi_t = 2$ or $\psi_t = 3$ is revealed at the end of period t, after all of the period t decisions are irreversible.

The state $\psi_t = 2$ is an aggregate state in which expected output losses for bank-financed investment projects do not actually materialize. The banking sector as a whole doesn't experience any further problems and production runs smoothly in period $t+1$. Patient investors realize a capital gain on their fire sale asset purchases, thus avoiding the need for government-provided insurance. The state $\psi_t = 2$ happens with probability $\phi_{2,t} = p_t\left(1-q\right)$

and is further called a *mild crisis* state. Note that a mild financial crisis still inflicts an output loss because the funds withdrawn from the financial system prematurely are not used in current production.

The state $\psi_t = 3$ is an aggregate state in which bank-financed investment projects suffer a loss of $(1 - \lambda)$ per unit of total output that would have been produced under $\psi_t \in \{1, 2\}$ states. The banking sector defaults on its liabilities to patient investors. Patient investors receive an insurance payment from the government, partially recovering losses on insured assets. The state $\psi_t = 3$ happens with probability $\phi_{3,t} = p_t q$ and is further referred to as a *severe crisis* state.

Period $t+1$ starts when the aggregate labour productivity z_{t+1} is realized. Production and asset return payments take place right after z_{t+1} is realized. After settlement of liabilities issued in the previous period t, all financial intermediaries established in that period are dissolved, thus giving way to new banks and patient investors.

3.1 The household problem

At the beginning of each period, the households supply a unit of labour services to each producer firm, in both bank-financed and patient investor–financed sectors. After the production takes place, households receive labour income, interest payments, and dividends and also pay lump-sum government taxes. These receipts and payments constitute the realized household wealth at the beginning of period t. Households consume a part of this wealth and lend the rest to banks and patient investors. It is convenient to state the representative household's problem at the point in time when households are making these consumption and savings decisions. The problem can be stated in a recursive form:

$$V_t = \max_{\substack{C_t,\, D_t^h,\, A_t^h \\ Z_t,\, N_t}} u\left(C_t\right) + v\left(D_t^h\right) + \beta \mathbf{E}_t \left[\sum_{\psi_t=1}^{3} \phi_{\psi,t} V_{t+1}\right] \tag{1}$$

subject to

$$C_t + Z_t + \frac{D_t^h}{R_t} + \frac{A_t^h}{R_t^A} + N_t \leq W_t \tag{2}$$

$$W_{t+1} = \begin{pmatrix} D_t^h - 1_{\psi_t \in \{2,3\}} \delta D_t^h \\ +A_t^h + R_{t+1}^Z Z_t + R_{t+1}^N N_t \\ +w_{t+1}^P h_{t+1}^P + w_{t+1}^B h_{t+1}^B - T_{t+1} \end{pmatrix} \tag{3}$$

$$h_{t+1}^P = 1 \text{ and } h_{t+1}^B = 1. \tag{4}$$

Here A_t^h are one-period bonds (issued by either banks or patient investors) and D_t^h are callable deposits. $\frac{1}{R_t}$ is the discount price of callable deposits and $\frac{1}{R_t^A}$ is the discount price of bonds. As mentioned before, bonds must be held to maturity, while callable deposits can be withdrawn early. Specifically, households pull their deposits out of banks upon arrival of a positive financial distress signal. The cost of premature withdrawals for depositors is that they must store withdrawn assets till the next period, incurring a depreciation/storage cost at the rate of δ per unit of deposits. Thus, the realized return on deposits in period $t+1$ is going to be lower during a bank run episode, as reflected here by the indicator function $1_{\psi_t \in \{2,3\}}$, which is equal to zero if $\psi_t = 1$ and one otherwise. Z_t is banks-issued equity, while N_t is patient investors–issued equity. R_{t+1}^Z and R_{t+1}^N are their corresponding state-contingent equity returns in period $t+1$. Each household supplies two units of labour services, which are divided equally between producers funded by banks and by patient investors: $h_{t+1}^B = 1$ and $h_{t+1}^P = 1$. In exchange, households receive sector-specific real wages w_{t+1}^B and w_{t+1}^P from banks and patient investors. T_{t+1} is the lump-sum tax collected by the government. The term $v\left(D_t^h\right)$ represents the utility value (or the liquidity service) from holding callable deposits. This value is the peace of mind households receive from being able to withdraw deposits at any time and adds to households' utility regardless of whether deposits are withdrawn prematurely after a distress signal.

With the assumed functional form of the utility function $\frac{(C)^{1-\sigma}-1}{1-\sigma}+\gamma\frac{\left(D^{h}\right)^{1-\sigma}-1}{1-\sigma}$, the optimal allocation of wealth between consumption and the household asset portfolio implies the following first-order optimality condition relating the return on bonds and on callable deposits:

$$\left(\frac{R_t^A}{R_t}-1\right)\mathbf{E}_t\sum_{\psi_t=1}^{3}\Lambda_{t+1|\psi_t}=\gamma\left[D_t^h\right]^{-\sigma}-\delta\mathbf{E}\left(\Lambda_{t+1|2}+\Lambda_{t+1|3}\right),$$

where $\Lambda_{t+1|\psi_t}$ represents the household's marginal utility of income in period $t+1$, conditional on a realized value of ψ_t. Other things equal, the supply of callable deposits by the households is diminishing in the size of the spread $\frac{R_t^A}{R_t}$. Intuitively, a larger spread increases the opportunity cost of callable deposits relative to bonds.

3.2 Financial sector and production of goods

The financial sector consists of an equal number of banks and patient investors, a measure one of each. All producers are exposed to the same aggregate labour productivity process, irrespective of whether they are financed by banks or patient investors:

$$\log z_{t+1}=\rho_z\log z_t+\varepsilon_{z,t+1},\ \ \varepsilon_{z,t+1}\sim N\left(0,\sigma_z^2\right). \tag{5}$$

In addition, banks are exposed to a log-normally distributed idiosyncratic revenue shock, $\log(\zeta)\sim N\left(0,\sigma_\zeta^2\right)$, realizing each period at the same time as the aggregate labour productivity shock, z_t. The idiosyncratic revenue shocks capture the cross-sectional variation in the revenue of banks and give rise to potential bank insolvencies and bank runs.

3.2.1 A bank's problem

Banks rely on three sources of funding: equity Z_t, bonds A_t^B, and callable deposits D_t. Callable deposits are not insured by the government, and in case of insolvency, are junior liabilities relative to bonds.[8] Thus a financial distress signal triggers premature deposit withdrawals from banks as households rush to ensure their safety. From the banks' point of view, callable deposits carry a lower cost of financing, as the interest rate on these deposits is lower than the one on bonds. The disadvantage is that premature withdrawals of callable deposits force banks to sell ownership rights to their illiquid assets at fire sale prices. Banks are facing a market-enforced borrowing constraint on the maximum proportion of their total liabilities funded by callable deposits. These borrowing constraints ensure banks' ability to repay callable deposits in case of a bank run. Individual banks treat the market-imposed limit on callable deposits as exogenous; however, their joint choices have a direct impact on the equilibrium upper bound. This collateral constraint gives rise to a standard pecuniary externality, since the banks treat the fire sale price as independent of their own actions.

To obtain the upper bound, we need to consider the amount of callable deposits the bank can repay under any circumstances given the equilibrium fire sale asset prices. The banks need to raise at least D_t to pay their depositors in case of a bank run.[9] We assume that the banks can sell/pledge ownership rights only to the capital share of output and only in a mild financial crisis state ($\psi_t = 2$).[10] The liquidation price of assets depends on whether the government supports this liquidation providing partial insurance to asset buyers. The probability that the government supports asset acquisition from a particular bank is a time-invariant policy parameter $\eta \in [0, 1]$. This eligibility randomization is designed to create some uncertainty for individual banks with regard to their ex post eligibility for government assistance. For a specific bank, eligibility is determined by a random draw conducted by the government bailout agency. With probability η, the bank wins the eligibility draw, in which case the government partly insures returns of patient investors buying this bank's assets.

[8] Bonds (callable deposits) in the calibrated model represent less (more) fragile sources of funding for financial institutions. Bonds stand for actual bond borrowing, but also insured household deposits. Callable deposits refer to uninsured corporate deposits and repos.

[9] We are making a simplifying assumption that prematurely withdrawn deposits do not incur a penalty fee, so the entire amount D_t may be withdrawn early.

[10] We exclude the revenue in the severe financial crisis state, $\psi_t = 3$, assuming that bond holders' debt has seniority over the patient investors' debt. Allowing banks to pledge the value of assets even in a severe crisis leads to a much higher share of short-term borrowing than in the data.

With probability $(1-\eta)$, the bank is not eligible, in which case the government does not offer any asset return guarantees to patient investors buying this bank's assets. In either case, the bank would have to liquidate enough assets to be able to return D_t to depositors. Ex ante, any given bank expects two possibilities: a high price of their liquidated assets κ_t^H with probability η and a low price of their liquidated assets κ_t^L with probability $(1-\eta)$. The fire sale prices, κ_t^H and κ_t^L, are taken as given by banks and are determined in equilibrium to clear the insured and uninsured fire sale markets.

Given these two possibilities, the expected fire sale value of the bank's assets,

$$\left\{\eta\kappa_t^H + (1-\eta)\kappa_t^L\right\}\mathbf{E}_t\left\{\int \zeta\left[(1-\delta)K_t^B + \theta z^B\left(K_t^B\right)^\theta\left(z_{t+1}L_{t+1|\psi_t}^B\right)^{1-\theta}\right]f(\zeta)\,d\zeta\ |\psi_t = 2\right\},$$

excludes the labour share of output $(1-\theta)z^B\left(K_t^B\right)^\theta\left(z_{t+1}L_{t+1|\psi_t}^B\right)^{1-\theta}$ as well as any revenue generated in the severe financial crisis state ($\psi_t = 3$). Here K_t^B represents the total amount of illiquid capital purchased by bank-financed producers

$$K_t^B \equiv Z_t + \frac{A_t^B}{R_t^A} + \frac{D_t}{R_t},$$

while $L_{t+1|\psi_t}^B$ is their labour demand realized at the beginning of period $t+1$. The expectation operator $\mathbf{E}_t[*]$ here and everywhere else is defined with respect to future realization of the labour productivity, z_{t+1}, and is conditional on the current state $S_t = \{W_t, z_t\}$.

Given the uncertainty regarding bailout eligibility, the maximum amount of callable deposits a specific bank can repay under any circumstances is bounded by the lower fire sale price of κ_t^L. The borrowing constraint can also be stated as a fraction of total capital raised by banks

$$\frac{D_t}{K_t^B} \leq d_t^{\max} \equiv \kappa_t^L\mathbf{E}_t\int \zeta\left[\left(1-\delta+\theta z^B\left(K_t^B\right)^{\theta-1}\left(z_{t+1}L_{t+1|2}^B\right)^{1-\theta}\right)\right]d\zeta. \tag{6}$$

Note that banks take the maximum deposit-to-capital ratio $d_t^{\max}$ as being a credit limit independent of their own actions.

Now we present a bank's profit maximization problem, taking into account the owner's valuations of the future states $\left(\Lambda_{t+1|\psi_t}\right)$ as well as the presence of idiosyncratic shocks, ζ, to the revenue of banks.

$$\max_{\substack{Z_t,\, K_t^B,\, A_t^B,\\ D_t,\, L_{t+1|\psi_t}^B}} \mathbf{E}_t \left(\begin{array}{c} \sum_{\psi_t=1}^{3} \Lambda_{t+1|\psi_t} \left(\begin{array}{c} \varphi_{\psi_t} \int \zeta \left[(1-\delta) K_t^B + z^B \left(K_t^B\right)^{\theta} \left(z_{t+1} L_{t+1|2}^B \right)^{1-\theta} \right] f(\zeta)\, d\zeta \\ -w_{t+1|\psi_t}^B L_{t+1|\psi_t}^B - A_t^B - D_t - Z_t R_{t+1|\psi_t}^Z \end{array} \right) \\ + \left[\left(\Lambda_{t+1|2} + \Lambda_{t+1|3} \right) - \Lambda_{t+1|2} \left(\frac{\eta}{\kappa_t^H} + \frac{1-\eta}{\kappa_t^L} \right) \right] D_t \end{array} \right)$$

subject to

$$K_t^B = \frac{D_t}{R_t} + \frac{A_t^B}{R_t^A} + Z_t$$

$$\frac{D_t}{K_t^B} \leq d_t^{\max}$$

$$\omega \leq \frac{Z_t}{K_t^B}$$

The term $\left[-\Lambda_{t+1|2} \left(\frac{\eta}{\kappa_t^H} + \frac{1-\eta}{\kappa_t^L} \right) \right] D_t$ in the bank's problem reflects the uncertainty a particular bank faces with regard to its eligibility for government bailout assistance.[11] The parameter φ_{ψ_t} in front of the production function is equal to $\lambda \in (0,1)$ in a severe financial crisis state $(\psi_t = 3)$ and is equal to one otherwise. This state-contingent productivity parameter captures our assumption that a fraction $(1-\lambda)$ of total output of the bank-financed sector is lost in a severe crisis.

The parameter ω in the last inequality stands for the minimum capital requirement ratio imposed by banking sector regulators. Given perfect competition and the lack of any tax

[11] Note that both bonds A_t^B and callable deposits D_t are assumed to offer "safe" returns, which do not depend on the realization of the future state S_{t+1}. This is a simplifying assumption in our model facilitated by dropping the requirement that the return on equity of an individual bank cannot be negative. If we imposed such limited liability assumption, then neither returns on bonds nor returns on callable deposits could be fully safe in period $t+1$. For an individual bank with debt, the probability of insolvency is always positive, as the idiosyncratic revenue shock ζ might be arbitrarily close to zero. With all returns accruing to the representative household, this simplifying assumption is not likely to have a material impact on final results. When calculating default probabilities in our model, negative equity returns are counted as bank default events.

advantages of debt finance in our model, both equity and debt promise the same (risk-adjusted) expected return

$$\mathbf{E}_t\left(\sum_{\psi_t=1}^{3}\Lambda_{t+1|\psi_t}\right)R_t^A=\mathbf{E}_t\left(\sum_{\psi_t=1}^{3}\Lambda_{t+1|\psi_t}R_{t+1|\psi_t}^Z\right),$$

making banks (and households) indifferent with respect to various equity-to-debt ratios. For this reason, we can simplify the bank's problem considerably by assuming that bank equity is determined by the regulatory constraint and thus equal to the fraction ω of total bank capital: $Z_t=\omega K_t^B$. Moreover, since the expected marginal costs and benefits of equity and debt financing are equal, the Lagrange multiplier on the constraint $\omega\leq\frac{Z_t}{K_t^B}$ is always zero. It is worthwhile to note that the share of bank equity has a quantitatively important impact on the crisis probability, as discussed in the results section below.

A simplified set of first-order optimality conditions for the bank's problem can be stated as follows:

$$\begin{aligned}
L^B &: z_{t+1}\left(1-\theta\right)\varphi_{\psi_t}z^B\left(K_t^B\right)^{\theta}\left(z_{t+1}L_{t+1|\psi_t}^B\right)^{-\theta}=w_{t+1|\psi_t}^B\\
K^B &: \mathbf{E}_t\left(\sum_{\psi_t=1}^{3}\Lambda_{t+1|\psi_t}\left[\theta\varphi_{\psi_t}z^B\left(K_t^B\right)^{\theta-1}\left(z_{t+1}L_{t+1|\psi_t}^B\right)^{1-\theta}-R_t^A\right]\right)=-\mu_t d_t^{\max}\\
Z &: \mathbf{E}_t\left(\sum_{\psi_t=1}^{3}\Lambda_{t+1|\psi_t}\right)R_t^A=\mathbf{E}_t\left(\sum_{\psi_t=1}^{3}\Lambda_{t+1|\psi_t}R_{t+1|\psi_t}^Z\right)\\
D &: \left(\frac{R_t^A}{R_t}-1\right)\mathbf{E}_t\left(\sum_{\psi_t=1}^{3}\Lambda_{t+1|\psi_t}\right)=\mu_t-\mathbf{E}_t\left(\Lambda_{t+1|2}+\Lambda_{t+1|3}-\Lambda_{t+1|2}\left(\frac{\eta}{\kappa_t^H}+\frac{1-\eta}{\kappa_t^L}\right)\right)\\
&\mu_t\geq 0,\ D_t\leq d_t^{\max}K_t^B,\ \mu_t\left(d_t^{\max}K_t^B-D_t\right)=0\\
0 &= \frac{D_t}{R_t}+\frac{A_t^B}{R_t^A}-K_t^B\left(1-\omega\right),
\end{aligned}$$

where the last equality captures our assumption that equity constitutes a share ω of capital raised by banks.

3.2.2 Patient investor's problem

The representative patient investor raises $N_t+\frac{A_t^P}{R_t^A}$ units of resources using equity N_t and bonds $\frac{A_t^P}{R_t^A}$. Unlike banks, patient investors do not have to invest immediately into illiquid capital. Instead, patient investors wait till the banking sector distress signal is revealed. When the distress signal is revealed, the patient investor still has liquid funds to buy assets from the banking sector.[12] The government offers a partial payoff insurance in a severe crisis state of up to fraction $\chi \in [0,1]$ of the transaction value. However, in order to discourage banks from relying on bailouts too much, this insurance coverage is not universal. The bailout insurance eligibility is available with probability η for any given distressed bank. This arrangement captures two aspects of the bailout support measures observed in 2008. First, to facilitate the Bear Stearns acquisition, the Federal Reserve Bank guaranteed a 29-billion-dollar loan to JPMorgan Chase for a 30-billion-dollar transaction. These amounts imply a high but not full insurance coverage, χ. Second, not all distressed financial institutions were bailed out, with Lehman Brothers providing the prime example. The parameters (η,χ) characterize the government ex ante bailout policy known by all agents.

Independent of the bank run situation, a patient investor can always invest remaining funds into its own production firm. The problem of the patient investor can be formulated as follows:

$$\max_{\substack{D_t^I,\, D_t^U,\, K_t^P,\\ N_t,\, A_t^P,\, L_{t+1|\psi_t}^P}} \mathbf{E}_t \left(\begin{array}{c} \sum_{\psi_t=1}^{3} \Lambda_{t+1|\psi_t} \left(\begin{array}{c} \left[(1-\delta) K_t^P + z^P \left(K_t^P\right)^{\theta} \left(z_{t+1} L_{t+1|\psi_t}^P \right)^{1-\theta} \right] \\ -R_{t+1|\psi_t}^P N_t - w_{t+1|\psi_t}^P L_{t+1|\psi_t}^P - A_t^P \end{array} \right) \\ + \left(\Lambda_{t+1|2} \left(\frac{D_t^I}{\kappa_t^H} + \frac{D_t^U}{\kappa_t^L} \right) + \Lambda_{t+1|3} \chi D_t^I \right) \end{array} \right)$$

subject to

$$K_t^P \le N_t + \frac{A_t^P}{R_t^A} - 1_{\psi_t \in \{2,3\}} \left[D_t^I + D_t^U \right]$$

[12]Patient investors in our model purposefully hold back funds in search of more profitable investment opportunities.

where D_t^I and D_t^U represent the amounts of funds spent on acquisition of assets from bailout-eligible (insured) and bailout-ineligible (uninsured) banks, correspondingly. Both D_t^I and D_t^U are equal zero in a normal state, $\psi_t = 1$, which does not have a fire sale event. The indicator function $1_{\psi_t \in \{2,3\}}$ in front of $\left[D_t^I + D_t^U\right]$ in the funding constraint reflects our assumption that the fire sale market opens after a positive distress signal rules out the normal state $\psi_t = 1$, but before it is known whether it is going to be state $\psi_t = 2$ or $\psi_t = 3$. The parameter $\chi \in [0,1]$ represents the fraction of the value of insured assets D_t^I that the patient investor is going to recover from the government bailout funds in case of a severe crisis state $\psi_t = 3$.

We abstract from portfolio heterogeneity across patient investors. The representative patient investor buys all of the fire sale assets, both insured and uninsured, diversifying away idiosyncratic revenue risks of individual banks. The purchases entitle the patient investor to state contingent returns

$$R^I_{t,\psi_t} = \left\{ \begin{array}{c} \frac{1}{\kappa_t^H}, \text{ if } \psi_t = 2 \\ \chi, \text{ if } \psi_t = 3 \end{array} \right\} \text{ and } R^U_{t,\psi_t} = \left\{ \begin{array}{c} \frac{1}{\kappa_t^L}, \text{ if } \psi_t = 2 \\ 0, \text{ if } \psi_t = 3 \end{array} \right\}$$

on each unit of acquired assets D_t^I and D_t^U correspondingly. The fire sale prices, κ_t^H and κ_t^L, adjust to clear both insured and uninsured fire sale asset markets.

The problem of the patient investor implies the following first-order optimality conditions:

$$D^I : \mathbf{E}_t\left(\frac{\Lambda_{t+1|2}}{\kappa_t^H} + \chi\Lambda_{t+1|3}\right) = \mathbf{E}_t\left(\sum_{\psi_t=2}^{3} \Lambda_{t+1|\psi_t}\theta z^P \left(K_t^P\right)^{\theta-1}\left(z_{t+1}L^P_{t+1|\psi_t}\right)^{1-\theta}\right) \tag{7}$$

$$D^U : \mathbf{E}_t\left(\frac{\Lambda_{t+1|2}}{\kappa_t^L}\right) = \mathbf{E}_t\left(\sum_{\psi_t=2}^{3} \Lambda_{t+1|\psi_t}\theta z^P \left(K_t^P\right)^{\theta-1}\left(z_{t+1}L^P_{t+1|\psi_t}\right)^{1-\theta}\right) \tag{8}$$

$$N : R^P_{t+1|\psi_t} = \theta z^P \left(K_t^P\right)^{\theta-1}\left(z_{t+1}L^P_{t+1|\psi_t}\right)^{1-\theta}$$

$$L^P : w^P_{t+1|\psi_t} = z_{t+1}\left(1-\theta\right) z^P \left(K_t^P\right)^{\theta}\left(z_{t+1}L^P_{t+1|\psi_t}\right)^{-\theta}.$$

Without loss of generality, we further assume that all of the patient investor's capital is funded by equity only, i.e. $A_t^P = 0$. Just like in the bank's problem above, this assumption is inconsequential. Under constant returns to scale and perfect competition assumed here, the optimal equity-to-debt ratio of patient investors is undetermined.

3.3 Government

The government in our model manages financial system risks with two policy tools: a regulation to restrict risk taking at all times and a bailout insurance policy to contain the negative consequences of a crisis. The regulation is a Basel-style capital adequacy ratio (CAR) ensuring that at least $100 \times \omega$ percent of capital at risk $\left(K_t^B\right)$ is financed by bank equity (Z_t). It is represented in our model by the minimum equity capital requirement ratio $\frac{Z_t}{K_t^B} \geq \omega$.[13] As a result, losses up to ω fraction of total assets are absorbed by bank equity without triggering insolvency. This fact is relevant when we are computing the risk of bank defaults, and the associated endogenous distress probability p_t, as explained in Section 3.4 below.

The second type of government intervention is the ex ante known bailout policy which is parameterized by η and χ. The bailout policy is funded with lump-sum taxes collected from the households in a severe financial crisis state. Thus, the lump-sum tax on the households is positive only in the realized severe crisis state: $T_{t+1|3} = \chi D_t^I$. In the other two states $(\psi_t = 1, 2)$, the lump-sum tax on households is zero.

The main focus of our paper is on the interaction between the three policy parameters, ω, η and χ, and the implications for the representative household's welfare.

3.4 Endogenous distress probability

As mentioned earlier, in our model the chance of a financial sector distress is linked to the composition of banks' liabilities. Specifically, the probability of an affirmative distress signal p_t is assumed to be equal to the probability of an insolvency problem arising for any given (ex ante identical) bank. This is a strong assumption that may not always hold in reality.

[13] In reality, CAR is not always equivalent to the equity-to-total-assets ratio. The assets in the denominator of CAR must be risk weighted, with less risky assets carrying less than full weight. For simplicity, in our model all of the banks' assets have the same risk.

However, it makes sense for the following two extreme cases. If banks never face insolvency problems, then logically, it wouldn't make sense for them to be in distress. At the other extreme, suppose it is almost certain that banks are going to be insolvent, then households should withdraw funds with near certainty. The presence of idiosyncratic revenue shocks ζ in the bank-financed production function assures that the probability of bank failures is always positive unless banks are 100 percent equity financed. The banks' financing choices regarding bond and callable deposit liabilities make their default probability endogenous.

In the model context, a solvency problem arises if banks can't pay the depositors and the bond holders without realizing negative equity returns. Formally, the assumption we make to relate the two events, solvency and distress signal, is

$$\Pr(\textit{distress signal in period } t) \equiv p_t = \Pr\left(\textit{insolvency in period } t\right).$$

The probability of *insolvency* is determined by

$$\begin{aligned}\Pr\left(\textit{insolvency in period } t\right) = {} & (1-p_t)\Pr\left(R^Z_{t+1|1}\left(\zeta\right)<0\right) + p_t q\left[\Pr\left(R^Z_{t+1|3}\left(\zeta\right)<0\right)\right] \\ & + p_t\left(1-q\right)\left[\eta\Pr\left(R^Z_{t+1|2}\left(\zeta,H\right)<0\right) + \left(1-\eta\right)\Pr\left(R^Z_{t+1|2}\left(\zeta,L\right)<0\right)\right].\end{aligned}$$

Where $R^Z_{t+1|2}\left(\zeta,H\right)$ is the equity return in a mild financial crisis, for a bailout-eligible bank, with the value ζ of its realized idiosyncratic revenue shock. As a bailout-eligible bank, it enjoys the higher fire sale price κ^H_t. Likewise, $R^Z_{t+1|2}\left(\zeta,L\right)$ is the return for a particular bank, which was not lucky to win eligibility for a government bailout and thus must accept a lower liquidation price κ^L_t for it assets. The returns on bank equity are calculated as profits per unit of equity:

$$
\begin{aligned}
R^Z_{t+1|\psi_t=\{1,3\}}(\zeta) &= \Pi_{t+1|\psi_t=\{1,3\}}(\zeta)/Z_t, \\
R^Z_{t+1|\psi_t=2}(\zeta, J) &= \Pi^J_{t=1|\psi_t=2}(\zeta)/Z_t, \\
& \qquad J=\{H,L\} \text{ for bailout eligible or ineligible banks.}
\end{aligned}
$$

The profit functions are different for bailout eligible and ineligible banks only in state $\psi_t = 2$, in which the banks honour their liabilities to patient investors:[14]

$$
\Pi_{t+1|1}(\zeta) = \zeta\left[(1-\delta)K^B_t + z^B\left(K^B_t\right)^\theta\left(z_{t+1}L^B_{t+1|1}\right)^{1-\theta}\right] - w^B_{t+1|1}L^B_{t+1|1} - A^B_t - D_t
$$

$$
\Pi^J_{t+1|2}(\zeta) = \zeta\left[(1-\delta)K^B_t + z^B\left(K^B_t\right)^\theta\left(z_{t+1}L^B_{t+1|2}\right)^{1-\theta}\right] - w^B_{t+1|2}L^B_{t+1|2} - A^B_t - \frac{D_t}{\kappa^J_t}
$$

$$
\Pi_{t+1|3}(\zeta) = \lambda\zeta\left[(1-\delta)K^B_t + z^B\left(K^B_t\right)^\theta\left(z_{t+1}L^B_{t+1|3}\right)^{1-\theta}\right] - w^B_{t+1|3}L^B_{t+1|3} - A^B_t
$$

We can rewrite the equation for the endogenous probability as follows:

$$
p_t = \frac{\Pr\left(\Pi_{t+1|1}(\zeta) < 0\right)}{\left(\begin{array}{c} 1 + \Pr\left(\Pi_{t+1|1}(\zeta) < 0\right) - q\Pr\left(\Pi_{t+1|3}(\zeta) < 0\right) \\ -(1-q)\left[\eta\Pr\left(\Pi^H_{t+1|2}(\zeta) < 0\right) + (1-\eta)\Pr\left(\Pi^L_{t+1|2}(\zeta) < 0\right)\right] \end{array}\right)} \tag{9}
$$

Notice that for bank runs to occur, it is essential that a positive measure of insolvencies is possible in normal times, i.e. $\Pr\left(\Pi_{t+1|1}(\zeta) < 0\right) > 0$.[15] The idiosyncratic revenue shock ζ makes sure that is always the case, as long as banks do not finance themselves with only equity.[16] In the calibration section we assess the degree of idiosyncratic revenue risk from the balance sheet data of U.S. depository institutions.

[14] In calculating these profits, we assume that the labour compensation $w^B_{t+1|1}L^B_{t+1|\psi_t}$ is independent of a bank-specific idiosyncratic revenue shock ζ.

[15] A similar insight led Angeloni and Faia (2013) to augment the standard productivity shock with a sizable idiosyncratic component.

[16] With $\Pr\left(R^Z_{t+1|1}(\zeta) < 0\right) = 0$, there could in principle be sunspot equilibria with bank runs. Our calibration rules them out.

3.5 Market clearing conditions

There are several markets in this economy: a final goods market that provides both consumption and investment goods, a callable deposit market, a bond market, an equity market, two fire sale markets (bailout insured and uninsured), and two labor markets. The market clearing conditions imply the following equalities:

$$C_t + K_t^B + N_t = W_{t|\psi_{t-1}}$$

$$W_{t+1|\psi_t} = \left(\begin{array}{c} (1-\delta) K_t^P + z^P \left(K_t^P\right)^\theta \left(z_{t+1} L_{t+1|\psi_t}^P\right)^{1-\theta} + \\ \varphi_{\psi_t} \left[(1-\delta) K_t^B + z^B \left(K_t^B\right)^\theta \left(z_{t+1} L_{t+1|\psi_t}^B\right)^{1-\theta} \right] \\ +1_{\psi_t \in \{2,3\}} (1-\delta) D_t^h \end{array} \right)$$

$$K_t^P = N_t - 1_{\psi_t \in \{2,3\}} \left[D_t^I + D_t^U\right]$$

$$D_t^h = D_t$$

$$A_t^h = A_t^B$$

$$D_t^I = \eta D_t$$

$$D_t^U = (1-\eta) D_t$$

$$L_{t+1|\psi_t}^B = h_{t+1|\psi_t}^B = 1$$

$$L_{t+1|\psi_t}^P = h_{t+1|\psi_t}^P = 1.$$

3.6 Policy options regarding financial stability

In our model, financial crises can happen only after a distress signal triggers a bank run and asset fire sales. While the assumption that banking crises cannot happen without bank runs is strong, it gives government policy the best chance of achieving its financial stability objectives by discouraging fragile sources of funding and ensuing fire sales. With the endogenous distress probability tied to the banks' insolvency, as discussed in section 3.4, the government policy can reduce the likelihood of financial crises by making bank failures less likely. A reduction in the probability of bank failures could be achieved by restricting the amount of callable liabilities issued by banks or increasing the equity share in total banks' liabilities. Since the representative household derives utility from callable deposits, eliminating fragile funding cannot be optimal. The optimal policy in our model must strike a balance between the utility benefits of callable deposits and their potential costs in a crisis. The bailout insurance policy presents an additional policy trade-off. On the one hand, it helps to alleviate the banking sector's losses in a crisis. On the other hand, it may encourage more risk taking by the private sector. As discussed in the results section, a generous bailout insurance policy is welfare beneficial if complemented with a tighter capital adequacy requirement, but not necessarily without it.

3.7 The numerical solution method

Our model features strong nonlinearities resulting from tail events associated with bank runs, fire sales, and output losses. A global solution method is needed to reliably assess the benefits of financial stability policies not only in the vicinity of the stochastic steady state, but also during the low probability events associated with bank runs. We solve the model using a modified version of the endogenous gridpoints method proposed by Carroll (2006). Our modification allows us to reduce the problem's state space at the expense of creating two root-finding problems. Specifically, instead of keeping track of the two capital stocks K_t^B, K_t^P and the deposits D_t^h, we summarize the current period endogenous state by the representative household's wealth $W_{t|\psi_{t-1}}$. The two root-finding problems help to determine the optimal household portfolio in terms of two capital stocks $K^B\left(W_{t|\psi_{t-1}}, z_t\right)$, $K^P\left(W_{t|\psi_{t-1}}, z_t\right)$ and the callable deposits $D^h\left(W_{t|\psi_{t-1}}, z_t\right)$. The Compecon package of Miranda and Fackler (2003) was used to approximate these decision policy functions using splines with 45 grid points for the endogenous state variable $W_{t|\psi_{t-1}}$ and seven grid points for the exogenous state variable z_t. Starting with an initial guess,[17] we iterate by solving the portfolio problem and generating

[17] To generate an initial guess for the consumption policy function $C\left(W_{t|\psi_{t-1}}, z_t\right)$, as well as for capital allocations, K^B and K^P, we start by solving a frictionless version of the model without financial crises, and

updates for the endogenous grid over K^P. Appendix A.1 contains the complete system of dynamic equations used to solve and simulate our model economy.

Endogenous default probabilities were estimated at each step by fitting Epanechnikov kernel distributions to the state contingent profits $\Pi_{t+1|\psi_t=\{1,3\}}(\zeta)$ and $\Pi^J_{t+1|\psi_t=2}(\zeta)$, simulated with 300,000 random realizations of the idiosyncratic shock, ζ.

4 Calibration

We calibrate the model to match key moments of the U.S. economy and its financial sector for the period before the Great Financial Crisis. The basic macroeconomic parameters are set in accordance with their conventional business cycle values for an annual frequency model. They are the depreciation rate $\delta = 0.1$; the relative risk aversion in the utility function, $\sigma = 2$; and the Cobb-Douglas parameter in the production functions of all producers, $\theta = 0.33$. The aggregate labour productivity process was parameterized by fitting an AR1 process to the U.S. labour-augmenting productivity series inferred from the annual frequency PWT 9.0 data (Feenstra et al. 2015). The resulting AR1 parameters estimates are $\rho_z = 0.881$ for the persistence and $\sigma_z = 0.029$ for the standard deviation of innovations. These basic macroeconomic parameters are summarized in Table 1.

The other parameters are more specific to our model. The benchmark policy parameters are set at values consistent with the Basel II framework, prevalent before the Great Financial Crisis. Specifically, the capital adequacy parameter, ω, is set to 0.08, while both bailout policy parameters are zero: $\chi = \eta = 0$ because, arguably, there was no expectation of bailout insurance before the Great Financial Crisis.

We estimate the remaining six parameters using a minimum distance estimation procedure, which aims to match simulated model moments to their counterparts in the data. The moments for model and data are listed in Table 3. The parameter estimates are in Table 2.

without debt financing. Our initial guess for the deposits policy function posited a proportional relationship between D^h and K^B.

These parameter estimates were obtained by solving the following optimization problem

$$\min_{\tau} g(\tau)' W_{6\times 6} \; g(\tau),$$

where $\tau = \left(\beta, \gamma, \frac{z^B}{z^P}, q, \lambda, \sigma_\zeta\right)'$ and $g(\tau)$ is a six-by-one vector of normalized moment deviations $\left(\frac{\hat{m}_i(\tau)}{m_i} - 1\right)$, with m_i being one of the six data moments and $\hat{m}_i(\tau)$ being the corresponding model moment averaged over a simulation with 300,000 periods. The matrix $W_{6\times 6}$ weighs all the simulated moments equally except the one corresponding to the average default probability p_t. We increased the weight on this moment one hundredfold, given its importance in our model.[18] Table 3 indicates a very close fit between the model and data moments.

Focusing on specific moments, the decline in output level in a mild financial crisis state $(\psi_t = 2)$, relative to the normal state $(\psi_t = 1)$, targets the peak-to-trough decline in the (exponentially de-trended) U.S. real GDP per capita during the Great Recession of 2008-2009.

$$100\left(1 - \frac{z^P \left[K_t^P - D_t^h\right]^\theta z_t^{1-\theta} + z^B \left[K_t^B\right]^\theta z_t^{1-\theta}}{z^P \left[K_t^P\right]^\theta z_t^{1-\theta} + z^B \left[K_t^B\right]^\theta z_t^{1-\theta}}\right) = \|\Delta GDP_{2008-2009}\| = 8.65\%$$

This moment helps to pin down the calibrated value of z^B relative to the normalized value of $z^P = 1$ and thus determines the relative size of the bank-financed sector.

The decline in output level in the severe financial crisis state $(\psi_t = 3)$, relative to the normal state $(\psi_t = 1)$, targets the peak-to-trough decline in the (exponentially de-trended) U.S. real GDP per capita during the Great Depression of 1929-1931.

$$100\left(1 - \frac{z^P \left[K_t^P - D_t^h\right]^\theta z_t^{1-\theta} + \lambda z^B \left[K_t^B\right]^\theta z_t^{1-\theta}}{z^P \left[K_t^P\right]^\theta z_t^{1-\theta} + z^B \left[K_t^B\right]^\theta z_t^{1-\theta}}\right) = \|\Delta GDP_{1929-1931}\| = 34.75\%$$

This moment helps to determine the calibrated value of $(1 - \lambda)$, the fraction of bank-financed

[18] The diagonal matrix $W_{6\times 6}$ has ones in five of its main diagonal entries and 100 as the sixth diagonal element. All other elements are zero.

output lost in a severe financial crisis.

The remaining four model moments in Table 3 are from simulations without a realized financial crisis, as the corresponding data moments focus on a relatively calm recent period before the Great Financial Crisis. The average ratio of callable deposits D_t to total bank capital K_t^B in the model corresponds to the average ratio of short-term uninsured liabilities to total assets of private depository institutions (31.54%). This target moment was particularly important for the degree of market incompleteness and pecuniary externalities in the model arising because of the borrowing constraint on the ratio of callable deposits. We combined wholesale short-term funding (e.g. repos) with uninsured retail deposits to determine the fraction of funding exposed to premature withdrawals. These series were collected from the Financial Accounts of the United States (Z.1) dataset for private depository institutions for the period between 2002Q1 and 2007Q4. This moment helps us identify the probability q of a severe financial crisis state happening after a financial distress signal.

The next two moments are based on time series for the period between 1986Q1 and 2007Q4. The average return on bonds $100\left(R_t^A - 1\right)$ was matched with the average net real return calculated from Moody's series for AAA seasoned corporate bond yields, adjusted by subtracting the term spread between 5-year and 1-year government bonds. This adjustment is needed since Moody's corporate bonds typically have 5 to 10 years till maturity, while our model has only 1-year bonds. This moment (3.94%) pins down the value of the household discount factor, β.

The average level of the interest rate spread, $\left(\frac{R_t^A}{R_t} - 1\right)$, targets the average spread between Moody's corporate bond yields discussed in the previous item and the 5-year government bond rate. The average spread (1.5%) pins down the value of the liquidity preference parameter γ in the household utility function.

As mentioned above, in our parameter search procedure, we have been particularly careful about matching the average distress probability, which has an important impact on the welfare benefits of financial stability policies. The average value of the distress probability, p_t, in our simulations was targeted at the inverse of the number of years between the beginning of the Great Depression (a severe financial crisis) and the Great Recession (a mild financial crisis): $\frac{1}{2008-1929} = \frac{1}{79}$. Thus, an implicit assumption is that the start of the Great Recession happened the expected number of years after the start of the Great Depression, given the average crisis probability value.[19] This moment helps to pin down the volatility of idiosyncratic bank revenue shocks, ζ. The estimated standard deviation of these idiosyncratic shocks, $\sigma_\zeta = 0.025$, implies that the cross-sectional volatility of banks' profits should be 2.5 percent per year. To obtain independent evidence on the magnitude of idiosyncratic bank shocks, we looked at the cross-sectional balance sheet data for private depository institutions in the United States. The cross-sectional volatility of the profitability measure we collected, Net Operating Income per unit of Assets (NOIA), accords well with the cross-sectional volatility of bank profits in our model. The top panel of Figure 5 shows the cross-sectional standard deviation of NOIA from 1986 to 2010. We find that our estimate for idiosyncratic risk is at the lower end of the observed range of possible values. Thus we view our calibration as being a conservative one regarding the importance of financial distress risk in the economy. Furthermore, from the lower panel of Figure 5, we find that the share of depository institutions, facing operating losses in excess of the minimum regulatory equity holdings, reaches a value of more than 0.6 percent during the Great Recession, highlighting a sizable amount of risk similar to that in our model.

5 Results

For practical reasons, in this section, we align our capital adequacy constraint with the actual regulatory environments before and after the Great Financial Crisis. The tighter requirement captures the regulatory framework introduced as part of the Basel III initiative in response

[19] In our calibration procedure, we averaged the distress probability p_t over long simulated series without any realized bank run events. We excluded bank run events from this simulation because, arguably, there was no systemic financial crisis in the United States between the Great Depression and the Great Recession comparable in its severity to these two financial calamities.

to that crisis. One of the key enhancements of the Basel III framework relative to Basel II is that the minimum capital adequacy ratio for depository institutions was raised from 8 percent to 10.5 percent (BIS 2011). Our model captures these two regulatory regimes by setting the parameter ω at 0.08 and 0.105.

Our analysis confirms that capital adequacy requirements play a crucial role in controlling risk. Importantly, they also affect the desirability of bailout policies. Before discussing the interaction between policies, it is helpful to evaluate the impact of the capital adequacy ratio alone.

5.1 The aggregate implications of capital adequacy regulation

To isolate the effects of CAR regulation, we hold the bailout policy parameters (η, χ) fixed at their calibrated values of $(0, 0)$. With the bailouts thus rendered inactive, we compare several model-simulated moments for two otherwise identical economies, facing identical sequences of shocks, but with the values of ω equal to 0.08 or 0.105. Key implications of different CAR regulations are summarized in Table 4. All of the listed moments in the table are averaged over 100 simulations with 300,000 periods in each series and reported in percentage points.

As shown in the second row of Table 4, the tighter regulation, $\omega = 0.105$, substantially reduces the financial crisis risk in the economy by lowering the average distress probability from 1.33 to 0.11 percent. The lower distress probability is a direct consequence of lower average default rates induced by a higher proportion of equity buffers on banks' balance sheets. Tighter regulation does not only affect the average probability. It changes the entire distribution of distress probability realizations significantly (Figure 6). The tighter regulation leads to a distribution that is much closer to zero (left histogram), and substantially more concentrated than the distribution under looser regulation (right histogram).

The lower financial risk in the economy with tighter CAR significantly raises the average welfare. Measured in units of extra lifetime consumption (LTCE), the welfare increase from tighter regulation amounts to 1.68 percent of additional consumption (the third line of Table

4).[20] The welfare loss magnitudes reported in Table 4 are relative to the *first best* allocation, found as the solution of the Social Planner's problem. In the Social Planner's problem, the distress probability is a constant equal to 0.11 percent, consistent with the average p_t in our benchmark economy with $\omega = 0.105$. The Social Planner also has more freedom in selecting the amount of callable deposits, D_t^h, being restricted only by feasibility and not by the funding constraint the banks face. The welfare gain in the economy with tighter regulation is made possible by higher investment rates that raise the average amount of wealth in the economy. Specifically, the economy with $\omega = 0.105$ accumulates 3.65 percent more wealth, on average, than the economy with looser regulation, and 1.02 percent more than the first best allocation (the fourth line of Table 4).[21]

Consistent with the regulatory tightening, the average share of callable deposits as a fraction of total bank assets goes down from 31.78 percent under a looser CAR to 30.63 percent under the tighter regime (line 5 of Table 4). Despite the reduced share of fragile funding, the economy with higher ω suffers larger output losses in both mild (line 6) and severe (line 7) crisis episodes. These output losses are due to the higher wealth levels attained under $\omega = 0.105$. The differences in output losses between the two economies are, however, not very large. Finally, the average returns are higher by 33 basis points in the economy with tighter regulation, despite the rise in average wealth (line 8 of Table 4). The higher average return is made possible by the reduction in the frequency of destructive crisis episodes in the economy with larger bank equity buffers.

Overall, our analysis suggests that Basel III tightening of capital adequacy ratios had a substantial positive impact not only by strengthening financial stability but also by raising household welfare and wealth.

Our results regarding the welfare benefits of tighter CAR regulation contradict, to some extent, the findings in Elenev et al. (2021). The optimal equity capital buffers in their model

[20] Appendix A.2 defines our LTCE welfare measure in mathematical terms.

[21] Average wealth is reported as the net percentage points increase relative to the average wealth in the first best allocation.

are lower than those in existence prior to the Great Financial Crisis. While our models are not directly comparable, we think that the primary source of the difference is that financial equity issuance in Elenev et al. (2021) involves quadratic adjustment costs. In our model, neither equity of any kind nor debt issuance impose direct resource costs. All the funding costs are associated with the endogenous crises and the fire sale externality. Adding equity issuance costs is an interesting extension of our model left for future research.

5.2 Assessing bailout policies

We now analyze the implications of different CAR regimes for the effects of bailout policies. We use a series of three-dimensional surface plots to present the results, which show policy outcomes for various combinations of (η, χ) pairs while holding the capital adequacy ratio ω fixed either at 0.08 or 0.105. All surface plots, such as Figure 7, position the most generous bailout insurance policy closest to the viewer. By most generous, we mean the bailout framework with 100 percent loss coverage ($\chi = 1$) and *nearly* full certainty for individual banks regarding their assets' ex post bailout insurance eligibility ($\eta = 0.99$).[22]

Two key results emerge from our analysis of the welfare impact of bailout insurance provisions in the economies with tighter and looser CAR regulations (Figures 7 and 8 respectively). First, a tighter CAR regime raises welfare substantially, independent of the bailout policy. Second, with looser CAR regulation, the bailout policy configuration matters, as different coverage and eligibility ratios have non-monotone welfare implications.

Focusing first on the case of tighter regulation, the welfare loss is decreasing both in the coverage ratio χ and in the eligibility probability η. The rate of welfare improvement is accelerating as χ approaches one. In contrast, for the case of a looser CAR, we find a strongly non-monotone response of welfare losses to various combinations of the bailout insurance ratios. Starting from an economy without any bailout support and increasing

[22] We excluded the limiting case of full certainty from our consideration because, for most values of χ, the equilibrium computation procedure failed to converge with $\eta = 1$. This discontinuity arises because at $\eta = 1$ the worst-case fire sale collateral price in the banks' borrowing constraint (6) switches from κ_t^L to κ_t^H.

both eligibility and coverage ratios at the same time, we see that welfare loss initially rises as bailout policies become more generous and more certain. However, as we approach the upper bound, the welfare loss starts to fall and reaches 1.80 percent of lifetime consumption for the most generous bailout insurance ($\chi = 1,\ \eta = 0.99$), which is 3 basis points below its level without bailout support (i.e. with either $\chi = 0$ or $\eta = 0$) and 14 basis points below its peak. Interestingly, the optimal bailout configuration under a loose CAR regime includes full loss coverage yet only an 80 percent chance of eligibility. This means that a moderate number of bank failures during a financial crisis is socially desirable when capital adequacy constraints are less tight. As we shall see, this bailout policy configuration reduces the average probability of a crisis relative to the most generous insurance. The ranges of welfare changes due to variations in bailout policies are modest: 3 basis points of LTCE for tighter regulation and 14 basis points for looser regulation. These welfare differences are an order of magnitude smaller than the welfare improvement associated with changes in the capital adequacy ratio. From a policy perspective, our quantitative results suggest that generous but not 100 percent assured bailout support of financial institutions is likely to be welfare beneficial, or at least not very costly, as long as the CAR requirements are sufficiently tight and effective.

One key concern regarding bank bailouts is that banks will anticipate them and assume a more than the prudent amount of financial risk. Our model allows us to quantify the implications of various bailout and capital adequacy regimes for the average distress probability (Figures 9 and 10). Both probability surfaces have similar shapes, though different implications regarding financial system stability. As before, we move from the least generous bailout regime (no coverage, no chance of eligibility) to the most generous regime (full coverage, 99 percent eligibility). Initially, more generous bailouts lead to a higher probability of distress. However, the distress probability eventually starts to decline as we approach the $(1, 0.99)$ limit. This decline is very sharp under the tighter CAR regime. The fraction of insured losses, χ, has a more pronounced effect on the distress probabilities and has to be higher than 0.93 for default probabilities to show a substantial decline for both CAR regimes. The key difference between the CAR regimes is the vertical range of the probability surfaces. A tighter CAR implies that the bailout regime barely affects the distress probability. Hence, the higher proportion of bank equity induced by the tighter CAR regulation reduces the sensitivity of aggregate risk taking to changes in the bailout expectations, dampening their impact on distress probability.

This is not the case when the regulatory policy is less restrictive, $\omega = 0.08$. The distress probability rises rapidly from 1.33 to 1.66 percent, and then moderates by a mere 0.1 percent from its peak as the bailout policy framework becomes more generous.

The non-monotone response of the distress probability to variation in χ and η is a reflection of two opposing effects. First, higher χ and η values imply a lower default prevalence among banks during financial crises since they raise the fire sale price of bailout-eligible bank assets, κ_t^H. The range of the increase in κ_t^H is $0.29 - 0.65$ for the economy with $\omega = 0.105$ and $0.3 - 0.69$ for $\omega = 0.08$. The eligibility probability parameter η has a relatively limited impact on the fire sale price κ_t^H, as most of the variation in the κ_t^H is due to changes in the insurance coverage fraction, χ. The second effect arises because more generous bailout support prompts increases in household holdings of bank equity, thus increasing the size of the banking sector's balance sheet relative to that of the patient investors. This reduces the capacity of patient investors to absorb bank assets during a crisis, leading to lower fire sale prices for uninsured banks $\left(\kappa_t^L\right)$. As a result, banks' default probabilities increase. In addition, a larger amount of bank assets raises the borrowing limit on callable deposits (see equation 6). The second effect increases aggregate risk taking and captures the commonly expected risk-shifting effect of public bailouts. It has a dominant effect on distress probabilities at lower levels of χ and η.

If we use the crisis probability as the indicator of financial stability, then our results suggest that an appropriately set capital adequacy regulation is key both for (i) greater financial stability and (ii) the merits of bailout policies in terms of financial stability and welfare objectives. Specifically, generous bailouts are welfare improving and financial stability enhancing when the CAR is tight. In contrast, a looser CAR implies that a no-bailout policy is best for financial stability but not for welfare.

To gauge the importance of endogenous distress probability, we assess the aggregate effects of bailout policies in a model with exogenous distress probability. Specifically, we consider an otherwise identical model, in which the distress probability p is a constant value of 0.0133, consistent with the average distress probability in our endogenous probability model with $\omega = 0.08$. Focusing on welfare (Figure 11), we see that the absence of an endogenous response of distress probability to bailouts makes a generous bailout policy unambiguously desirable. The welfare loss surface is monotonically decreasing and much more linear in bailout framework ratios compared to the endogenous probability setup (Figure 8).

Turning back to the endogenous probability model, Figures 12 and 13 show the average wealth surfaces for $\omega = 0.105$ and $\omega = 0.08$, respectively, normalized by the average wealth from our Social Planner problem. The average wealth levels in both economies are rising at accelerating rates as bailout policy parameters become more generous. However, the range of wealth increases is an order of magnitude wider under the less restrictive CAR, reaching 1.3 percentage points versus 0.17 percentage points in the economies with tighter regulation.

6 Conclusions

The Great Recession of 2008-2009 was a painful reminder of the disruptive forces associated with financial crises. Asset fire sales, financial sector defaults, and household sector defaults, as well as credit market dislocations, contributed to large and lasting effects of the crisis on output, investment, employment, and social welfare. Governments around the world improvised with unprecedented fiscal and monetary support measures aimed at alleviating financial system stress. Few of the government support measures generated as much public discontent and pushback as emergency bailouts of distressed financial institutions. Despite being much less costly ex post than initially feared, the bailouts raised concerns about their potential to increase the likelihood of ruinous future financial crises, as people anticipate similar bailout support measures and take on excessive risk.

We contribute to the debate about the merits of bank bailouts by developing and carefully calibrating a quantitative framework with endogenous financial crises and asset fire sales. Then we employ the model to consider the costs and benefits of different bailout arrangements, taking into account the capital adequacy regulation. We find that generous bailout insurance for financial institutions is likely to be beneficial, or at least not very costly in the long run, provided the equity capital buffer enhancements, introduced as part of Basel III, remain effective. With looser capital adequacy regulation, bailouts could indeed lead to excessive risk taking and elevated crisis risks, with detrimental consequences for public welfare. Thus, policymakers and regulators should be vigilant to avoid the erosion of capital adequacy regulations by ever-present financial engineering and lobbying.

With modifications, our framework can be adapted to evaluate other financial stability measures and regulatory tools. Given the powerful impact of changes in the capital adequacy ratio in our model, we think a welfare analysis of countercyclical capital buffers could be a fruitful future research endeavor.

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7 Tables

Table 1: Basic macroeconomic parameters

Parameter	Value	Determination
Capital income share	$\theta = 0.33$	Standard value for RBC literature
Depreciation rate	$\delta = 0.1$	Standard value for RBC literature
Relative risk aversion	$\sigma = 2$	Standard value for RBC literature
Labour productivity process		
persistence	$\rho_z = 0.881$	Fitting AR(1) process to U.S. labor
standard deviation	$\sigma_z = 0.029$	productivity inferred from PWT 9.0

Table 2: Estimated model parameters

Parameters		Value
Household discount factor	β	0.96
Liquidity preference weight	γ	0.006
Relative TFP of the bank-financed sector	$\frac{z^B}{z^P}$	1.57
St.Dev.of idiosyncratic bank productivity shocks	σ_ζ	0.025
Probability of a severe crisis after bank run, in %	q	57
Fraction of bank-financed output lost in a severe crisis, in %	$1-\lambda$	40

Table 3: Model simulated moments and data moments

Moments in percent	Data	Model
Average spread	1.50	1.50
Average real return on bonds	3.94	3.93
Average share of fragile funding	31.54	31.78
RGDP drop during Great Recession	8.65	8.60
RGDP drop during Great Depression	34.75	34.98
Average financial distress probability	1.266	1.266

Table 4: Average moments for the economies with different equity to capital ratios

Moments in percent	$\omega = 0.08$	$\omega = 0.105$
Average financial distress probability	1.33	0.11
Average welfare loss (LTCE)	1.83	0.14
Average wealth relative to first best	-2.63	1.02
Average share of callable funding	31.78	30.63
RGDP drop in a Mild Crisis	8.60	9.28
RGDP drop in a Severe Crisis	34.98	35.97
Average real return on bonds	3.93	4.26

8 Figures

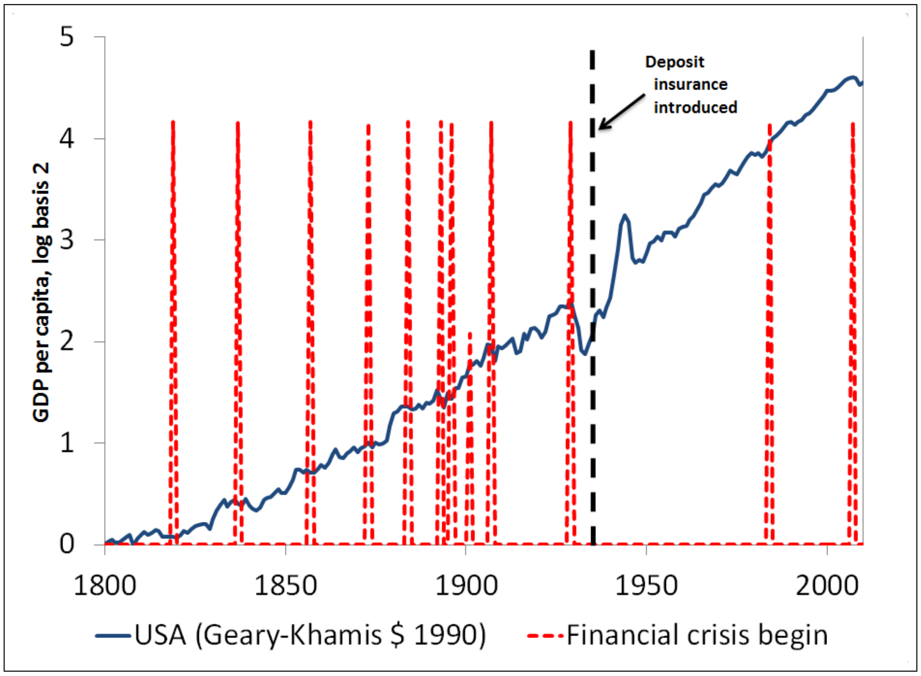

Figure 1: Financial crises events (dashed spikes show begining period) and real activity from 1800 to 2010. Source: Angus Maddison Database and Reinhart and Rogoff (2011)

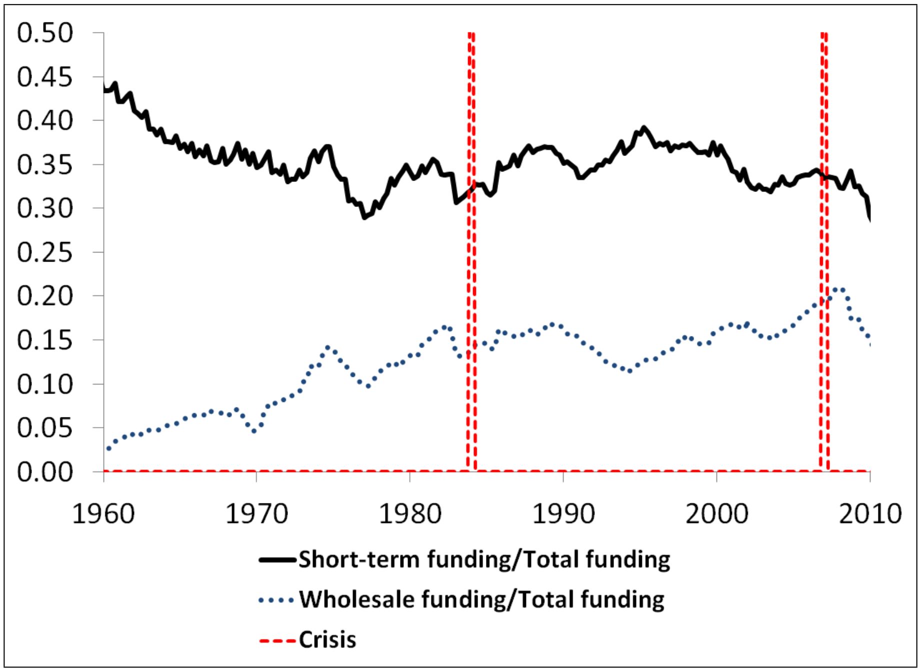

Figure 2: Short-term funding of deposit taking institutions, brokers and dealers in the US from 1960 to 2010. Source: Flow of Funds and Reinhart and Rogoff (2011)

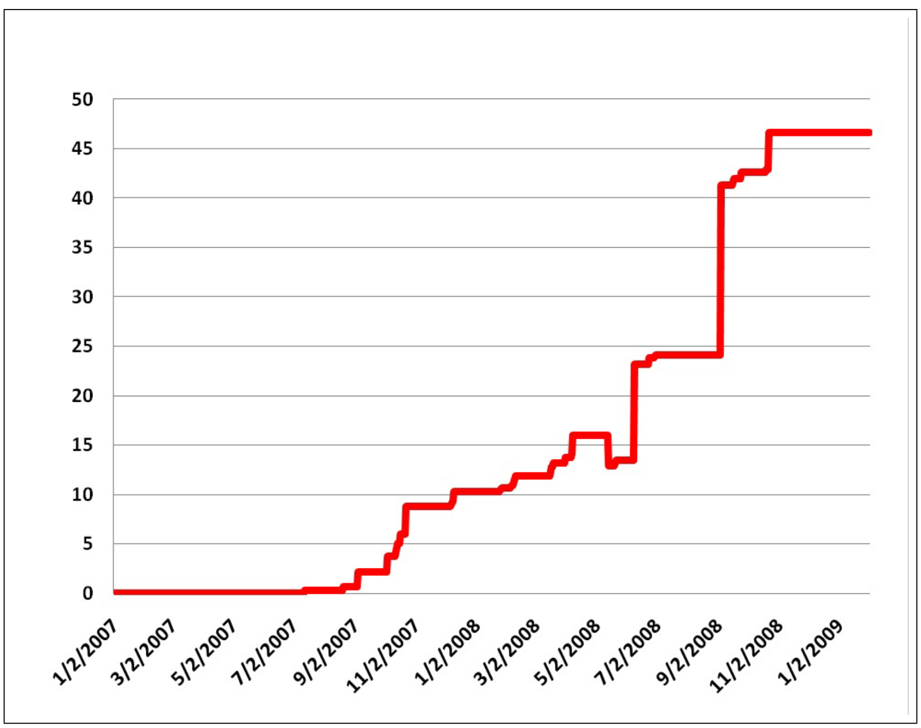

Figure 3: Average haircut of structured repos during the 2007–09 financial crisis, in %. Source: Gorton and Metrick (2012)

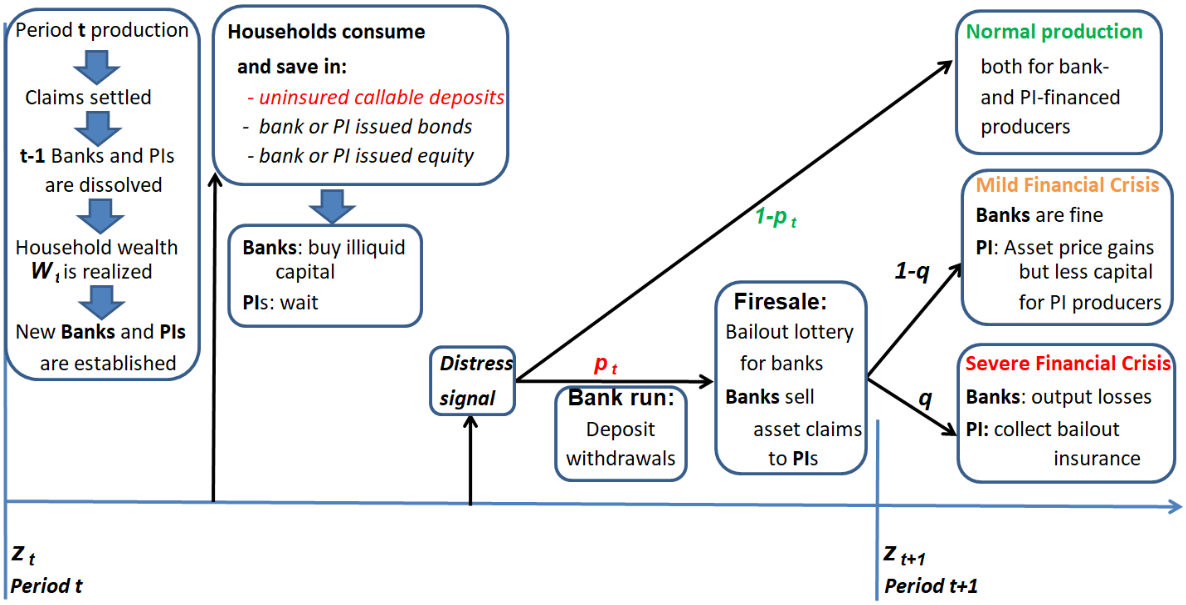

Figure 4: The timing of events and resolution of uncertainty in the model economy

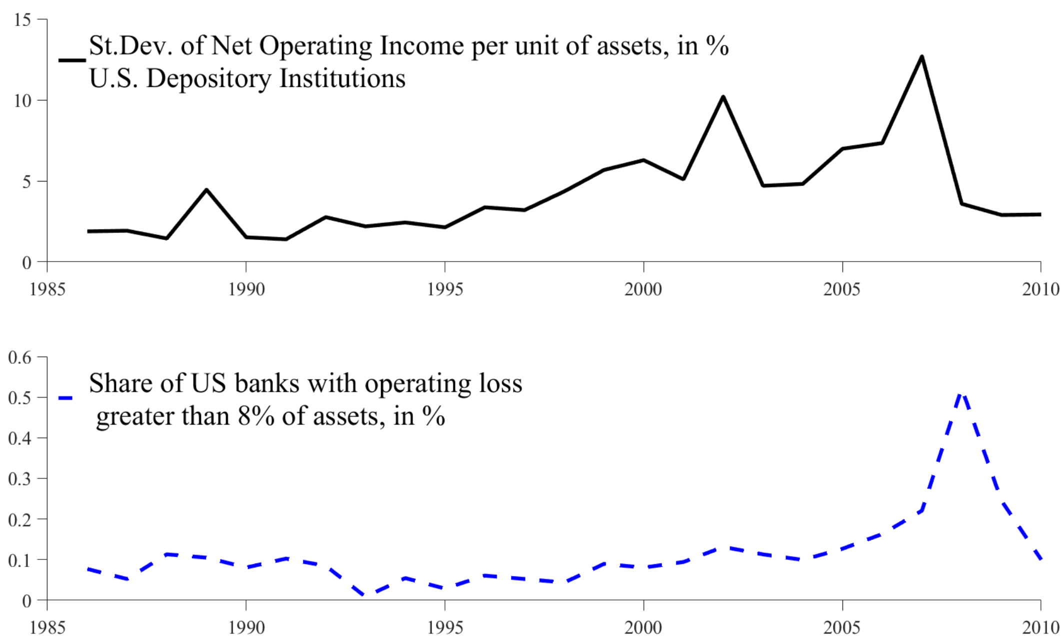

Figure 5: Cross-sectional data for US private depository institutions. Source: WRDS Bank Regulatory database

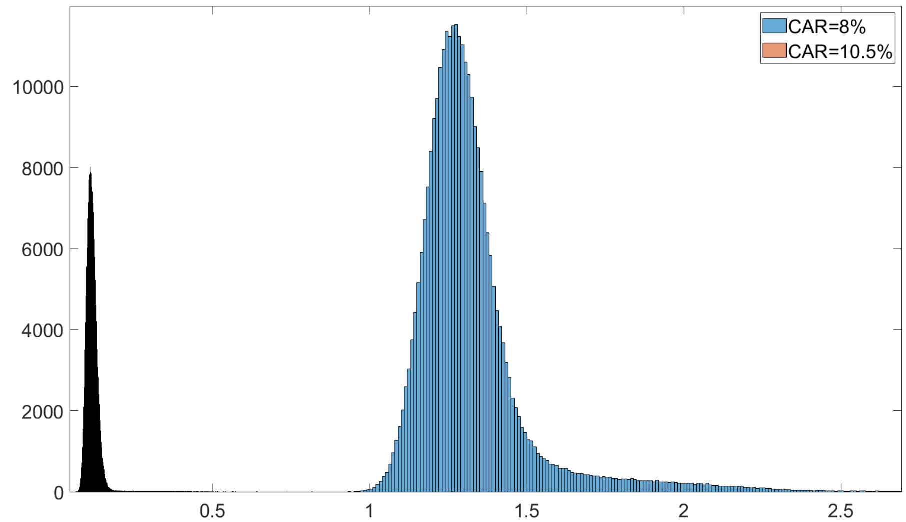

Figure 6: The distributions of distress probability in the economies with the capital adequacy ratios $\omega = 0.08$ and $\omega = 0.105$

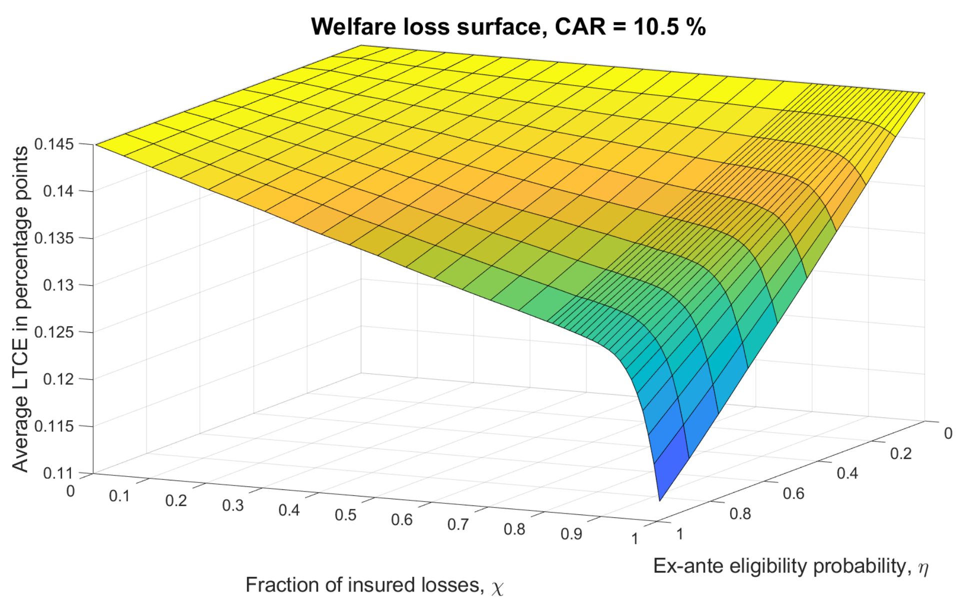

Figure 7: Welfare loss surface for $\omega = 0.105$

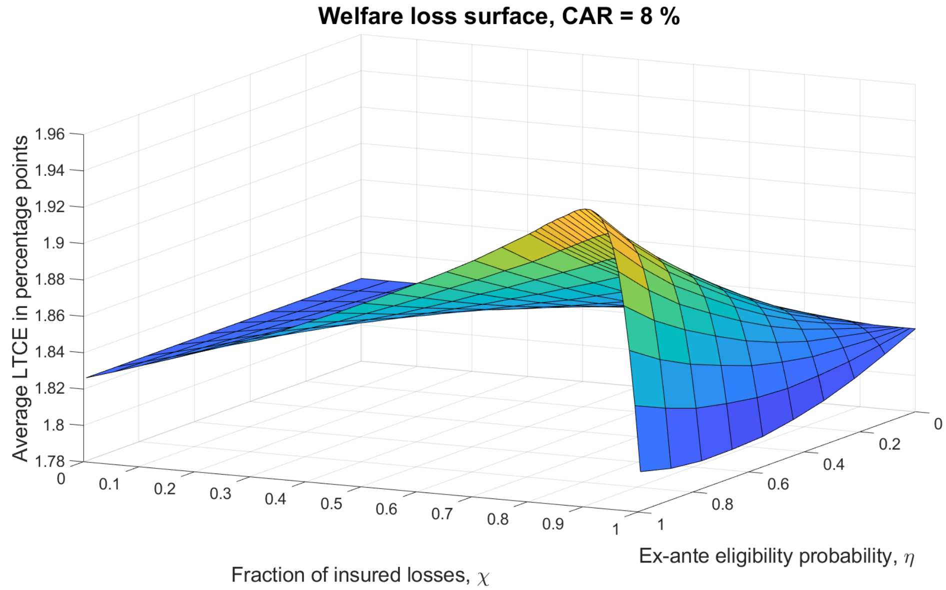

Figure 8: Welfare loss surface for $\omega = 0.08$

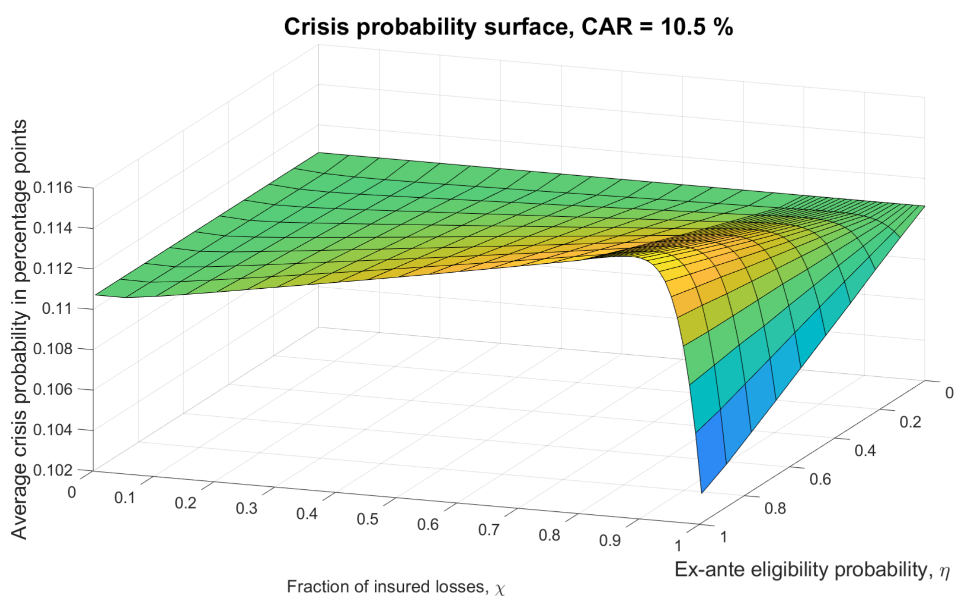

Figure 9: Distress probability surface for $\omega = 0.105$

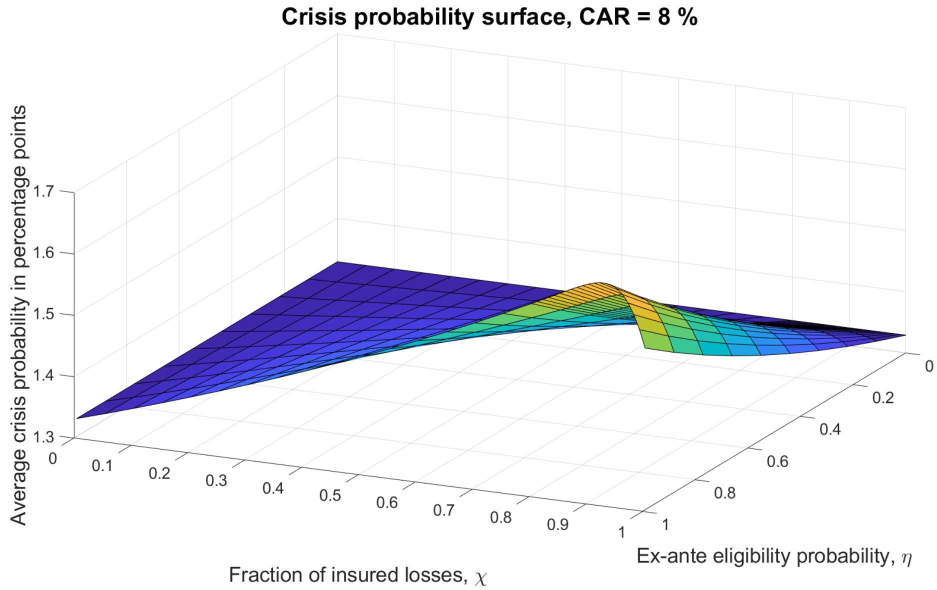

Figure 10: Distress probability surface for $\omega = 0.08$

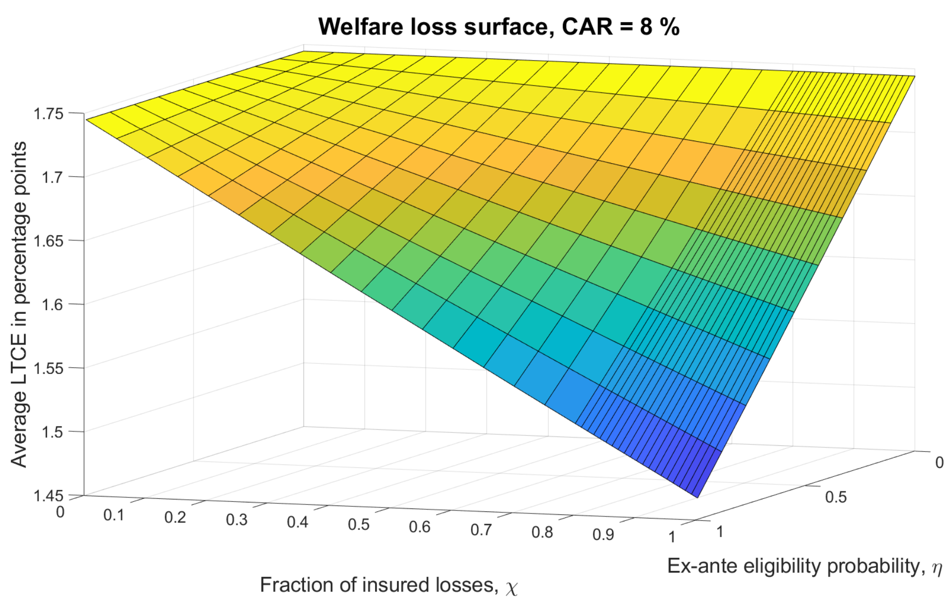

Figure 11: Average welfare loss with Exogenous distress probability $p = 0.0133$.

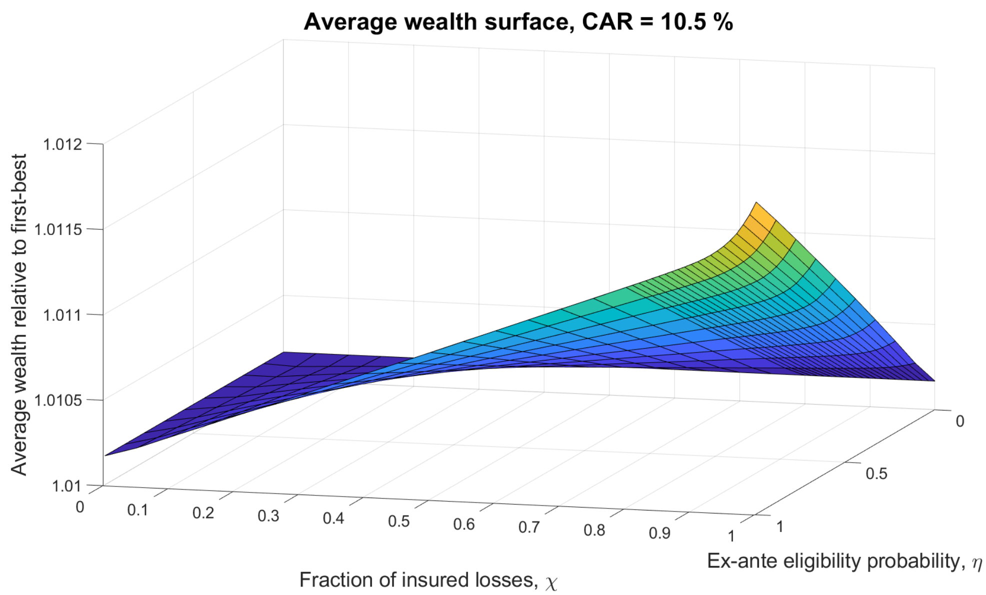

Figure 12: Average wealth (relative to the first best) surface for $\omega = 0.105$

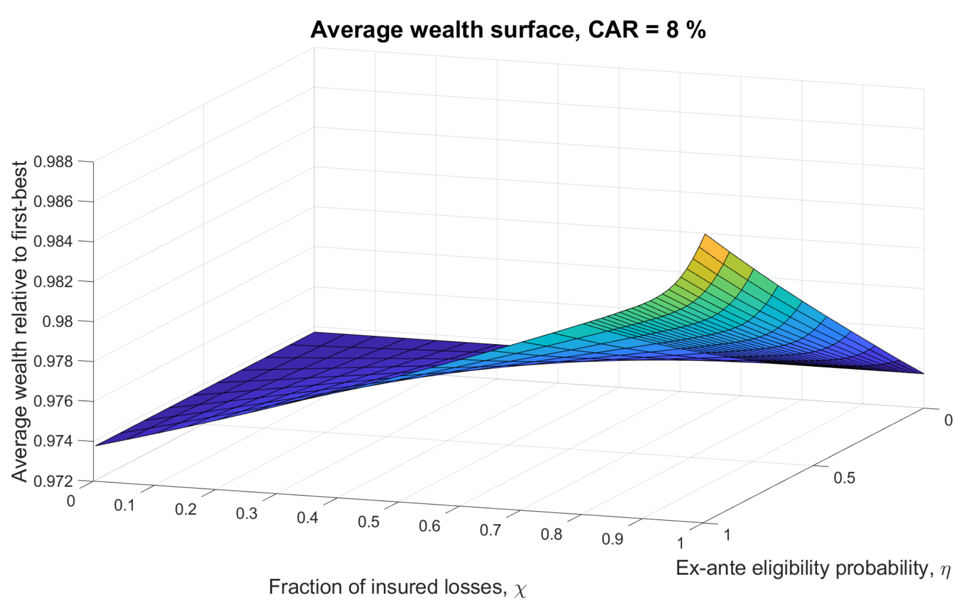

Figure 13: Average wealth (relative to the first best) surface for $\omega = 0.08$

A Appendix

A.1 Full set of equilibrium equations

The final system of dynamic equations fully characterizing a solution to our model has 22 equations in 22 dynamic variables: z_t, C_t, K_t^B, K_t^P, $W_{t+1|\psi_t}$, $\Lambda_{t+1|\psi_t}$, D_t^h, N_t, R_t^A, $R_{t+1|\psi_t}^P$, R_t, κ_t^H, κ_t^L, $w_{t+1|\psi_t}^P$, $w_{t+1|\psi_t}^B$, μ_t, $d_t^{\max}$, A_t^B, p_t, $\Pi_{t+1|1}$, $\Pi_{t+1|2}^J$, $\Pi_{t+1|3}$. The dynamic equations are

$$\log z_{t+1} = \rho_z \log z_t + \varepsilon_{z,t+1},\ \ \varepsilon_{z,t+1} \sim N\left(0, \sigma_z^2\right) \tag{A.1}$$

$$C_t + K_t^B + K_t^P = W_{t|\psi_{t-1}} \tag{A.2}$$

$$W_{t+1|\psi_t} = \left(\begin{array}{c} \left(1-\delta\right) K_t^P + \left[K_t^P\right]^{\theta} z_{t+1}^{1-\theta} \\ +\varphi_{\psi_t} \left(\left(1-\delta\right) K_t^B + z^B \left[K_t^B\right]^{\theta} z_{t+1}^{1-\theta}\right) \end{array} \right) \tag{A.3}$$

$$C_t^{-\sigma} = R_t^A \mathbf{E}_t \sum_{\psi_t=1}^{3} \Lambda_{t+1|\psi_t} \tag{A.4}$$

$$C_t^{-\sigma} = \mathbf{E}_t \sum_{\psi_t=1}^{3} \Lambda_{t+1|\psi_t} R_{t+1|\psi_t}^P \tag{A.5}$$

$$\frac{R_t^A}{R_t} - 1 = \frac{\gamma \left[D_t^h\right]^{-\sigma}}{\mathbf{E}_t \sum_{\psi_t=1}^{3} \Lambda_{t+1|\psi_t}} - \frac{\delta \mathbf{E}\left(\Lambda_{t+1|2} + \Lambda_{t+1|3}\right)}{\mathbf{E}_t \sum_{\psi_t=1}^{3} \Lambda_{t+1|\psi_t}} \tag{A.6}$$

$$\Lambda_{t+1|\psi_t} = \beta \phi_{\psi,t} C_{t+1|\psi_t}^{-\sigma} \tag{A.7}$$

$$\mathbf{E}_t\left(\frac{\Lambda_{t+1|2}}{\kappa_t^H}+\chi\Lambda_{t+1|3}\right)=\mathbf{E}_t\left(\sum_{\psi_t=2}^{3}\Lambda_{t+1|\psi_t}\left(1-\delta+\theta\left[K_t^P\right]^{\theta-1}z_{t+1}^{1-\theta}\right)\right) \tag{A.8}$$

$$\mathbf{E}_t\left(\frac{\Lambda_{t+1|2}}{\kappa_t^L}\right)=\mathbf{E}_t\left(\sum_{\psi_t=2}^{3}\Lambda_{t+1|\psi_t}\left(1-\delta+\theta\left[K_t^P\right]^{\theta-1}z_{t+1}^{1-\theta}\right)\right) \tag{A.9}$$

$$K_t^P=N_t-1_{\psi_t\in\{2,3\}}D_t^h \tag{A.10}$$

$$R_{t+1|\psi_t}^P=1-\delta+\theta\left[K_t^P\right]^{\theta-1}z_{t+1}^{1-\theta} \tag{A.11}$$

$$w_{t+1|\psi_t}^P=(1-\theta)\left[K_t^P\right]^{\theta}z_{t+1}^{1-\theta} \tag{A.12}$$

$$w_{t+1|\psi_t}^B=\varphi_{\psi_t}(1-\theta)\,z^B\left[K_t^B\right]^{\theta}z_{t+1}^{1-\theta} \tag{A.13}$$

$$-\mu_t d_t^{\max}=\mathbf{E}_t\sum_{\psi_t=1}^{3}\Lambda_{t+1|\psi_t}\left(\varphi_{\psi_t}\left\{1-\delta+\theta z^B\left[K_t^B\right]^{\theta-1}z_{t+1}^{1-\theta}\right\}-R_t^A\right) \tag{A.14}$$

$$\mu_t=\left(\frac{R_t^A}{R_t}-1\right)\mathbf{E}_t\left(\sum_{\psi_t=1}^{3}\Lambda_{t+1|\psi_t}\right)+\mathbf{E}_t\left(\begin{array}{c}\Lambda_{t+1|2}+\Lambda_{t+1|3}\\ -\Lambda_{t+1|2}\left(\frac{\eta}{\kappa_t^H}+\frac{1-\eta}{\kappa_t^L}\right)\end{array}\right) \tag{A.15}$$

$$\mu_t\geq 0,\;\; D_t^h\leq d_t^{\max}K_t^B,\;\; \mu_t\left(d_t^{\max}K_t^B-D_t^h\right)=0 \tag{A.16}$$

$$0=\frac{D_t^h}{R_t}+\frac{A_t^B}{R_t^A}-K_t^B(1-\omega) \tag{A.17}$$

$$d_t^{\max}\equiv\kappa_t^L\mathbf{E}_t\left[1-\delta+\theta z^B\left[K_t^B\right]^{\theta-1}z_{t+1}^{1-\theta}|\psi_t=2\right] \tag{A.18}$$

$$p_t=\frac{\Pr\left(\Pi_{t+1|1}(\zeta)<0\right)}{\left(\begin{array}{c}1+\Pr\left(\Pi_{t+1|1}(\zeta)<0\right)-q\Pr\left(\Pi_{t+1|3}(\zeta)<0\right)\\ -(1-q)\left[\eta\Pr\left(\Pi_{t+1|2}^H(\zeta)<0\right)+(1-\eta)\Pr\left(\Pi_{t+1|2}^L(\zeta)<0\right)\right]\end{array}\right)} \tag{A.19}$$

$$\Pi_{t+1|1}(\zeta)=\zeta\left[(1-\delta)K_t^B+z^B\left[K_t^B\right]^{\theta}z_{t+1}^{1-\theta}\right]-w_{t+1|1}^B-A_t^B-D_t^h \tag{A.20}$$

$$\Pi_{t+1|2}^J(\zeta)=\zeta\left[(1-\delta)K_t^B+z^B\left[K_t^B\right]^{\theta}z_{t+1}^{1-\theta}\right]-w_{t+1|2}^B-A_t^B-\frac{1}{\kappa_t^J}D_t^h,\;\; J=\{H,\,L\} \tag{A.21}$$

$$\Pi_{t+1|3}(\zeta)=\zeta\lambda\left[(1-\delta)K_t^B+z^B\left[K_t^B\right]^{\theta}z_{t+1}^{1-\theta}\right]-w_{t+1|3}^B-A_t^B. \tag{A.22}$$

A.2 Lifetime consumption equivalent (LTCE) welfare measure

We use the LTCE measure to compare welfare across economies with various policy configurations (ω, η, χ). This appendix shows how we define this measure. Suppose the expected welfare in an economy with a policy configuration (ω, η, χ) is

$$E_0 \sum_{t=0}^{\infty} \beta^t \left[\frac{C_t^{1-\sigma}}{1-\sigma} + \gamma \frac{D_t^{1-\sigma}}{1-\sigma} \right], \tag{A.23}$$

while the Social Planner's (first-best) allocation benchmark yields

$$\tilde{U} = E_0 \sum_{t=0}^{\infty} \beta^t \left[\frac{\tilde{C}_t^{1-\sigma}}{1-\sigma} + \gamma \frac{\tilde{D}_t^{1-\sigma}}{1-\sigma} \right]. \tag{A.24}$$

We define the LTCE measure as the value ε such that

$$\mathbf{E}_0 \sum_{t=0}^{\infty} \beta^t \left[\frac{\left[(1+\varepsilon) C_t \right]^{1-\sigma}}{1-\sigma} + \gamma \frac{D_t^{1-\sigma}}{1-\sigma} \right] = \tilde{U}. \tag{A.25}$$

If multiplied by 100, the LTCE measure ε is interpreted as the percentage increase in lifetime consumption necessary to make the representative household indifferent between the two compared allocations.