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EUROPEAN CENTRAL BANK

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## Working Paper Series

Dick Oosthuizen, Ryan Zalla    Funding deposit insurance

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## **Abstract**

We present a quantitative model of deposit insurance. We characterize the policymaker's optimal choices of coverage for depositors and premiums raised from banks. Premiums contribute to a deposit insurance fund that lowers taxpayers' resolution cost of bank failures. We find that risk-adjusted premiums reduce moral hazard, enabling the policymaker to increase deposit insurance coverage by 3 percentage points and decrease the share of expected annual bank failures from 0.66% to 0.16%. The model predicts a fund-to-covered-deposits ratio that matches the data and declines in taxpayers' income due to taxpayers' risk aversion.

**Keywords:** Deposit Insurance, Bank Runs, Bank Regulation

**JEL:** G21, G28

## Non-Technical Summary

How should deposit insurers finance the costs of bank failures? In practice, bank failures are resolved with funds collected from all banks before a crisis or from taxpayers after. According to 2018 data from the International Association of Deposit Insurers (IADI), countries' deposit insurance funds vary from zero to more than ten percent of their total insured deposits. Credible guidance for financing a deposit insurance system is scarce, which is problematic for two reasons. First, mature deposit insurance systems, including the United States, have suffered major losses in recent years, revealing weaknesses in funding schemes. Second, since the Great Recession, the European Union and other countries have started implementing deposit insurance systems. These events make the question of how to finance deposit insurance particularly relevant today.

We construct a quantitative model to determine optimal deposit insurance financing. In the model, the policymaker chooses both the amount of insurance to offer depositors and the premiums to collect from banks. Premiums are then stored in an insurance fund. A major challenge to deposit insurance systems is that banks may engage in moral hazard, where banks exploit the protection of deposit insurance by making riskier investments. We show that if premiums are risk-adjusted – that is, if the policymaker charges higher premiums to banks that make riskier investments – then fewer banks will engage in moral hazard. The policymaker does not want to charge higher premiums than necessary because doing so could restrict credit access in the economy by reducing banks' loanable funds.

We compare two types of deposit insurance systems: one where an insurance fund is built with risk-adjusted premiums, and another where all funds are raised from taxpayers post-crisis. The former allows the policymaker to increase depositors' coverage by 3 percentage points. Because risk-adjusted premiums discourage moral hazard, the expected share of banks that fail annually decreases from 0.66% to 0.16% based on our model calibration with the 2019 Survey of Consumer Finance (SCF) and 2001-2020 Federal Deposit Insurance Corporation (FDIC) data.

According to our model, after the insurance fund reaches a sufficient level, the policymaker should taper off premiums so banks can invest these funds productively. It is true that lowering premiums

while preserving the coverage level may encourage riskier behavior by banks. Nonetheless, the policy-maker optimally accepts this tradeoff to balance depositors' benefit of higher returns with taxpayers' protection by a mature insurance fund.

Our paper emphasizes the importance of risk-adjusted premiums and deposit insurance funds for maximizing the benefits of deposit insurance to the financial system. Building a fund with risk-adjusted premiums enables policymakers to increase coverage to depositors and lower moral hazard among banks. We argue that the latter financing structure should be preferred to a deposit insurance system in which taxpayers are entirely responsible for absorbing bank failures.

# 1 Introduction

How should deposit insurers finance the costs of bank failures? In practice, bank failures are resolved with funds collected from all banks before a crisis (*ex ante*) or from taxpayers after (*ex post*). Figure 1 reveals a negative correlation between ex-ante deposit insurance funds and countries' income levels. The variance in funds indicates that credible guidance for financing a deposit insurance scheme is needed. Mature deposit insurance systems have suffered major overdrafts in recent years, revealing weaknesses in current funding schemes. Before the Great Recession, the Federal Deposit Insurance Corporation (FDIC) collected \$32 billion in premiums and maintained a deposit insurance fund equivalent to 1.21% (\$50.2 billion) of insured deposits in 2006 (FDIC, 2007). By the end of 2009, the fund was overdrawn (-\$20.9 billion) and premiums increased to \$17.7 billion (FDIC, 2011). Following the Great Recession, the European Union and other countries have started building deposit insurance systems. These events make the question of how to finance deposit insurance particularly relevant today.

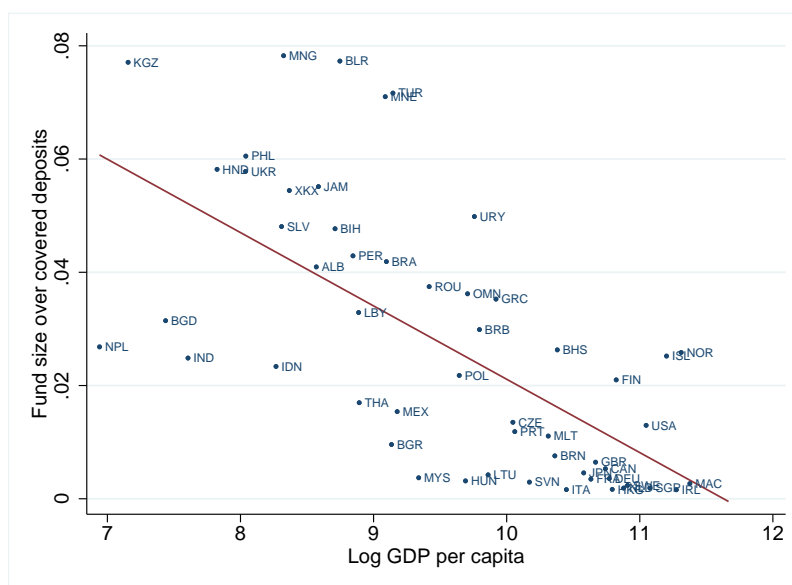


Figure 1: Fund size over covered deposits (2018) relative to log GDP per capita. GDP per capita is in U.S. 2018 dollars. Trend line is weighted by log population.

We construct a quantitative model to characterize the optimal allocation of deposit insurance funding. Deposit insurance schemes comprise two policy instruments: the levels of coverage and premi-

ums. The policymaker chooses both the depositors' coverage level and the premiums collected from banks for the insurance fund. Banks may exploit equity holders' protection from deposit insurance and engage in moral hazard by offering a higher deposit rate. Risk-adjusted premiums curtail excessive risk-taking by banks and lower the probability of failure in our model.

Banks incur opportunity costs from the policymaker's premiums, because banks could have productively invested them. Banks' ability to satisfy their obligations to depositors is also sensitive to the timing of premium collection. The key model tension is the policymaker's dynamic tradeoff between building a fund to discourage moral hazard and protect taxpayers, and allowing banks to productively invest their deposits. The policymaker chooses the two policy instruments as a function of the fraction of banks that the policymaker would allow to fail before ex-post taxation is necessary.

Our quantitative analysis confirms that risk-adjusted premiums deter moral hazard. The policymaker alleviates taxpayers' potential burden from crises with an insurance fund to mitigate fiscal shortfalls. Premiums allow the policymaker to increase the share of covered deposits by three percentage points and lower the expected share of banks that fail each period from 0.66% to 0.16%. The welfare gain from premiums concentrates among depositors whose coverage increases. Welfare for partially-insured depositors without bank equity increases by a weighted 14.57% and by more for equity holders.

Moral hazard leads to a lower fraction of expected failures when premiums are collected, but a higher fraction when the fund reaches its optimal size and premiums are tapered off. The policymaker chooses both a higher coverage level and fund size when banks can engage in moral hazard by varying their deposit rate in response to the coverage and premium levels. After the fund reaches an optimal level, the policymaker reduces premiums despite the potential for moral hazard because the opportunity cost of reducing banks' investment rises. The policymaker uses the higher fund to guard taxpayers against larger expected outlays from moral hazard. To further reduce taxpayers' risk exposure, the policymaker sets a higher coverage level to lower the annual expected share of banks that fail.

Whether premiums are advantageous or detrimental to the financial system depends on the timing



of their collection. If premiums are collected *before* aggregate states are realized, premiums would increase expected bank failures and should be discarded. Moreover, collecting premiums would accomplish only a redistribution of wealth from banks to the policymaker without productive investment. Premiums should be collected only from surviving banks *after* the aggregate states are realized. We elaborate on the rationale in Section 6.4.

As a quantitative application, we solve the model for different income and deposit levels, holding the ratio of total income to total deposits constant. While the optimal share of covered depositors remains the same across calibrations, we find that as taxpayers' income increases, the optimal fund-to-covered-deposits ratio decreases as a result of risk-averse taxpayers. As income increases, agents exhibit decreasing absolute risk aversion and receive lower utility from insurance. Consequently, the model is able to match the observed decline of the fund-to-covered-deposits ratio in income (see Figure 1).

Our paper extends the recently developed framework of [Dávila and Goldstein \(2021\)](#) to include optimal deposit insurance premiums. [Dávila and Goldstein](#) augment the canonical model of bank runs by [Diamond and Dybvig \(1983\)](#) to feature depositors with heterogeneous deposit balances. Heterogeneous depositors and an aggregate shock to the profitability of banks' investments enable the study of fundamental-based and panic-based bank failures. [Dávila and Goldstein](#) derive the effect of changes in the coverage level on social welfare by using a small number of sufficient statistics, such as the failure probability and expected losses. Their identified variables have a first-order effect on welfare and constitute sufficient statistics for assessing changes in the coverage level.

We add two extensions to the model of [Dávila and Goldstein \(2021\)](#). First, we incorporate their static game into an infinite horizon framework, which allows us to model a dynamic deposit insurance fund with premium collection. Second, we introduce ex-post bank heterogeneity to allow for a variable crisis size, matching the empirical observation that a small amount of deposit insurance funds is regularly dispatched to failing banks ([IADI, 2009](#)). We use these two extensions to study the role of premiums.

Our paper builds on the deposit insurance literature through multiple dimensions. First, we contribute to the literature on financial fragility, banking, and bank runs that follows the canonical model of [Diamond and Dybvig \(1983\)](#). Other theoretical extensions include studies by [Allen and Gale \(1998\)](#), [Rochet and Vives \(2004\)](#), [Goldstein and Pauzner \(2005\)](#), [Uhlig \(2010\)](#), and [Keister \(2016\)](#). [Mitkov \(2020\)](#) highlights the relevance of deposit distributions and the cost of public funds for intervention. [Mitkov](#) argues that the distribution of depositors' wealth influences the policymaker's response to banking crises. We advance this literature by using the cross-section of depositors to study optimal premiums and deposit insurance coverage. Both policy instruments affect the composition of insured depositors and financial fragility.

Second, we characterize the welfare implications of risk-adjusted deposit insurance premiums and their effect on moral hazard, augmenting previous studies such as [Pennacchi \(1999\)](#), [Pennacchi \(2006\)](#), [Acharya \*et al.\* \(2010\)](#), and [Kim and Rezende \(2020\)](#). [Pennacchi \(2006\)](#) argues that while government deposit insurance improves liquidity during times of financial distress, actuarially fair insurance premiums – premiums that equal the expected cost to the deposit insurance provider – could, if assessed to insure systemic risks instead of idiosyncratic risks, create moral hazard and lead to longer-run economic instability. [Acharya \*et al.\* \(2010\)](#) analyze the efficient level of deposit insurance premiums and examine the relevance of systemic risk in the financial sector. They find that premiums should account for systemic risk caused by correlation among banks' returns, size, and interconnection. [Kim and Rezende \(2020\)](#) take an empirical approach and examine the effect of deposit insurance premiums on banks' demand for reserves and on interbank lending in the federal funds market. They find that premiums reduce demand for reserves and increase banks' supply of federal funds, indicating that balance sheet costs can induce banks to reach for yield. Our paper evaluates the optimal choices of premiums and coverage in light of intertemporal social welfare.

Third, we quantitatively assess the tradeoffs between ex-ante and ex-post deposit insurance systems. We inform conversations about the optimal financing of deposit insurance in the broader policy literature by [Demirgüç-Kunt and Detragiache \(2002\)](#), [Demirgüç-Kunt and Huizinga \(2004\)](#), [Demirgüç-](#)

Kunt *et al.* (2005), Demirgüç-Kunt *et al.* (2008), Anginer *et al.* (2014), Demirgüç-Kunt *et al.* (2015), and Anginer and Demirguc-Kunt (2018). We introduce a structural model to the largely empirical policy literature to better understand the tradeoffs of building a fund with premiums rather than ex-post taxation. Our model accommodates the policymaker's decision about the level of crisis severity that the deposit insurance fund should absorb before ex-post taxation is necessary.

We organize our paper as follows. Section 2 describes the benchmark model. Section 3 characterizes the static equilibrium. Section 4 provides a normative analysis of the socially optimal coverage and premiums. Section 5 discusses our calibration of the quantitative model. Section 6 reveals our quantitative results with the U.S. calibration, while Section 7 assesses the robustness of different income levels. Section 8 concludes. All proofs and derivations are in the Appendix.

## 2 Model

### 2.1 Environment

Our model builds on Dávila and Goldstein (2021) with two key modifications. First, we incorporate their static game into an infinite horizon framework to allow a dynamically evolving deposit insurance fund. An intertemporal model lets us capture the slow buildup of funds observed in the data and investigate the importance of when premiums are collected within a period. Moreover, we can abstract from the distributional implications of premium rebates if there is a surplus. Second, we introduce ex-post heterogeneous banks to allow for a variable crisis size in which only a fraction of banks may fail. The variable crisis size captures the empirical observation that a small number of banks fails each year (IADI, 2009). In practice, policymakers choose the share of bank failures that are insured by the fund relative to the share that taxpayers absorb ex-post.

Time is discrete. Each period  $t$  consists of three subperiods  $\tilde{t} = 0, 1, 2$ , with a single consumption good (dollars) as the numeraire. There is a continuum of banks  $b$  (mass normalized to 1) and each bank draws a return on assets  $\rho$ , which can be either high ( $\rho_h$ ) or low ( $\rho_l$ ), where  $\rho_h > \rho_l$ . There are two aggregate shocks: the fraction  $s$  of banks drawing the low-return state and the value of the low-return state  $\rho_l$ . Both shocks are publicly realized at the end of subperiod 1. The probability of drawing a low

(high) return is  $s(1-s)$ , where  $s \in [0, 1]$  is distributed according to the cdf  $H(\cdot)$ . Under a law of large numbers,  $s$  and  $1-s$  are the proportions of banks with low and high returns on assets. Next, we assume the value of the low-return state  $\rho_l \in [\underline{\rho}_l, \bar{\rho}_l]$  is distributed according to the cdf  $R(\cdot)$ . These aggregate shocks allow us to vary the fraction of banks that fail and their severity of failure.

In addition to the banks, the economy is populated by a continuum of depositors  $i$  and a continuum of taxpayers  $\tau$ . A new generation replaces banks and depositors each period. We use the index  $j$  to denote both depositors and taxpayers. There is also a benevolent policymaker.

### 2.1.1 Depositors

Each depositor is endowed with  $D_{0i}$  dollars that are deposited in banks. As banks are ex-ante identical and have a mass normalized to one, we assume all depositors have  $D_{0i}$  in each bank  $b$ . The cross-sectional holdings of total deposits are distributed according to  $G(\cdot)$  with support  $[\underline{D}, \bar{D}]$  where  $\bar{D} < \infty$ . We denote the total mass of depositors by  $\bar{G} = \int_{\underline{D}}^{\bar{D}} dG(i)$ .

Depositors have ex-ante identical preferences and are uncertain about their preferences over future consumption. We refer to those who want to consume only at subperiod 1 as early depositors and others who want to consume only at subperiod 2 as late depositors. At subperiod 0, depositors know the probability of being an early or late depositor. At subperiod 1, depositors privately learn their type. The probability of being an early (late) type is  $\lambda$  ( $1-\lambda$ ). Under a law of large numbers,  $\lambda$  and  $1-\lambda$  are respectively the exact proportions of early and late depositors with initial deposits  $D_{0i}$ .

The ex-ante utility of a depositor  $i$  is given by

$$V_i = \mathbb{E}_{\rho_l} [\mathbb{E}_s [\mathbb{E}_\lambda [U(C_{ti}(s, \rho_l))]]] = \mathbb{E}_{s, \rho_l} [\lambda U(C_{1i}(s, \rho_l)) + (1-\lambda)U(C_{2i}(s, \rho_l))], \quad (1)$$

where  $C_{1i}(s, \rho_l)$  and  $C_{2i}(s, \rho_l)$  respectively denote the consumption of early and late depositors for a given realization of the aggregate states  $s$  and  $\rho_l$ . Depositors' flow utility  $U(\cdot)$  satisfies standard regularity conditions:  $U'(\cdot) > 0$ ,  $U''(\cdot) < 0$ , and  $\lim_{C \rightarrow 0} U'(C) = \infty$ . We assume all depositors have a strictly positive deposit balance and an external source of income. Figure 2 displays the sequence of events in the model.

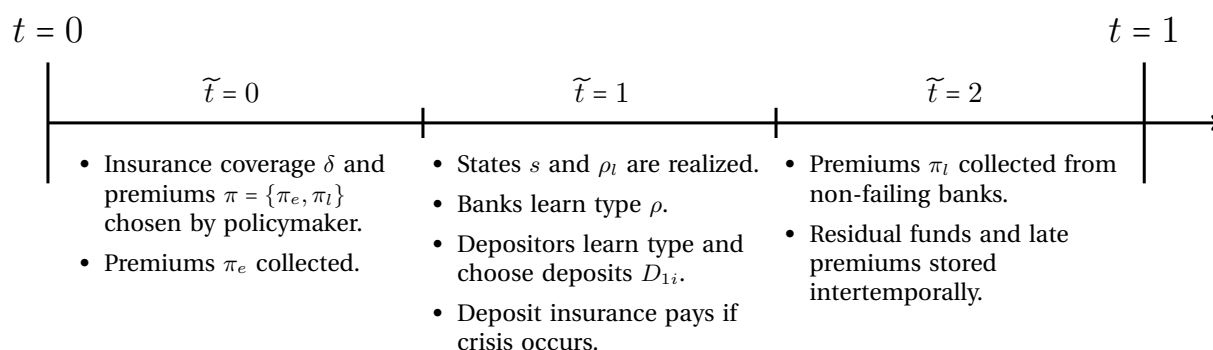


Figure 2: Timeline

Early depositors receive a stochastic endowment  $Y_{1i} > 0$  at subperiod 1, whereas late depositors receive  $Y_{2i} > 0$  at subperiod 2. These endowments reflect the payoffs from the rest of the depositors' portfolios. Late depositors also have access to a storage technology between subperiods 1 and 2.

At subperiod 1, after learning their type and observing the aggregate state  $s$  at the end of the subperiod, depositors can modify their deposit balance at each bank by choosing a new deposit level  $D_{1i}(\rho)$ . This is depositors' only decision.

### 2.1.2 Banks' Technology and Deposit Contract

Banks have access to two production technologies. First, for every unit of consumption good invested at subperiod 0, banks receive  $\rho_{1h} \geq 0$  units of consumption good at subperiod 1 in the high-return state and  $\rho_{1l} \geq 0$  in the low-return state. Second, for every unit of consumption good invested at subperiod 1, banks receive either  $\rho_{2h}$  or  $\rho_{2l}$  units of consumption good at subperiod 2, depending on the state realized in subperiod 1. We simplify our analysis by assuming that  $\rho_{1l} = \rho_{2l} = \rho_l$  and  $\rho_{1h} = \rho_{2h} = \rho_h$ , where  $\rho_h > \rho_l$ . Note the value of  $\rho_l$  is risky and realized at the start of the subperiod.

Depositors have a deposit contract with each bank. A depositor who deposits their endowment at subperiod 0 earns a non-contingent gross return  $R_1 \geq 1$  which accrues at subperiod 1. We refer to this interest rate on deposits as the *deposit rate*. Consequently, a depositor  $i$  who deposits  $D_{0ib}$  in bank  $b$  at subperiod 0 may withdraw up to  $D_{0ib}R_1$  at subperiod 1. At subperiod 1, depositors may withdraw funds or leave them in the bank, but they cannot deposit additional funds, i.e.,  $D_{1ib}(\rho) \in [0, D_{0ib}R_1]$  for  $\rho \in [\rho_l, \rho_h]$ . A depositor withdraws a strictly positive amount from bank  $b$  at subperiod 1 when  $D_{0ib}R_1 >$

$D_{1i}(\rho)$ , which is given by  $\Omega_{i,b}(\rho) = D_{0ib}R_1 - D_{1ib}(\rho)$ . A depositor leaves their balance unchanged when  $D_{0ib}R_1 = D_{1ib}(\rho)$ . We denote the depositors' deposit choices over all banks by  $D_{1i}(s, \rho) = \int_b D_{1ib}(\rho) db$  and total period 1 deposits as  $D_1(s, \rho) = \int_{\underline{D}}^{\bar{D}} D_{1i}(s, \rho) dG(i)$ . We summarize the total net withdrawals for each bank with return draw  $\rho$  by

$$\Omega_b(\rho) = \int_{\underline{D}}^{\bar{D}} (D_{0ib}R_1 - D_{1ib}(\rho)) dG(i) = D_0R_1 - D_1(\rho),$$

where  $D_0 = \int_{\underline{D}}^{\bar{D}} D_{0i} dG(i)$  and  $D_1(\rho) = \int_{\underline{D}}^{\bar{D}} D_{1i}(\rho) dG(i)$  respectively denote the aggregate amount of bank deposits in subperiods 0 and 1, exploiting the unit mass of banks. We can summarize all withdrawals by  $\Omega = \int_b \Omega_b(\rho) db$ .

Both deposit and withdrawal decisions are made jointly in subperiod 1. Following [Allen and Gale \(1998\)](#), given withdrawal decisions, if banks are unable to meet their financial obligations to depositors, then banks liquidate and distribute funds proportionally to depositors after deposit insurance is paid. A depositor's ex-post payoff depends on the fraction of banks with the low-return state, the return to banks' investments, the deposit rate, the behavior of other depositors, the deposit insurance premium, and the level of deposit insurance coverage. We elaborate on these elements below.

All remaining proceeds of the banks' investment in subperiod 2 are distributed among equity holders, who are depositors that own the banks. To distinguish between equity holders and depositors in the model, we introduce equity weights  $w_{Ei}$  for depositors. We assume that the depositors with the lowest calibrated deposit holdings do not hold equity. We normalize the other equity weights such that  $\int_{\underline{D}}^{\bar{D}} w_{Ei} dG(i) = 1$ .

### 2.1.3 Deposit Insurance and Financing

The policymaker has two instruments available: the level of deposit insurance  $\delta$  and the level of deposit insurance premiums  $\pi$  collected from banks, both measured in units of the consumption good. Depositors' holdings are insured up to a level  $\delta \geq 0$  for any realization of the aggregate state  $s$ . The coverage level is chosen under commitment by the policymaker in subperiod 0 and paid to depositors only after a bank failure in subperiod 1. The premium level is also chosen under commitment at subperiod

0 and has two components. Early premiums  $\pi_e$  are collected from banks at the end of subperiod 0 before the aggregate states are realized. Late premiums  $\pi_l$  are collected at the start of subperiod 2 after the aggregate states are realized from banks that do not fail. We assume that  $\pi_e = (1 - w_l)\pi$  and  $\pi_l = w_l\pi$ , where the policymaker chooses the premium level  $\pi$ , and the weight  $w_l$  on late premiums is exogenous. Given the timing of premium collection, early premiums are available for deposit insurance payouts at  $\tilde{t} = 1$  while late premiums are available only in future periods.

Premiums are stored intertemporally in a deposit insurance fund  $F$  to finance future deposit insurance payouts. The fund earns a return of  $r^F \geq 0$  between periods but no return within a period. The law of motion for the fund within and between periods is as follows. We assume that at  $\tilde{t} = 0$ , the initial size of the fund is  $F$  and the premiums collected from all banks is  $\pi_e$ . The late premiums  $\pi_l$  are collected only from non-failing banks at  $\tilde{t} = 2$ . Then the fund at  $\tilde{t} = 1$  is<sup>1</sup>

$$F_1(\pi_e, F) = \pi_e + F, \quad (2)$$

and the law of motion is

$$F'(\delta, \pi, F) = (1 + r^F) \left[ \max \left\{ F + \pi_e - \tilde{q}^F \max \left[ \int_D^{\bar{D}} (\min\{D_{0i}R_{1i}, \delta\} - \chi(\rho_l)\rho_l(D_{0i} - \pi_e)) dG(i), 0 \right], 0 \right\} + (1 - \tilde{q}^F)\pi_l \right], \quad (3)$$

where  $\tilde{q}^F$  is the indicator function for the realized fraction of banks that fail within the period.

The premiums collected from banks are one of two possible ways the policymaker can finance deposit insurance payments. In addition, the policymaker collects taxes from taxpayers at the end of subperiod 1 if the fund is insufficient. We denote the fiscal shortfall in states  $s$  and  $\rho_l$  by  $T(s, \rho_l)$ . Taxation is inefficient because accessing public funds is costly; that is, every dollar collected incurs a resource loss of  $\kappa(T(s, \rho_l)) \geq 0$  dollars. We assume that  $\kappa(\cdot)$  is a weakly increasing and convex function that satisfies  $\kappa(0) = 0$  and  $\lim_{t \rightarrow \infty} \kappa(T) = \infty$ . When banks fail and deposit insurance is disbursed, the policymaker only recovers a fraction  $\chi(\rho_l) \in [0, 1]$  of any resources held by banks. The remaining fraction  $1 - \chi(\rho_l)$  captures deadweight losses associated with bank failure.

Finally, we assume that a continuum of identical taxpayers, who have the same flow utility  $U(\cdot)$  as depositors, bear the burden of all taxes and associated deadweight losses. Taxpayers consume only at

<sup>1</sup>Note that  $F_1(\pi, F)$  is the fund balance after premiums are collected but before payments (if any) are made.

subperiod 1 and have an endowment  $Y_\tau$  that is adequate to cover any funding shortfall  $T(s, \rho_l)$  generated by deposit insurance for all states  $s$  and  $\rho_l$ . The benevolent policymaker commits to a deposit insurance coverage level that can be financed in all possible aggregate states, either through taxation or the deposit insurance fund. If a crisis occurs at the end of  $\tilde{t} = 1$ , the fund is used first and taxpayer revenue, if necessary, is used second. By distinguishing between taxpayers and depositors, we highlight the distributional consequences of the given funding scheme.

#### 2.1.4 Deposit Rate Determination

Banks' ability to determine the deposit rate given the levels of coverage or premiums injects moral hazard into the model. The interest rate on deposits is chosen competitively by banks. Banks choose  $R_1$  at  $\tilde{t} = 0$  to maximize a weighted average of depositors' expected utilities, taking the coverage and premium levels as given. Banks internalize how their choice of the deposit rate affects the likelihood and severity of bank failure. Moral hazard arises because banks do not internalize how their deposit rate may harm taxpayers by causing a fiscal shortfall during failure. We model the risk-weighted premiums by allowing the policymaker to post a menu  $\pi(R_1)$  so premiums are proportionate to deposit rates.

### 3 Static Equilibrium

We characterize an equilibrium of the static game for a given level of coverage, premium, initial fund size, and deposit rate.

#### 3.1 Equilibrium Definition

An equilibrium, for a given level of coverage  $\delta$ , premiums  $\pi = \{\pi_e, \pi_l\}$ , initial fund size  $F$ , and deposit rate  $R_1$ , is defined as depositors' consumption allocations  $C_{1i}(s, \rho_l)$  and  $C_{2i}(s, \rho_l)$  and deposit choices  $D_{1i}(s, \rho_l)$  over all banks such that depositors maximize their utility. A depositor assumes that other depositors behave optimally and taxpayers cover any funding shortfall.

#### 3.2 Equilibria at Subperiod 1

Given the aggregate state  $s$  and the low-return state  $\rho_l$ , a fraction  $\tilde{q}^F$  of banks fail and  $(1 - \tilde{q}^F)$  do not fail. For each bank there are two possible equilibria. In a *no-failure equilibrium*, partially-insured depositors leave their funds in banks to claim the promised returns at subperiods 1 and 2. In a *failure equilibrium*, partially-insured depositors run on banks and withdraw all uninsured deposits, forcing



banks to default on their obligations in subperiods 1 and 2. Regardless of bank failure, early depositors optimally withdraw their deposits, whereas fully-insured late depositors optimally keep their deposits in place.

We rewrite Equation (15) which determines the type of equilibrium as follows:

$$\begin{aligned} \text{Bank Failure,} & \quad \text{if } \widehat{D}_1(R_1, \pi, \rho_l) > D_1, \\ \text{No Bank Failure,} & \quad \text{if } \widehat{D}_1(R_1, \pi, \rho_l) \leq D_1, \end{aligned} \tag{4}$$

where the failure threshold  $\widehat{D}_1(R_1, \pi, \rho_l)$  is given by<sup>2</sup>

$$\widehat{D}_1(R_1, \pi, \rho_l) = \begin{cases} \frac{\rho_l}{\rho_l - 1} \left[ D_0 R_1 - \rho_l (D_0 - \pi_e) \right] & \text{if } \rho_l > 1 \\ \infty & \text{if } \rho_l \leq 1. \end{cases} \tag{5}$$

In Equation (4),  $D_1$  denotes the level of deposits at subperiod 1 after withdrawal decisions are made. The two types of withdrawal behavior by partially-insured late depositors determine the value of  $D_1$ . First, they could withdraw deposits in excess of the coverage level. This implies the aggregate level of deposits is equal to the aggregate level of insured deposits:

$$D_1 = D_1^-(\delta, R_1) \equiv (1 - \lambda) \int_D^{\bar{D}} \min\{D_0 i R_1, \delta\} dG(i). \tag{6}$$

Then again, if partially-insured late depositors leave their funds in banks, the aggregate level of deposits is

$$D_1 = D_1^+(R_1) \equiv (1 - \lambda) D_0 R_1. \tag{7}$$

Banks never fail in the high-return state  $\rho_h$ , but they could fail in the low-return state  $\rho_l$ . Figure 3 maps the values of the low-return state  $\rho_l$  to equilibria. We first simplify the problem by assuming  $\rho_{1l} = \rho_{2l} = \rho_l$ . There are three regions which occur depending on the parameterized value of  $\rho_l$ : a unique failure equilibrium region, a multiple equilibria region, and a unique no-failure equilibrium region. First, for sufficiently low realizations of  $\rho_l$ , both  $D_1^+$  and  $D_1^-$  are beneath the failure threshold,  $\widehat{D}_1(\rho_l)$ . Even if there are no withdrawals by late depositors, banks' profitability is sufficiently low to

<sup>2</sup>Without any simplification, the threshold for  $\rho_l > 1$  would be:  $\rho_l [\rho_l(s)(D_0 - \pi_e) - D_0 R_1 + \widehat{D}_1(\rho_l)]$ .

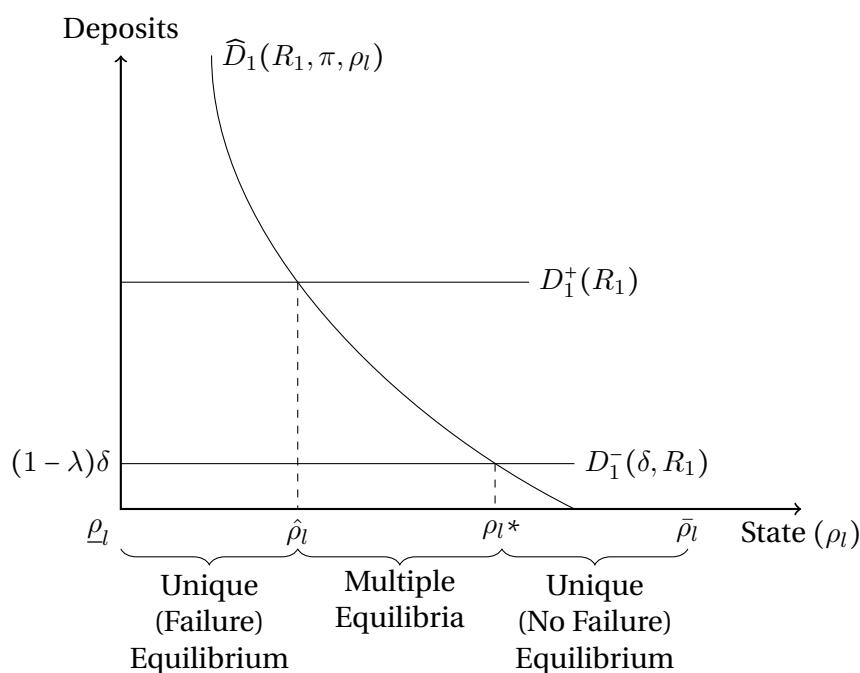


Figure 3: Equilibrium regions

induce a unique fundamental failure equilibrium.<sup>3</sup> Second, for intermediate realizations of  $\rho_l$ , there can be multiple outcomes. If the level of aggregate deposits corresponds to  $D_1^+$ , banks can meet their obligations to depositors and a no-failure equilibrium materializes. On the other hand, if the level of aggregate deposits corresponds to  $D_1^-$ , then banks are unable to meet their obligations to depositors and a failure equilibrium occurs. We refer to failures in this region as panic failures. Finally, for sufficiently high realizations of  $\rho_l$ , both  $D_1^+$  and  $D_1^-$  exceed the failure threshold  $\widehat{D}_1(R_1, \pi, \rho_l)$ . Therefore, even if partially-insured late depositors withdraw all of their funds, banks are profitable and able to meet their obligations to depositors. Thus, a unique no-failure equilibrium exists.

Figure 3 also reveals the relationship between the coverage level  $\delta$  and the equilibrium outcome. Because  $D_1^-$  is increasing in  $\delta$ , a higher level of coverage shrinks the multiplicity region. Note as well that bank failure is possible even if all deposits are insured, that is,  $\lim_{\delta \rightarrow \bar{D}_{R_1}} D_1^-(\delta, R_1) = D_1^+(R_1)$ .

<sup>3</sup>The literature conventionally distinguishes between fundamental failures (business cycle view) and panic failures (sunspot view). This model, as in [Dávila and Goldstein \(2021\)](#), allows for either, depending on the value of  $\rho_l$ . Earlier explorations include [Chari and Jagannathan \(1988\)](#), [Gorton \(1988\)](#), and [Jacklin and Bhattacharya \(1988\)](#), whereas more recent discussions include [Allen and Gale \(1998, 2007\)](#) and [Goldstein \(2012\)](#).

We characterize the regions of state realization  $\rho_l$  that correspond to each equilibrium outcome:

$$\begin{aligned}
&\text{Unique (Failure) equilibrium,} && \text{if } \underline{\rho}_l \leq \rho_l < \hat{\rho}_l(R_1, \pi), \\
&\text{Multiple equilibria,} && \text{if } \hat{\rho}_l(R_1, \pi) \leq \rho_l < \rho_l^*(R_1, \pi, \delta), \\
&\text{Unique (No Failure) equilibrium,} && \text{if } \rho_l^*(R_1, \pi, \delta) \leq \rho_l \leq \bar{\rho}_l,
\end{aligned} \tag{8}$$

where the thresholds  $\hat{\rho}_l(R_1, \pi)$  and  $\rho_l^*(R_1, \pi, \delta)$  are given by

$$\hat{\rho}_l(R_1, \pi) = \{\rho_l | D_1^+(R_1) = \widehat{D}_1(R_1, \pi, \rho_l)\}, \tag{9}$$

$$\rho_l^*(R_1, \pi, \delta) = \{\rho_l | D_1^-(\delta, R_1) = \widehat{D}_1(R_1, \pi, \rho_l)\}, \tag{10}$$

and where  $\rho_l^*(R_1, \pi, \delta) = \bar{\rho}_l$  whenever  $D_1^-(\delta, R_1) \neq \widehat{D}_1(R_1, \pi, \rho_l)$  cannot be satisfied for any value of  $\rho_l$ . In Appendix B, we derive and characterize analytical expressions for the thresholds.

### 3.3 Probability of Bank Failure

While the previous subsection describes the model dynamics for realizations of the low-return state  $\rho_l$ , we now turn our attention to joint realizations of the share of banks that draw the low-return state  $s$  and the value of the low-return state  $\rho_l$ . For each realization of  $s$  and  $\rho_l$  in subperiod 1, we need to know the ex-ante probability of a given equilibrium in order to compute expected welfare. We write the unconditional probability of a bank failure in this economy as

$$q^F(\pi, \delta, R_1) = E_s[s] \left[ R(\hat{\rho}_l(R_1, \pi)) + \gamma [R(\rho_l^*(R_1, \pi, \delta)) - R(\hat{\rho}_l(R_1, \pi))] \right].$$

Given the realization of  $s$  and  $\rho_l$ , we can denote the realized fraction of bank failures as  $\tilde{q}^F(\pi, \delta, R_1)$ , where

$$\tilde{q}^F(\pi, \delta, R_1, s, \rho_l) = \begin{cases} s & \text{if } \rho_l \leq \hat{\rho}_l, \\ \gamma s & \text{if } \rho_l > \hat{\rho}_l \ \& \ \rho_l \leq \rho_l^*, \\ 0 & \text{if } \rho_l > \rho_l^*. \end{cases} \tag{11}$$

To aid future derivations, we express the sensitivity of the failure probability to changes in the level of the premium, coverage level, and deposit rate, holding other variables constant:

$$\frac{\partial q^F}{\partial \pi} = \mathbb{E}_s \left[ (1 - \gamma)r(\hat{\rho}_l(\pi, R_1)) \frac{\partial \hat{\rho}_l}{\partial \pi} + \gamma r(\rho_l^*(\pi, \delta, R_1)) \frac{\partial \rho_l^*}{\partial \pi} \right] \leq 0, \quad (12)$$

$$\frac{\partial q^F}{\partial \delta} = \mathbb{E}_s \gamma r(\rho_l^*(\pi, \delta, R_1)) \frac{\partial \rho_l^*}{\partial \delta} \leq 0, \quad (13)$$

$$\frac{\partial q^F}{\partial R_1} = \mathbb{E}_s \left[ (1 - \gamma)r(\hat{\rho}_l(\pi, R_1)) \frac{\partial \hat{\rho}_l}{\partial R_1} + \gamma r(\rho_l^*(\pi, \delta, R_1)) \frac{\partial \rho_l^*}{\partial R_1} \right] \geq 0. \quad (14)$$

### 3.4 Depositors' Optimal Choices

We solve the static equilibrium backwards by first characterizing depositors' equilibrium choices in subperiod 1, leading to an equilibrium of the static game for a given optimal coverage  $\delta^*$ , premium  $\pi^*$ , and fund  $F$ .

In subperiod 2, banks can access remaining funds after aggregate deposit withdrawals. Given a low return  $\rho_l$  on assets, there are two potential scenarios depending on the level of aggregate deposit claims after subperiod 1,  $D_1(\rho)$ . If the bank does not fail, then it has sufficient funds to honor the deposit contracts. If, however, the bank does not have sufficient funds to honor the deposit contracts at subperiod 1 or subperiod 2, it fails and depositors submit insurance claims.

More formally,

$$\begin{aligned} \text{Bank Failure} & \quad \text{if } \rho_l[\rho_l(D_0 - \pi_e) - \Omega_b(\rho_l)] < D_1(\rho_l), \\ \text{No Bank Failure} & \quad \text{if } \rho_l[\rho_l(D_0 - \pi_e) - \Omega_b(\rho_l)] \geq D_1(\rho_l), \end{aligned} \quad (15)$$

where the left side of equation (15) represents the total funds available to banks to fulfill deposit claims at subperiod 2. Next, we address the behavior of (i) early depositors, (ii) fully-insured late depositors, and (iii) partially-insured late depositors under both failure and no-failure scenarios. Given our assumptions, early depositors optimally withdraw all of their deposits at subperiod 1, setting  $D_{1i}^*(\rho) = 0$ ,  $\forall \rho \in \{\rho_l, \rho_h\}$ . The equilibrium consumption of early depositors is given by

$$C_{1i}(s, \rho_l) = \tilde{q}^F \left( \min\{D_{0i}R_1, \delta\} + \alpha_F \max\{D_{0i}R_1 - \delta, 0\} \right) + (1 - \tilde{q}^F)D_{0i}R_1 + Y_{1i}, \quad (16)$$

where  $\alpha_F \geq 0$  is the equilibrium recovery rate on uninsured deposits, which we define in Equation (18) below.

Late depositors can either be fully-insured ( $D_{0i}R_1 \leq \delta$ ) or partially insured ( $D_{0i}R_1 > \delta$ ). Fully-

insured late depositors have deposit holdings that are less than the level of coverage. Regardless of how other depositors behave, fully-insured late depositors are indifferent between withdrawing or keeping their deposits in banks during failures, provided depositors have access to a perfect storage technology. If we assume that there is a small withdrawal penalty or an imperfect storage technology, then we can rationalize the “do nothing” equilibrium where depositors keep their balances in banks and choose  $D_{1i}^*(\rho) = D_{0i}R_1$ .

Partially-insured late depositors have deposit holdings that exceed the level of coverage. If there is no failure, depositors optimally choose  $D_{1i}^*(\rho) = D_{0i}R_1$  because they will receive a positive net return on their deposits between subperiods 1 and 2 as shown by Equation (17). If there is a failure, we restrict our attention to equilibria in which these depositors choose fully-insured positions by setting  $D_{1i}^*(\rho) = \delta$ . [Martin et al. \(2018\)](#) rationalize this assumption by demonstrating that depositors are apprehensive of exceeding coverage thresholds when the risk of bank failures is high.

More formally, the equilibrium consumption of both fully-insured and partially-insured late depositors is given by

$$C_{2i}(s, \rho_l) = \tilde{q}^F \left( \min\{D_{0i}R_1, \delta\} + \alpha_F \max\{D_{0i}R_1 - \delta, 0\} \right) + (1 - \tilde{q}^F) \left( D_{0i}R_1 + w_{Ei}(\alpha_N - 1)D_{0i}R_1 \right) + Y_{2i}, \quad (17)$$

where  $\alpha_N \geq 1$  denotes the equilibrium gross return on deposits accrued between subperiods 1 and 2 when there is no failure, which we define in Equation (19). Observe that, if there are bank failures, then the consumption of early and late depositors with the same deposit balance is identical. If banks do not fail, then late depositors receive a higher return relative to early depositors, proportional to  $\alpha_N(\rho)$  and their equity share of the banks  $w_{Ei}$ .

### 3.5 Depositors' Equilibrium Consumption

To finish our description of the equilibrium consumption allocations, we characterize the equilibrium rates  $\alpha_F(\rho)$  and  $\alpha_N(\rho)$ . We define the recovery rate on uninsured claims under failure in the low return state as

$$\alpha_F(\rho) = \frac{\max \left\{ \chi(\rho)\rho[D_0 - \pi_e] - \int_{\bar{D}} \min\{D_{0i}R_1, \delta\} dG(i), 0 \right\}}{\int_{\bar{D}} \max\{D_{0i}R_1 - \delta, 0\} dG(i)}. \quad (18)$$

The recovery rate is given by the ratio of residual funds after insurance payments to the total amount of uninsured deposits. These residual funds are calculated as the difference between total bank funds,  $\chi(\rho)\rho[D_0 - \pi_e]$ , and the level of insured deposits,  $\int_{\underline{D}}^{\bar{D}} \min\{D_{0i}R_1, \delta\}dG(i)$ . It is straightforward to compute the level of uninsured deposits as  $\int_{\underline{D}}^{\bar{D}} \max\{D_{0i}R_1 - \delta, 0\}dG(i)$ . If the recovery rate on assets  $\chi(\rho)$  is sufficiently low such that  $\alpha_F(\rho) = 0$ , then banks are unable to retrieve any uninsured deposits. In that case, there will be a positive funding shortfall,  $T(s, \rho_l) > 0$ . The value of  $\alpha_F(\rho) \in [0, 1)$  is decreasing in the deposit rate  $R_1$  and the level of coverage  $\delta$ , but increasing in the value of the low-return state.

Next, we define the gross return on deposits under the no-failure scenario as

$$\alpha_N(\rho) = \frac{\rho \left[ \rho \left( 1 - \frac{\pi_e}{D_0} \right) - \lambda R_1 - \frac{\pi_l}{D_0} \right]}{(1 - \lambda)R_1}, \quad (19)$$

where  $\rho \in \{\rho_l, \rho_h\}$ . If there is no bank failure, then the realized return on bank funds is given by the ratio of  $\rho[\rho(D_0 - \pi_e) - \lambda R_1 D_0 - \pi_l]$ , the available funds at subperiod 2, to  $D_1 = (1 - \lambda)D_0 R_1$ , the level of subperiod 1 deposits. The value of  $\alpha_N(\rho)$  is increasing in the levels of bank return  $\rho$ , and decreasing in  $\lambda$ ,  $R_1$  and  $\pi$ . Note that it is required that  $\alpha_N(\rho) \geq 1$  in the no-failure equilibrium, which leads to an upper bound for  $\pi_l$  in each period. There is no restriction on  $\pi_e$  as banks can fail. However, if banks do not fail, equity holders are not worse off by having an equity share. This upper bound for  $\pi_l$  depends on the realized  $\rho$  drawn by each bank:  $\pi_l \leq D_0 \left[ \rho \left( 1 - \frac{\pi_e}{D_0} \right) - \lambda R_1 - \frac{(1-\lambda)R_1}{\rho} \right]$ . The realized late-premium depends upon the realized return in the low state  $\rho_l$  and the fraction of banks drawing that low return  $s$ .

### 3.6 Funding Shortfall and Taxpayers' Equilibrium Consumption

Next, we characterize the funding shortfall  $T(s, \rho_l)$  in state  $\{s, \rho_l\}$ , which is given by

$$T(s, \rho_l) = \max \left[ \tilde{q}^F \left( \int_{\underline{D}}^{\bar{D}} \min\{D_{0i}R_1, \delta\}dG(i) - \chi(\rho_l)\rho_l(D_0 - \pi_e) \right) - (F_0 + \pi_e), 0 \right] \quad (20)$$

The funding shortfall is the difference between total deposit insurance claims and the sum of total liquidated banking resources and deposit insurance funds. When there are more claims than available funds, a positive shortfall exists. Note that a positive shortfall implies the recovery rate on uninsured deposits is zero, that is,  $\alpha_F = 0$ . Otherwise, if there are at least as many available funds  $\chi(\rho_l)\rho_l(D_0 -$

$\pi_e) + F_0 + \pi_e$  as insured claims  $\int_{\underline{D}}^{\bar{D}} \min\{D_{0i}R_1, \delta\}dG(i)$ , then no ex-post taxation is needed.

To conclude, we can express taxpayers' equilibrium consumption over possible states as

$$C_\tau(s, \rho_l) = Y_\tau - T(s, \rho_l) - \kappa(T(s, \rho_l), Y_\tau), \quad (21)$$

where  $T(s, \rho_l)$  is defined in Equation (20). If taxes are collected, the associated deadweight loss  $\kappa(T(s), Y_\tau)$  is borne by taxpayers. Thus, the taxpayers' consumption gap between failure and no-failure equilibria is the sum of the funding shortfall and cost of public funds, that is,  $T(s, \rho_l) + \kappa(T(s, \rho_l), Y_\tau)$ .

## 4 Normative Analysis

After characterizing the equilibrium of this economy for a given level of the deposit insurance coverage and premium, we now study how changes in the levels of coverage and premium affect social welfare. In this section, we initially consider a scenario in which the deposit rate offered by banks is predetermined and invariant to the level of coverage. This case provides a tractable benchmark before we study optimal premiums when we allow banks to choose their interest rate on deposits.

### 4.1 Exogenous Deposit Rate

We first assume the deposit rate  $R_1$  offered by banks is predetermined. There is no moral hazard because banks cannot alter the deposit rate in response to changes in either of the two policy instruments. In Section 4.2, we introduce moral hazard by allowing banks to choose the deposit rate after both of the policymaker's instrument rules are chosen.

We define social welfare as the sum of depositors' and taxpayers' ex-ante expected utilities and a future continuation value. We denote social welfare by  $W(\delta, \pi; F, Y_\tau)$ <sup>4</sup> which corresponds to

$$W(\delta, \pi; F, Y_\tau) = \underbrace{\int_{\underline{D}}^{\bar{D}} V_i(\delta, \pi)dG(i)}_{\text{Depositors}} + \underbrace{V_\tau(\delta, \pi; F, Y_\tau)}_{\text{Taxpayers}} + \beta \underbrace{W'(\delta', \pi'; F', Y_\tau)}_{\text{Future value}}, \quad (22)$$

where  $V_i(\delta, \pi)$  denotes depositors' ex-ante indirect utility for a given level of insurance coverage and premium,  $V_\tau(\delta, \pi; F, Y_\tau)$  denotes taxpayers' indirect utility, and  $\beta$  denotes the policymaker's discount

<sup>4</sup>Exogenous variation in  $Y_\tau$  will be important for our quantitative analysis, so we emphasize the dependence of social welfare  $W(\delta, \pi; F, Y_\tau)$  on  $Y_\tau$ .

factor. We can express  $V_i(\delta, \pi)$  and  $V_\tau(\delta, \pi; F, Y_\tau)$  as

$$V_i(\delta, \pi) = \lambda \mathbb{E}_{s, \rho_l} [U(C_{1i}(s, \rho_l))] + (1 - \lambda) \mathbb{E}_{s, \rho_l} [U(C_{2i}(s, \rho_l))], \quad (\text{Depositors}) \quad (23)$$

$$V_\tau(\delta, \pi; F, Y_\tau) = \mathbb{E}_{s, \rho_l} [U(C_\tau(s, \rho_l))]. \quad (\text{Taxpayers}) \quad (24)$$

It is useful to decompose the effects of bank failures on depositors' consumption. Let  $C_{ti}^F$  and  $C_{ti}^N$  denote consumption of deposits held by failed and non-failed banks, respectively. We can rewrite depositor consumption as

$$\mathbb{E}_{s, \rho_l} [U(C_{ti}(s, \rho_l))] = q^F(s, \rho_l) U(C_{ti}^F(s, \rho_l)) + (1 - q^F(s, \rho_l)) U(C_{ti}^N(s, \rho_l)), \quad (25)$$

where

$$C_{1i}^F(s, \rho_l) = C_{2i}^F(s, \rho_l) = \min\{D_{0i}R_1, \delta\} + \alpha_F \max\{D_{0i}R_1 - \delta, 0\} + Y_{ti},$$

$$C_{1i}^N(s, \rho_l) = D_{0i}R_1 + Y_{1i},$$

$$C_{2i}^N(s, \rho_l) = D_{0i}R_1 + w_{Ei}(\alpha_N(\rho_l) - 1)D_{0i}R_1 + Y_{2i}.$$

Similarly, we can rewrite taxpayer consumption as

$$\mathbb{E}_{s, \rho_l} [U(C_\tau(s, \rho_l))] = q^F(s, \rho_l) U(C_\tau^F(s, \rho_l)) + (1 - q^F(s, \rho_l)) U(C_\tau^N(s, \rho_l)), \quad (26)$$

where

$$C_\tau^F(s, \rho_l) = Y_\tau - T(s, \rho_l) - \kappa(T(s, \rho_l), Y_\tau),$$

$$C_\tau^N(s, \rho_l) = Y_\tau.$$

We obtain Equations (25) and (26) by partitioning Equations (16), (17), and (21) by failure and no-failure states.



### 4.1.1 Deposit Insurance Coverage

In Proposition 1, we characterize the relationship between social welfare and the coverage level. Note that integrals over the index  $j$  account for all depositors and taxpayers, so the notation  $C_j$  could represent  $C_{1i}$ ,  $C_{2i}$ , or  $C_\tau$ .

**Proposition 1 (Directional test for a change in the level of coverage  $\delta$ )** *The change in social welfare  $W$  in response to a marginal change in the level of deposit insurance  $\delta$  is given by:*

$$\begin{aligned} \frac{\partial W}{\partial \delta} &= \int_{\underline{D}}^{\overline{D}} \frac{\partial V_i}{\partial \delta} dG(i) + \frac{\partial V_\tau}{\partial \delta} + \beta \frac{\partial W'}{\partial F'} \frac{\partial F'}{\partial \delta} \\ &= q^F \int_j \mathbb{E}_{s, \rho_i, \lambda}^F \left[ U'(C_j^F) \frac{\partial C_j^F}{\partial \delta} \right] dj - \frac{\partial q^F}{\partial \delta} \int_j \left[ U(C_j^N(\rho_i^*)) - U(C_j^F(\rho_i^*)) \right] dj \\ &\quad + \beta q^F \mathbb{E}_{s, \rho_i}^F \left[ U'(C_\tau^F) \frac{\partial C_\tau^F}{\partial F'} \right] \frac{\partial F'}{\partial \delta}, \end{aligned} \quad (27)$$

where  $\mathbb{E}_s^F$  stands for a conditional expectation over bank failure states and  $q^F$  denotes the unconditional probability of bank failure. If  $\frac{\partial W}{\partial \delta} > (<) 0$ , it is optimal to increase (decrease) the level of coverage.

Proposition 1 characterizes the effect on welfare of a marginal change in the level of deposit insurance. We derive Equation (27) in Appendix C.

The first line in the Equation (27) contains two terms. The first term captures the marginal cost of a one-dollar increase in the level of deposit insurance coverage. A marginal increase in the level of coverage changes depositors' consumption during bank failures, which occur with probability  $q^F$ , by  $\frac{\partial C_j^F}{\partial \delta}$ . This cost reflects the distortionary taxation that is used to pay for deposit insurance claims if the fund is insufficient and there is a fiscal shortfall. We interpret the second term as the marginal benefit of a one-dollar increase in the level of deposit insurance coverage. A marginal increase in the level of coverage decreases the probability of bank failure by  $\frac{\partial q^F}{\partial \delta}$ . The corresponding marginal benefit of this decline is given by the difference in utilities in the no-failure and failure equilibria evaluated at state  $\rho_i^*$ ,  $U(C_j^N(\rho_i^*)) - U(C_j^F(\rho_i^*))$ . Finally, the third term of Equation (27) represents the future cost to the insurance fund of raising the coverage level (i.e.  $\frac{\partial F'}{\partial \delta} \leq 0$ ). The lower future fund size increases the expected fiscal shortfall, which directly reduces taxpayers' consumption during bank failures, lowering their future welfare.

### 4.1.2 Deposit Insurance Premium

Next, we determine the sensitivity of welfare to a marginal change in the deposit insurance premium. In Proposition 2, we provide a test for whether to optimally increase the level of deposit insurance premiums. We derive Equation (28) in Appendix D.

**Proposition 2 (Directional test for a change in the level of premiums  $\pi$ )** *The change in social welfare  $W$  in response to a marginal change in the deposit insurance premium  $\pi$  is given by:*

$$\begin{aligned}
\frac{\partial W}{\partial \pi} = & \int_{\underline{D}}^{\overline{D}} \mathbb{E}_{\lambda} \left\{ q^F \mathbb{E}_{\rho_l} \left[ U'(C_{ti}^F(s, \rho_l)) \frac{\partial C_{ti}^F}{\partial \pi} \right] + (1 - q^F) \mathbb{E}_{\rho_l} \left[ U'(C_{ti}^N(s, \rho_l)) \frac{\partial C_{ti}^N}{\partial \pi} \right] \right. \\
& + \mathbb{E}_s[s] \left[ [U(C_{ti}^F(s, \hat{\rho}_l)) - U(C_{ti}^N(s, \hat{\rho}_l))] (1 - \gamma) r(\hat{\rho}_l) \frac{\partial \hat{\rho}_l}{\partial \pi} + [U(C_{ti}^F(s, \rho_l^*)) - U(C_{ti}^N(s, \rho_l^*))] \gamma r(\rho_l^*) \frac{\partial \rho_l^*}{\partial \pi} \right] \Big\} dG(i) \\
& + \mathbb{E}_s[s] \left[ [U(C_{\tau}^F(s, \hat{\rho}_l)) - U(C_{\tau}^N(s, \hat{\rho}_l))] (1 - \gamma) r(\hat{\rho}_l) \frac{\partial \hat{\rho}_l}{\partial \pi} + [U(C_{\tau}^F(s, \rho_l^*)) - U(C_{\tau}^N(s, \rho_l^*))] \gamma r(\rho_l^*) \frac{\partial \rho_l^*}{\partial \pi} \right] \\
& + q^F \mathbb{E}_{\rho_l} \left[ U'(C_{\tau}^F) \frac{\partial C_{\tau}^F}{\partial \pi} \right] + \beta \mathbb{E}_{s', \rho_l'} U'(C_{\tau}(s', \rho_l')) \frac{\partial C_{\tau}'}{\partial F'} \frac{\partial F'}{\partial \pi}.
\end{aligned} \tag{28}$$

where  $\mathbb{E}_{\lambda}$  denotes the expectation of the distribution of early and late depositors,  $\mathbb{E}_s$  and  $\mathbb{E}_{\rho_l}$  denote the expected values of the two aggregate shocks, and  $q^F$  denotes the unconditional probability of bank failure. If  $\frac{\partial W}{\partial \pi} > (<) 0$ , it is optimal to locally increase (decrease) the level of deposit insurance premium.

We interpret the first line of Equation (28) as the (intensive) marginal cost to depositors of a one-dollar increase in the level of the deposit insurance premium. When banks pay premiums from deposits, banks have less capital to productively invest. Naturally, banks earn lower investment income in no-failure states and diminish the amount of recoverable funds in failure states, assuming that premiums are collected before a crisis. All depositors' consumption suffers in failure states if premiums are collected before a crisis, whereas in no-failure states only the consumption of late-withdrawing depositors who own equity is affected.

The second and third line capture the (extensive) marginal costs to depositors and taxpayers, respectively, of a one-dollar increase in the premium level. These costs arise only with early premiums, because banks have fewer resources to pay depositors. This makes failures more likely

and increases the thresholds for fundamental failures ( $\hat{\rho}_l$ ) and panic failures ( $\rho_l^*$ ). Hence, the derivatives  $\frac{\partial \hat{\rho}_l}{\partial \pi}$  and  $\frac{\partial \rho_l^*}{\partial \pi}$  are weakly positive if premiums are collected before a crisis. Given that failures become more likely, the cost to depositors is the difference in utilities between the failure and no-failure states,  $[U(C_{ti}^F(s, \hat{\rho}_l)) - U(C_{ti}^N(s, \hat{\rho}_l))]$  and  $[U(C_{ti}^F(s, \rho_l^*)) - U(C_{ti}^N(s, \rho_l^*))]$ , which are negative. An analogous statement applies to taxpayers. These extensive marginal costs to depositors and taxpayers are weighted by the expected fraction of banks that fail,  $\mathbb{E}_s[s]$ .

The fourth line is composed of two terms. The first term captures the (intensive) marginal benefit to taxpayers of a one-dollar increase in the premium level. Taxpayers' consumption increases because the higher premium reduces the likelihood of a fiscal shortfall that would befall taxpayers. The second term on the fourth line captures the (intensive) future marginal benefit to taxpayers of a one-dollar increase in the premium. Because premiums increase the fund size ( $\frac{\partial F'}{\partial \pi} \geq 0$ ), a larger fund reduces the likelihood of a fiscal shortfall and the associated ex-post taxation. Consequently, the larger fund lessens the burden on taxpayers and increases their consumption during bank failures ( $\frac{\partial C_{ti}^{F'}}{\partial F'} \geq 0$ ).

## 4.2 Endogenous Deposit Rate

Next, we introduce moral hazard in the model by endogenizing the deposit rate. Banks choose  $R_1(\pi, \delta)$  at  $\tilde{t} = 0$  to maximize a weighted average of depositors' expected utilities, taking the coverage level and premiums as given. For convenience, we slightly abuse notation by defining  $R_1 := R_1(\pi, \delta)$  in this section. Banks choose the deposit rate  $R_1 \in [1, \bar{R}_1]$  by solving

$$\operatorname{argmax}_{R_1} \int_{\underline{D}}^{\bar{D}} V_i dG(i), \quad (29)$$

where  $V_i$  is defined in Equation (1). The deposit rate captures the optimal degree of risk sharing between early and late depositors, which reflects both aggregate uncertainty and the private cost of bank failure. Banks internalize how their choice of the deposit rate affects the likelihood and severity of bank failure. Moral hazard arises because banks do not internalize how their deposit rate may harm taxpayers by causing a fiscal shortfall during failure. We derive Equation (30) in Appendix D.

**Proposition 3 (Directional test for a change in the level of premiums  $\pi$ )** *The change in social welfare*

$W$  in response to a marginal change in the deposit insurance premium  $\pi$  is given by:

$$\begin{aligned}
\frac{\partial W}{\partial \pi} = & \int_{\underline{D}}^{\overline{D}} \mathbb{E}_{\lambda} \left\{ q^F \mathbb{E}_{\rho_l} \left[ U'(C_{ti}^F(s, \rho_l)) \frac{\partial \widetilde{C}_{ti}^F}{\partial \pi} \right] + (1 - q^F) \mathbb{E}_{\rho_l} \left[ U'(C_{ti}^N(s, \rho_l)) \frac{\partial \widetilde{C}_{ti}^N}{\partial \pi} \right] \right. \\
& + \mathbb{E}_s[s] \left[ [U(C_{ti}^F(s, \hat{\rho}_l)) - U(C_{ti}^N(s, \hat{\rho}_l))] (1 - \gamma) r(\hat{\rho}_l) \frac{\partial \widetilde{\rho}_l}{\partial \pi} + [U(C_{ti}^F(s, \rho_l^*)) - U(C_{ti}^N(s, \rho_l^*))] \gamma r(\rho_l^*) \frac{\partial \widetilde{\rho}_l^*}{\partial \pi} \right] \Big\} dG(i) \\
& + \mathbb{E}_s[s] \left[ [U(C_{\tau}^F(s, \hat{\rho}_l)) - U(C_{\tau}^N(s, \hat{\rho}_l))] (1 - \gamma) r(\hat{\rho}_l) \frac{\partial \widetilde{\rho}_l}{\partial \pi} + [U(C_{\tau}^F(s, \rho_l^*)) - U(C_{\tau}^N(s, \rho_l^*))] \gamma r(\rho_l^*) \frac{\partial \widetilde{\rho}_l^*}{\partial \pi} \right] \\
& + q^F \mathbb{E}_{\rho_l} \left[ U'(C_{\tau}^F) \frac{\partial \widetilde{C}_{\tau}^F}{\partial \pi} \right] + \beta \mathbb{E}_{s', \rho_l'} U'(C_{\tau}(s', \rho_l')) \frac{\partial C_{\tau}'}{\partial F'} \frac{\partial \widetilde{F}'}{\partial \pi},
\end{aligned} \tag{30}$$

where

$$\frac{\partial \widetilde{X}}{\partial \pi} := \frac{\partial X}{\partial \pi} + \frac{\partial X}{\partial R_1} \frac{\partial R_1}{\partial \pi}, \quad X \in \{C_{ti}^F, C_{ti}^N, C_{\tau}^F, \rho_l^*, \hat{\rho}_l, F'\}. \tag{31}$$

Above,  $\mathbb{E}_{\lambda}$  denotes the expectation of the distribution of early and late depositors,  $\mathbb{E}_s$  and  $\mathbb{E}_{\rho_l}$  denote the expected values of the two aggregate shocks, and  $q^F$  denotes the unconditional probability of bank failure. If  $\frac{\partial W}{\partial \pi} > (<) 0$ , it is optimal to locally increase (decrease) the level of deposit insurance premium.

Relative to Proposition 2, Proposition 3 allows banks' choice of the deposit rate to depend on the policymaker's premium, holding the coverage level fixed. Equation (31) captures the indirect effect of changes in the premium on the deposit rate. The policymaker employs risk-adjusted premiums to reduce moral hazard, so an increase in the premium reduces the deposit rate chosen by banks, i.e.,  $\frac{\partial R_1}{\partial \pi} \leq 0$ . In our model, risk-adjusted premiums are the reason why premiums reduce the probability of a banking crisis. Because the rest of the analysis in Proposition 2 remains unchanged, we confine our discussion to the implications of Equation (31).

The first line of Equation (30) reflects the (intensive) marginal cost to depositors of a one-dollar increase in the level of the deposit insurance premium. If we hold the risk of bank failure constant, depositors' consumption increases from higher interest rates on their deposits, i.e.,  $\frac{\partial C_{ti}^F}{\partial R_1} \geq 0$  and  $\frac{\partial C_{ti}^N}{\partial R_1} \geq 0$ . Because premiums apply downward pressure to deposit rates, depositors consume less than when deposit rates are predetermined, i.e.,  $\frac{\partial \widetilde{C}_{ti}^F}{\partial \pi} \leq \frac{\partial C_{ti}^F}{\partial \pi} \leq 0$  and  $\frac{\partial \widetilde{C}_{ti}^N}{\partial \pi} \leq \frac{\partial C_{ti}^N}{\partial \pi} \leq 0$ . The indirect effect of the

premium on the deposit rate increases the marginal cost of premiums to depositors.

The second line of Equation (30) captures the (extensive) marginal cost to depositors of a one-dollar increase in the premium level. As discussed in Proposition 2, premium collection reduces the assets available to banks to pay depositors, increasing the likelihood of failure for any given low-return state, i.e.,  $\frac{\partial \hat{\rho}_l}{\partial \pi} \geq 0$  and  $\frac{\partial \rho_l^*}{\partial \pi} \geq 0$ . In other words, the failure regions expand when premiums increase, reducing depositors' consumption. Combining the effects, we observe that the deposit rate decreases in the premium level, and the failure-region thresholds  $\hat{\rho}_l$  and  $\rho_l^*$  increase in the deposit rate, i.e.,  $\frac{\partial \rho_l^*}{\partial R_1} \frac{\partial R_1}{\partial \pi} \leq 0$  and  $\frac{\partial \hat{\rho}_l}{\partial R_1} \frac{\partial R_1}{\partial \pi} \leq 0$ . Overall, the endogenous deposit rate reduces the extensive cost to depositors of premiums relative to a predetermined deposit rate, i.e.,  $\frac{\partial \rho_l^*}{\partial \pi} \leq \frac{\partial \widetilde{\rho}_l^*}{\partial \pi}$  and  $\frac{\partial \hat{\rho}_l}{\partial \pi} \leq \frac{\partial \widetilde{\hat{\rho}_l}}{\partial \pi}$ . The indirect effect of the premium on the deposit rate is present whether premiums are collected early or late, but the direct effect of the premium on the failure-region thresholds  $\hat{\rho}_l$  and  $\rho_l^*$  exists only for early premiums. The third line of Equation (30) has an analogous interpretation for taxpayers.

The fourth line of Equation (30) contains two terms. The first term captures the (intensive) marginal benefit to taxpayers of a one-dollar increase in the premium level. Because the optimal deposit rate is decreasing in the premium level, and because taxpayers' consumption is decreasing in the deposit rate, taxpayers' consumption will be higher when the deposit rate is sensitive to the premium level, i.e.,  $\frac{\partial C_\tau^F}{\partial \pi} \geq \frac{\partial C_\tau^F}{\partial R_1} \frac{\partial R_1}{\partial \pi}$ . When risk-adjusted premiums induce banks to choose lower deposit rates, the potential burden on taxpayers is alleviated. This endogenous response of the optimal deposit rate to premiums further increases the intensive marginal benefit of premiums to taxpayers.

The second term captures the (intensive) future marginal benefit to taxpayers of a one-dollar increase in the premium. A higher premium, by lowering the optimal deposit rate, reduces the likelihood and cost of deposit insurance disbursements, increasing the future fund size:  $\frac{\partial F'}{\partial R_1} \leq 0$ . Consequently, an endogenous deposit rate implies that a marginal change in the premium has a larger effect on the future fund size, i.e.,  $\frac{\partial \widetilde{F}'}{\partial \pi} \geq \frac{\partial F'}{\partial \pi}$ . A higher future fund size reduces the likelihood of a fiscal shortfall and the associated ex-post taxation, lowering the burden on taxpayers of providing deposit insurance coverage in the future. Overall, an endogenous interest rate on deposits increases the intensive future marginal benefit to taxpayers.

## 5 Calibration

To numerically solve the model, we posit functional forms. We interpret a period in our model as a year, and a one-dollar unit in the model represents \$100,000. We combine externally chosen parameters and internally calibrated targets. We target moments in the United States during 2018, which correspond to our most recent year of Federal Deposit Insurance Corporation (FDIC) and International Association of Deposit Insurers (IADI) data.

First, we describe the parameters for depositors. We assume that the distribution of account balances is log-normally distributed with parameters  $(\mu_D, \sigma_D)$  and truncated support  $[\underline{D}, \overline{D}]$ . We use these four parameters to jointly target (i) a median balance of \$5,140, (ii) a mean deposit balance of \$45,628,<sup>5</sup> (iii) an 8.6% share of deposits with a balance of more than \$100,000, and (iv) a 25<sup>th</sup> percentile of \$1,000 for deposits. To match these targets, we choose  $\mu_D = -3.6$ ,  $\sigma_D = 2.1$ ,  $\underline{D} = 0.03$ , and  $\overline{D} = 5$ . In the quantitative exercise, we discretize the deposits grid to 200 points that are drawn using the Legendre-Gauss Quadrature method.

We assume that depositors' incomes scale proportionally with the level of their deposits, that is,  $Y_{1i}(s) = y_1(s)D_{0i} + Y_0$  and  $Y_{2i}(s) = y_2(s)D_{0i} + Y_0$ . To match key labor income moments in the 2019 Survey of Consumer Finance (SCF), we set  $y_1 = 2$ ,  $y_2 = 2.1$ , and  $Y_0 = 0.075$ . These choices imply a model-generated median income for depositors of \$32,180 and a mean income of \$76,250, slightly below the 2019 SCF data moments of \$56,000 and \$86,124, respectively, for depositors holding more than \$2,500 in deposits. For the taxpayers' income, we set  $Y_\tau(s) = y_1(s)D_0$ , so that total taxpayers' income is twice total deposit holdings. Finally, we calibrate the equity weights  $w_{Ei}$  to target a skewed wealth distribution. For instance, the wealth generated by the fraction of corporate equities and mutual fund shares owned by the richest 10% of all households in 2018 was 88%, following the U.S. Distributional Financial Accounts (DFAs, [Batty et al., 2019](#)). To capture the inequality, we set the equity weights to zero for the poorest depositors to match the equity share of 88% for the wealthiest decile of depositors in our model.

Next, we discuss the calibration of the two aggregate shocks. The first shock can be interpreted as the fraction  $s$  of banks that draw the low-return state  $\rho_l$ . The aggregate distribution of banks drawing the low-return state is log-normally distributed according to  $H(s)$  with a truncated support  $[\underline{s}, \overline{s}]$ . We

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<sup>5</sup>We use the 2019 Survey of Consumer Finance to get these statistics, defining deposits as certificates of deposits (cds), money market deposit accounts (mmda), checking accounts (checking), saving accounts (saving), and call accounts (call).

calibrate these parameters to match the FDIC historical ratios of failed-assets-to-domestic-deposits for the period 2008-2019.<sup>6</sup> We set  $\mu_s = -9$  and  $\sigma_s = 4.5$  to match the average and median ratios during that time period (0.75% and 0.06%, respectively). We also set  $[\underline{s}, \bar{s}] = [0, 1]$ . We discretize the  $s$ -grid to 40 points that are drawn using the Legendre-Gauss Quadrature method, resulting in a mean value of 4.40% and a median value of 0.46%. We describe the distribution of the  $s$  shock in Appendix F.

The second shock is the value  $\rho_l$  of the low-return state. The aggregate distribution of low-return state values is log-normally distributed according to  $R(\rho_l)$  with a truncated support  $[\underline{\rho}_l, \bar{\rho}_l]$ . We set  $\underline{\rho}_l = 1.001$  and  $\bar{\rho}_l = 1.005$ , together with  $\sigma_{\rho_l} = 0.025$  and  $\mu_{\rho_l} = 0.00175$ . We use 80 gridpoints for this distribution. Together, the distributions of  $s$  and  $\rho_l$  jointly determine the share of banks that are expected to fail. For instance, if the coverage level is set to zero and banks choose the safe deposit rate,  $R_{1,safe}$ , we find that the share of banks expected to fail is 1.18%, while the probability that at least one bank fails is 29.71%. We choose a standard value in the literature for the share of early depositors,  $\lambda = 0.025$ . For computational tractability, we allow banks to choose between only two interest rates on deposits,  $R_{1,safe} = 1.0025$  and  $R_{1,risky} = 1.0031$ . In Appendix F, we show the expected share of bank failures for the two deposit rates. These deposit rates are chosen such that  $R_{1,safe}$  has a failure rate that is 0.50% below the failure rate under  $R_{1,risky}$  in the model. We choose the parameters for the deadweight loss of bank failures to match the average deadweight loss of 28% as measured by [Granja et al. \(2017\)](#). Specifically, our calibration assumes the deadweight loss  $(1 - \chi(\rho_l))$  does not exceed 50% of the deposits value, reflected by  $\chi(\underline{\rho}_l) = 0.5$  and  $\chi(\bar{\rho}_l) = 1$ . The share of recovered deposits is given by

$$\chi(\rho_l) = \chi_1(\rho_l - \chi_3)^{\chi_2}, \quad \text{where } \chi_1, \chi_2, \chi_3 \geq 0.$$

We choose  $\chi_1 = 39.78$ ,  $\chi_2 = 0.7177$ ,  $\chi_3 = 0.9995$ . This results in  $\chi(E\rho_l) = 0.72$ , i.e., banks are expected to recover 72% of assets after a failure. We set the return value  $\rho_h = 1.1$ , resulting in an expected annual return of 9.54%.

To finish the calibration, we make assumptions on (i) the utility function, (ii) the cost of public funds  $\kappa(T)$ , (iii) the timing of deposit insurance premium collection  $w_l$ , and (iv) the discount rate  $\beta$  and interest rate  $r_F$  for the deposit insurance fund. First, we assume that depositors and taxpayers

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<sup>6</sup>The ratios of failed-assets-to-domestic-deposits for the period 2008-2019 are (in percentages): 4.9616, 2.2049, 1.1696, 0.3988, 0.1230, 0.0617, 0.0281, 0.0615, 0.0024, 0.0421, 0.0000, 0.0016.

have isoelastic utility with an elasticity of intertemporal substitution  $\frac{1}{\gamma}$ , that is,  $U(c) = \frac{c^{1-\gamma_c}}{1-\gamma_c}$ . In the baseline parameterization, we set  $\gamma_c = 1.25$ . Second, we consider a marginal cost of public funds  $\kappa(T)$  of the following exponential-affine form

$$\kappa(T, Y_\tau) = \frac{\kappa_1}{\kappa_2} \left( e^{\kappa_2 \frac{T}{Y_\tau}} - 1 \right), \quad \kappa_1, \kappa_2 \geq 0,$$

where we scale the funding shortfall as a percentage of taxpayers' income. We set  $\kappa_1 = 0.13$  and  $\kappa_2 = 0.25$ . Scaling the funding shortfall by taxpayers' income ensures that marginal costs are the same for countries when the outlays, measured as a percentage of income, are the same. In Appendix G, we compare our parameterization to [Dávila and Goldstein \(2021\)](#) for different levels of taxpayers' income. Third, we exclusively set  $w_l = 1$  in the calibration, implying that only late premiums are collected from banks. Finally, we choose  $r_F = 0.02$  for the interest rate on the fund balance, and  $\beta = \frac{1}{1.04}$  for the policymaker's discount factor.

Table 1 summarizes the choice of baseline parameters and functional forms.

Parameter	Value	Description	Empirical target	Model moment
<b>Utility function</b>				
$\gamma_c$	1.25	Elasticity of intertemp. substitution	Standard choice	
<b>Distribution D</b>				
$D \sim \text{LogN}(\mu_D, \sigma_D)$	(-3.6, 2.1)	Distribution of deposits	Median and mean deposits (\$5,140 and \$45,628)	\$13,780 and \$32,740
$[\underline{D}, \bar{D}]$	[0.03, 5]	Truncation parameters	25th perc and fraction > \$100,000 (\$1,000 and 8.6%)	\$4,480 and 8.24%
<b>Distribution s</b>				
$s \sim \text{LogN}(\mu_s, \sigma_s)$	[-9, 4.5]	Distribution of state draws	Mean and median, failed assets data FDIC 2008-2019 (0.75% and 0.06%)	4.46% and 0.26%
<b>Endowments</b>				
$\lambda$	0.025	Fraction of impatient depositors	Standard	
$[y_1, y_2]; y_{add}$	[2, 2.1]; 0.075	Depositors' endowment	Depositors' mean and median labor income (\$86,124 and \$56,000)	\$76,250 and \$32,180
$y_\tau$	2	Taxpayers' endowment	Households' mean income (\$63,800)	\$65,470
$W_{Ei}$	$w_{Ei}(D_{0i} < (D_{0i}))^* = 0$	Skewed equity holdings	Top 10% has 88% equity	Top 10% has 87.21% equity
<b>Deadweight loss</b>				
$[\chi_1, \chi_2, \chi_3]$	[39.78, 0.7177, 0.9995]	Deadweight loss from failure	Deadweight loss from failure 28%	28%
<b>Miscellaneous</b>				
$R_{1, safe}$	1.0025	Safe deposit rate	Standard	
$R_{1, risky}$	1.0031	Risky deposit rate	Standard	
$[\kappa_1, \kappa_2]$	[0.13, 0.25]	Cost of public funds	<a href="#">Dávila and Goldstein (2021)</a>	
$r_F$	0.02	Interest on DIS fund	Standard	
$\beta$	$\frac{1}{1.04}$	Policymaker's discount rate	Standard	

Table 1: Parameter values for calibration. See Section 5 for functional form assumptions.

## 6 Model Results

In this section, we describe the quantitative results from the model solution where we assume that the deposit rate  $R_1$  is determined endogenously by banks.



## 6.1 Steady State Results

A major challenge to deposit insurance systems is the presence of moral hazard. When the coverage level rises, banks increase their risk by offering depositors a higher interest rate on their deposits. For computational tractability, we restrict banks' choice of the deposit rate to  $R_1 \in \{R_{1,safe}, R_{1,risky}\}$  where  $R_{1,safe} < R_{1,risky}$ . Figure 4 illustrates how banks' choice of the deposit rate depends on the coverage level and affects financial fragility. All else equal, the share of banks that are expected to fail is decreasing in the coverage level but increasing in the deposit rate. Both the premiums and fund size are zero in Figure 4. Our model suggests that the policymaker can mitigate the problem of moral hazard by introducing a risk-adjusted deposit insurance premium.

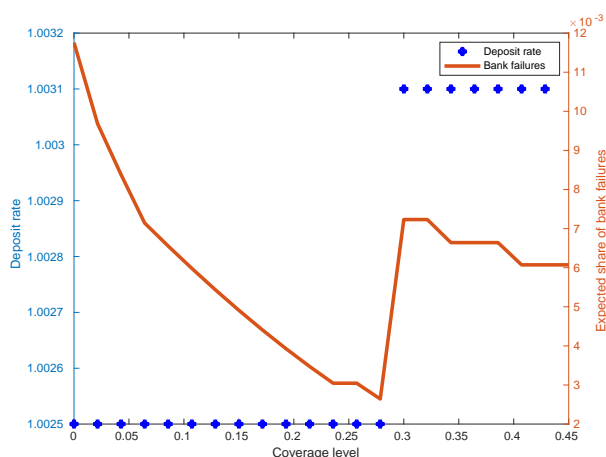
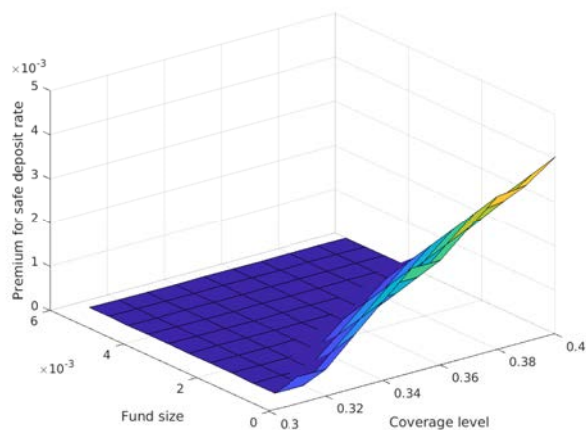


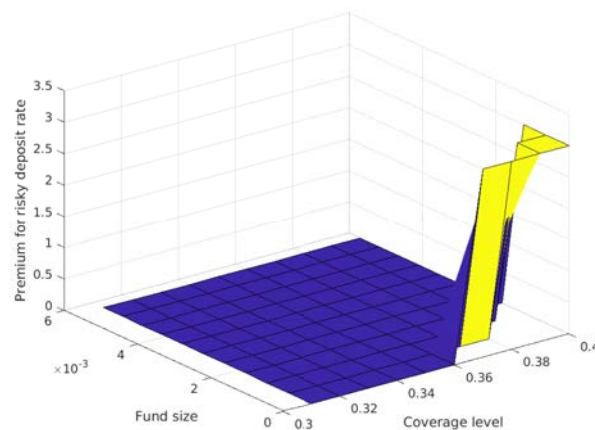
Figure 4: We plot the share of banks that are expected to fail as a function of the coverage level and the corresponding optimal deposit rate by banks. We assume both the fund size and premium are zero.

For each deposit rate, we illustrate the policymaker's policy function for the premium level in Figure 5. Because we restrict banks to a choice of a safe or risky deposit rate, the policymaker will post a menu of two premium levels that correspond to either deposit rate. In other words, Figure 5 displays the premium menu that the policymaker offers to banks. We observe that the policymaker charges a significantly higher premium for a higher (riskier) deposit rate than a lower (safer) deposit rate. Because the premium corresponds to the deposit rate, we refer to the premiums as *risk-adjusted*. Risk-adjusted premiums mitigate moral hazard in the model.

Next, we jointly examine the optimal behavior of the policymaker and banks. In Figure 6, we plot the policy functions for the policymaker's optimal choice of premium level (panel a), the banks' optimal choice of deposit rate (panel b), and the resulting share of banks that are expected to fail (panel



(a) Premium for  $R_{1, safe}$



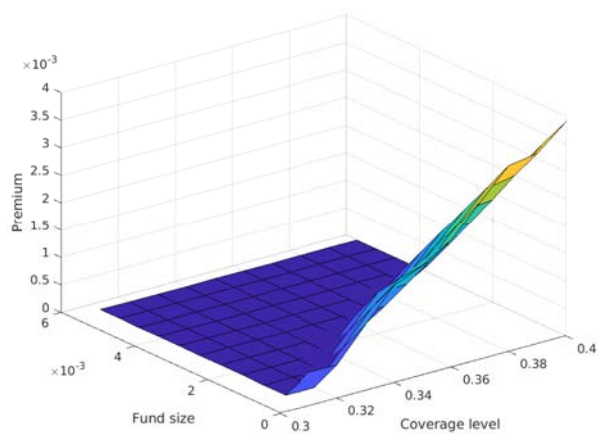
(b) Premium for  $R_{1, risky}$

Figure 5: We plot the policymaker’s menu of premiums offered to banks that choose either a safe ( $R_{1, safe}$ ) or risky ( $R_{1, risky}$ ) interest rate on deposits. This menu depends on the fund and coverage levels.

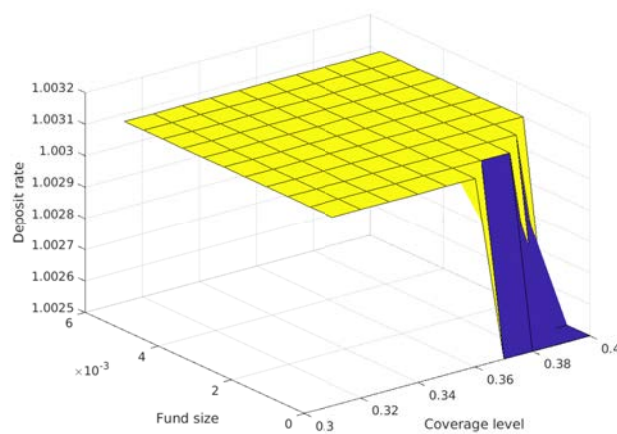
c). We observe how each policy function responds to a given level of the deposit insurance fund and coverage, which are consistent with the normative analysis in Section 4.

In panel (a), the policymaker’s choice of premium is decreasing in the fund size and increasing in the coverage level. In panel (b), banks’ choice of deposit rate is optimally riskier for higher coverage levels (corresponding in our model to  $\delta \geq 0.3$ ). For consistent comparison across panels, the coverage level in panel (b) starts at  $\delta = 0.3$  but banks optimally choose a safer deposit rate for coverage levels below 0.3 in the model. However, it is interesting to note that if the fund is approximately empty while the coverage level is high, the policymaker will charge a sufficiently high premium to induce banks to switch back from the risky to the safe deposit rate. This mechanism explains the drop in the optimal deposit rate for higher coverage levels in panel (b). Finally, in panel (c) we observe the share of banks that are expected to fail given the policymaker’s and banks’ optimal choices. The share of banks that are expected to fail is decreasing in the coverage level and fund size. As discussed in panel (b), we observe a sharp drop in the likelihood of failure for higher premium levels when the fund is nearly empty, because banks optimally respond to higher premiums by choosing a safer deposit rate.

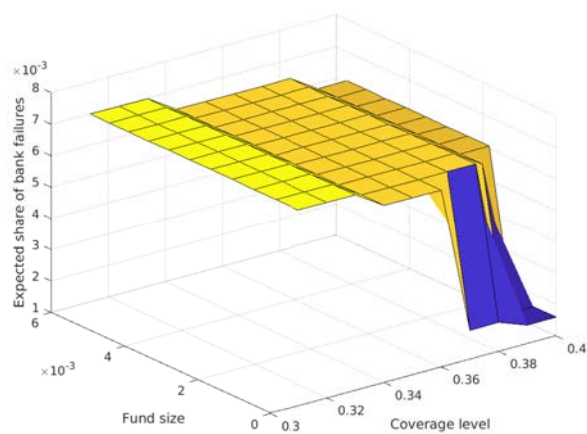
Generally speaking, policymakers neither can nor should build funds that are capable of absorbing catastrophic losses from tail events. In rare cases, the fund will be depleted and taxpayers will have to bail out the banking system. However, a small number of banks fail annually in most countries.



(a) Optimal premium



(b) Optimal deposit rate



(c) Expected bank failures

Figure 6: We plot the policymaker's optimal premium level in panel (a), banks' optimal deposit rate in panel (b), and the share of banks that are expected to fail in panel (c), all as a function of the fund and coverage levels. We solve the model following the calibration in Section 5.

The policymaker should anticipate and preempt the burden of recurring banking crises on taxpayers by selecting the share of bank failures that the deposit insurance fund can withstand without ex-post taxation. We denote this threshold of bank failures as  $s_x$  where  $\{s_x : E[T(s_x)] = 0, E[T(s_x + \epsilon)] > 0\}$ . Figure 7 displays the maximum share of banks that may fail without inducing a fiscal shortfall, given levels of the fund size and coverage. For this illustration, we set premiums to zero and assume banks choose the risky deposit rate.

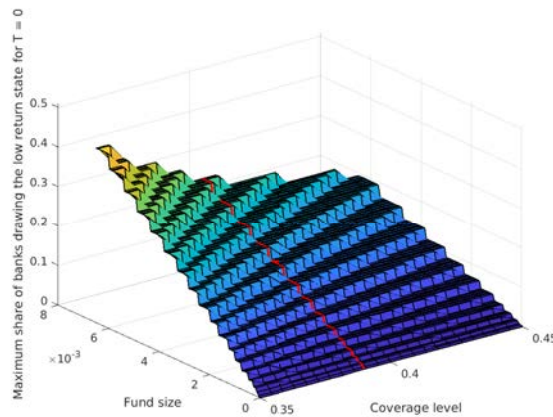


Figure 7: We plot the maximum share of banks that may fail without inducing a fiscal shortfall as a function of the fund and coverage levels, assuming the minimum low-return value is realized ( $\underline{\rho}_l$ ). We set premiums to zero and assume banks choose the risky interest rate on deposits. The red line corresponds to the optimal coverage level in the model ( $\delta = 0.39$ ).

As one would expect, the maximum share of bank failures that can be absorbed by the deposit insurance fund is decreasing in the coverage level and increasing in the fund size. A higher coverage level makes bank failures more costly to the policymaker while a higher fund size provides taxpayers with a greater buffer.

## 6.2 Welfare Considerations

Next, we evaluate the welfare effects of the optimal coverage and premiums. Recall the definition of welfare:

$$W(\delta, \pi; F, Y_\tau) = \int_{\underline{D}}^{\overline{D}} \left( \lambda \mathbb{E}_s[U(C_{1i}(s))] + (1 - \lambda) \mathbb{E}_s[U(C_{2i}(s))] \right) dG(i) \\ + \mathbb{E}_s[U(Y_\tau - T(s) - \kappa(T(s)))] + \beta W'(\delta', \pi'; F', Y_\tau).$$

To compare welfare effects across policies, we use the CRRA utility framework to deconstruct the welfare effects for all agents. Our two welfare measures are the conditional and unconditional changes in welfare. We measure the conditional welfare gain after a policy change by assuming the deposit insurance fund is initially empty. For both measures, we compute the welfare changes for each group (early depositors, late depositors, and taxpayers) in terms of their consumption-equivalent variation.

When we compare policies  $a$  and  $b$ , we obtain each group's welfare as

$$V_a(\cdot) = \frac{[(\bar{c}_a)^{1-\sigma}]}{(1-\beta)(1-\sigma)},$$

$$V_b(\cdot) = \frac{[(\bar{c}_b)^{1-\sigma}]}{(1-\beta)(1-\sigma)}.$$

Then we define the conditional welfare gain (CWG) of switching from policy regime  $a$  to policy regime  $b$  for each group as

$$CWG_{a \text{ to } b} = 100 \cdot \int_{s,i} \left[ \left( \frac{V_b(\cdot)}{V_a(\cdot)} \right)^{\frac{1}{1-\sigma}} - 1 \right] dG(i) dH(s),$$

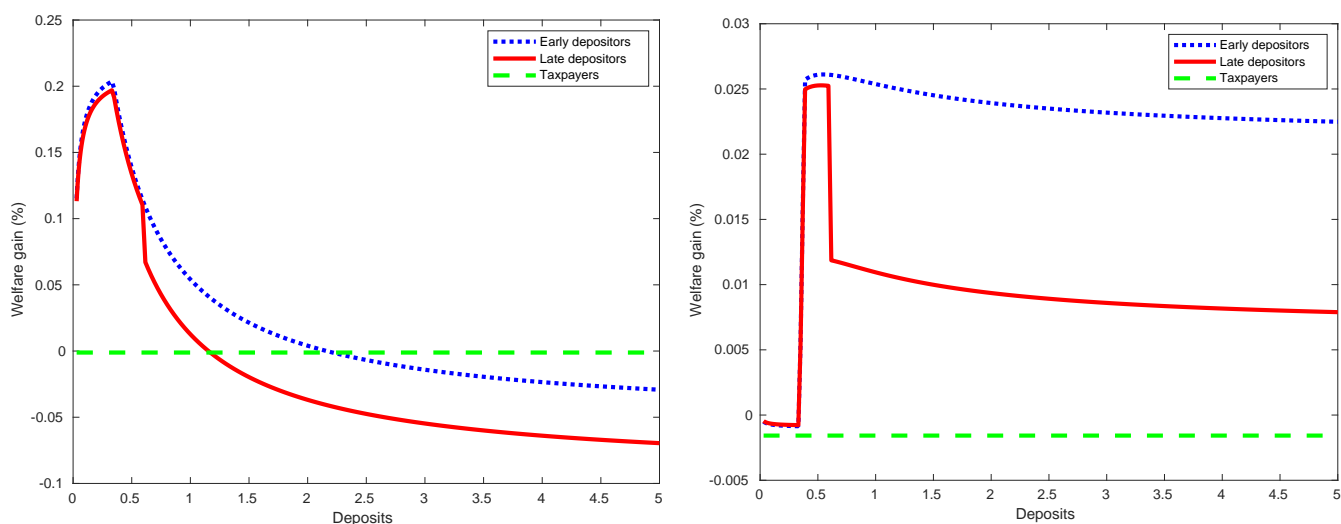
which generally provides a lower bound to the total welfare effect from switching policies. In Appendix E, we also compute the unconditional welfare gain (UWG), which acts as an upper bound.<sup>7</sup>

We evaluate the welfare consequences among early depositors, late depositors, and taxpayers, comparing three different policy regimes: no deposit insurance (regime 1), optimal deposit insurance coverage without premiums (regime 2), and optimal deposit insurance coverage with premiums (regime 3). In regime 2, we find that the optimal coverage level is 15% higher than in regime 3. This yields a covered-to-total-deposits ratio of 49.8% in regime 2 and 53.1% in regime 3. The share of banks that are expected to fail is 0.66% in regime 2 and 0.16% in regime 3 for a low initial fund size  $F$ . Eventually, the fund reaches an optimal level and premiums are tapered off. Then premiums cease to counteract moral hazard and banks choose the risky deposit rate, increasing the share of banks that are expected to fail from 0.16% to 0.61%.

To highlight the welfare effects of introducing more policy instruments, we measure the conditional total welfare gains between the different regimes in Figure 8. In panel (a) of Figure 8, we measure the conditional welfare gain from regime 1 (without deposit insurance) to regime 2 (with optimal cover-

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<sup>7</sup>In general, the welfare gains are robust between definitions.



(a) Conditional welfare gain from regime 1 (no deposit insurance) to regime 2 (optimal coverage but no premiums).

(b) Conditional welfare gain from regime 2 (optimal coverage) to regime 3 (optimal coverage and premiums).

Figure 8: Conditional welfare gains (%) between different regimes. We solve the model with an endogenous interest rate on deposits and late premiums only (i.e.,  $w_l = 1$ ).

age). As a result of the policy change, both early and late depositors are better off while taxpayers are slightly worse off. Early depositors receive the highest welfare gains. Late depositors enjoy a slightly smaller increase in welfare because their income endowment is larger and utility is concave. Depositors with more than 0.61 deposit units are bank equity holders and benefit from the reduced risk of panic failures. However, they are also hurt by the moral hazard of banks choosing the risky deposit rate when the coverage level is 0.34 deposit units. Without premiums, more failures occur in regime 2 than if moral hazard were absent. Equity holders' welfare gain is smaller for the same reason as late depositors because they earn a higher total income. The late depositors' welfare gain remains below the early depositors' welfare gain for all deposit balances.

In panel (b) of Figure 8, we show the conditional welfare gain from regime 2 (with optimal coverage) to regime 3 (with optimal coverage and premiums). Depositors with lower deposit balances receive the greatest marginal benefit from the policy change. The welfare gain peaks at 0.025 percentage points for depositors with balances just beneath the new optimal coverage at 0.39 deposit units. Then the welfare gain diminishes steadily for partially-insured depositors. Partially-insured depositors benefit from the higher deposit insurance coverage, but they have a lower recovery rate on uninsured claims under failure ( $\alpha_F$ ). The late depositors who are equity holders (depositors with more than 0.61 deposit

units) also miss out on higher equity-returns due to the premiums collected from banks, reducing their no-failure consumption.

With the addition of premiums in regime 3, depositors who were previously only partially-insured benefit from a higher coverage level. These depositors' welfare increases by a weighted 14.57% and the gain is even higher for those with equity. While moral hazard is absent when optimal premiums are collected and the coverage level is 0.39 deposit units, moral hazard is present when the coverage level is 0.34 without premiums. Premiums apply downward pressure to banks' choice of interest rate, where the loss in consumption is felt more heavily by the poorest depositors. This reasoning explains why the poorest depositors are slightly worse off in regime 3 relative to regime 2 (panel b of Figure 8).

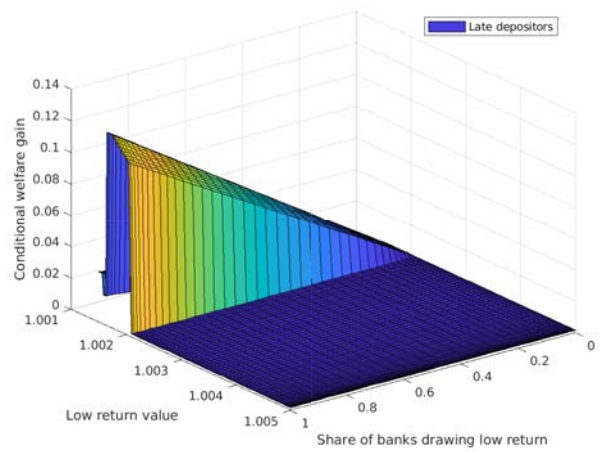
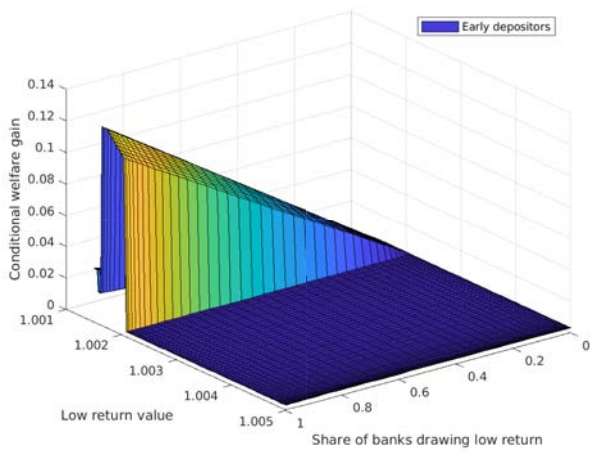
Next, we study the welfare gains realized over the aggregate states  $s$  (the share of banks that draw a low return) and  $\rho_l$  (the value of the low return). We discuss the difference only between regimes 2 and 3 to emphasize the importance of introducing premiums.

In Figure 9, we observe that the highest welfare gains from introducing premiums are realized for low values of the low return,  $\rho_l$ . The increased coverage in regime 3 eliminates the potential panic runs from regime 2. Even if fundamental failures occur, depositors are better off with premiums. Taxpayers' cost of a higher coverage level materializes only in states where banks fail.

	Regime	Early depositors	Late depositors	Taxpayers	Total
Conditional welfare gain	1 to 2	0.1468	0.1374	-0.0011	0.0732
	1 to 3	0.1518	0.1403	-0.0027	0.0740
	2 to 3	0.0050	0.0030	-0.0016	0.0008

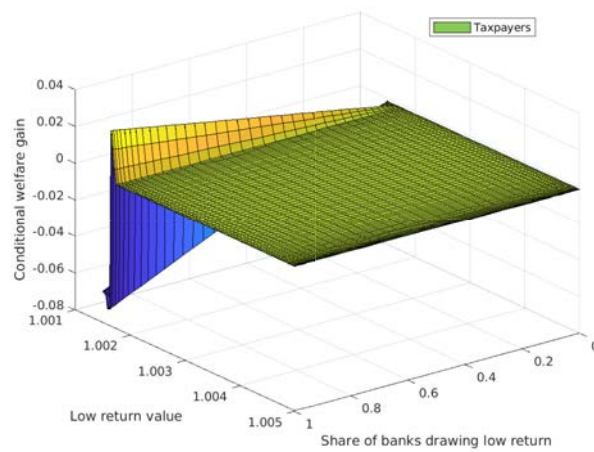
Table 2: Conditional welfare gains (%) by income level and regime. Regime 1 has no deposit insurance, regime 2 offers coverage without premiums, and regime 3 offers coverage and collects premiums. We solve the model with an endogenous interest rate on deposits and late premiums only (i.e.,  $w_l = 1$ ).

We summarize the conditional welfare gains for the three regimes in Table 2. The main beneficiaries of a deposit insurance fund are the early and late depositors with relatively low deposit balances. Specifically, the conditional welfare gain from regime 2 to 3 is largest for early and late depositors with balances just below the new coverage level (0.39 deposit units). The benefit then falls for partially-insured depositors, even becoming negative for those with higher deposit balances. Taxpayers are marginally worse off with premiums in regime 3 because the increase in optimal coverage from premiums outweighs the buffer of a deposit insurance fund. Overall, net welfare rises only marginally but



(a) CWG (%) from regime 2 to 3 for early depositors

(b) CWG (%) from regime 2 to 3 for late depositors



(c) CWG (%) from regime 2 to 3 for taxpayers

Figure 9: Conditional welfare gains



the premiums redistribute welfare gains to depositors with lower balances.

### 6.3 Importance of Moral Hazard

To understand the effects of moral hazard, we compare the model solution with and without an endogenous interest rate  $R_1$  on deposits.

Moment	Endogenous $R_1$	Predetermined $R_1$
Optimal coverage level	0.39	0.35
Maximum fund size over covered deposits (%)*	2.0587	1.083
Covered deposits to total deposits	0.531	0.505
Expected share of failing banks**	0.16%	0.19%

\*The maximum fund size is the maximum value obtained by the policy-functions when there are no bank failures.

\*\*The expected bank failure is measured at the initial fund size,  $F$ .

Table 3: Comparison of model solution with and without moral hazard. Only late premiums are collected (i.e.,  $w_l = 1$ ).

Table 3 reveals that moral hazard increases the optimal coverage and premium levels. The policymaker increases the coverage level to reduce expected bank failures and assesses risk-adjusted premiums that increase in the interest rate on deposits. While these premiums are initially high when the fund is low, the policymaker eventually decides to relax premiums as the fund converges to an optimal level (see Figures 5 and 6). Relaxing the premiums entices banks to choose a riskier deposit rate and increase their probability of failure. Given the fund size, the policymaker optimally judges the heightened fragility to be acceptable when weighed against the opportunity cost to banks and depositors of curtailing their investable funds. The absence of moral hazard reduces the optimal fund-to-covered-deposits ratio from 2% to 1%, allowing banks to retain more funds for investment.

### 6.4 Timing of Deposit Insurance Premiums

To understand the importance of timing in premium collection, we compare the model solution when premiums are collected either early or late. Early premiums are collected from all banks before aggregate shocks are realized ( $\tilde{t} = 0$ ), and late premiums are collected from non-failing banks after ( $\tilde{t} = 2$ ). See Figure 2 for the model timeline. Early premiums contribute to the fund before any possible disbursements and deprive banks of the opportunity to invest the premiums in either production technology  $\rho_1$  or  $\rho_2$ . Late premiums contribute to the fund only next period, and banks still incur opportunity costs by not investing the premiums in the production technology  $\rho_2$ . We rely on late premiums for our main results in Section 6.

Moment	Late premiums	Early premiums
Optimal coverage level	0.39	0.34
Maximum fund size over covered deposits (%)*	2.314	0
Covered deposits to total deposits	0.531	0.498
Expected share of failing banks**	0.17%	0.66%

\*The maximum fund size is the maximum value obtained by the policy-functions when there are no bank failures.

\*\*The expected bank failure is measured at the initial fund size,  $F$ .

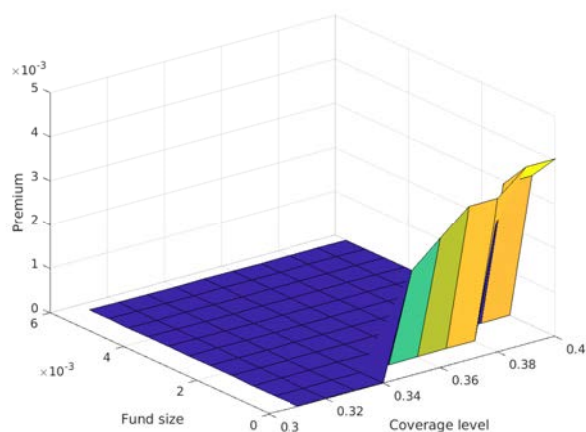
Table 4: Comparison of model solution with either late or early premiums. The interest rate on deposits is endogenous.

Table 4 shows that collecting premiums early lowers the optimal deposit insurance coverage and fund size. In fact, the optimal fund size is zero. This implies the policymaker optimally chooses not to collect premiums rather than collect early premiums, which is an initially surprising decision because the expected share of bank failures more than triples relative to late premiums. We elaborate on the intuition below.

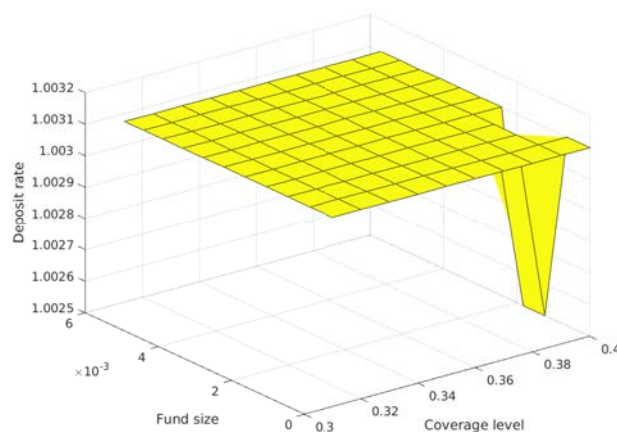
Figure 10 displays the policymaker's optimal premium (panel a), banks' optimal interest rate on deposits (panel b), and the share of banks that are expected to fail (panel c) when premiums are collected early. Early premiums are especially costly to banks because banks cannot invest these premiums in either production technology, and the reduction in banks' funds increases their risk of default. However, the policymaker must still contend with moral hazard because the interest rate on deposits is endogenous. As a compromise, the policymaker collects early premiums only when the fund size is low and ceases once the fund achieves some minimum threshold. The policymaker essentially trades off a heightened risk of bank failure from early premium collection today in exchange for a fund that mitigates taxpayers' exposure tomorrow. We observe in panel (b) that for a sufficiently low fund to coverage ratio, the policymaker charges early premiums that are high enough to deter a riskier choice of interest rate on deposits by banks. As a consequence of the policymaker's distaste for early premiums, the policymaker optimally chooses a lower coverage level of 0.34 deposit units, the same as when premiums are zero.

At first glance, it may seem counterintuitive that in a model with moral hazard, the policymaker optimally collects premiums from only the surviving banks. However, it is important to remember that the cost of failure to the banks' equity holders, who own a significant share of uninsured deposits, as well as the burden of risk-adjusted premiums during good times, outweighs their expected gains

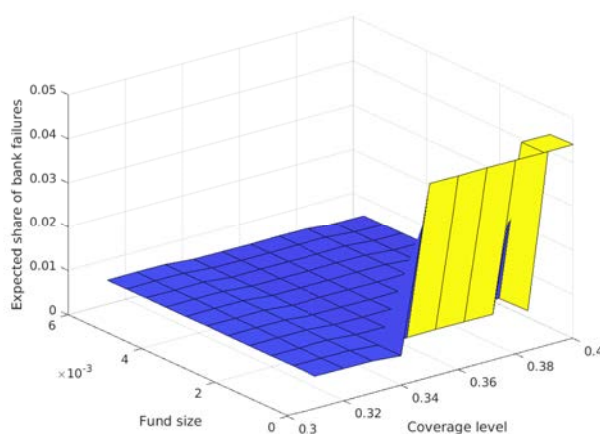
from a riskier interest rate on deposits. In other words, although premiums are collected only from survivors, the incomplete coverage on the equity holders' deposits and the consistent collection of risk-adjusted premiums during good times effectively mitigate moral hazard.



(a) Optimal premium



(b) Optimal deposit rate



(c) Expected bank failures

Figure 10: We plot the policymaker's optimal premium level in panel (a), banks' optimal deposit rate in panel (b), and the share of banks that are expected to fail in panel (c), all as a function of the fund and coverage levels. We solve the model with an endogenous interest rate on deposits and early premiums only (i.e.,  $w_l = 0$ ).

## 6.5 Great Recession Simulation

To assess the performance of our model, we use FDIC data on failed assets to simulate the effect of the Great Recession on our deposit insurance fund in Figure 11.<sup>8</sup> As a benchmark, we plot the simulated path of our fund size relative to the FDIC’s fund size from 2001–2020. Our model delivers a more shallow drop and more rapid recovery in fund size relative to the steeper drop and sluggish recovery of the United States. This juxtaposition emphasizes the usefulness of risk-adjusted premiums and their ex-post collection. More importantly, Figure 11 verifies that our model appropriately captures the deposit insurance fund dynamics exhibited in the data.

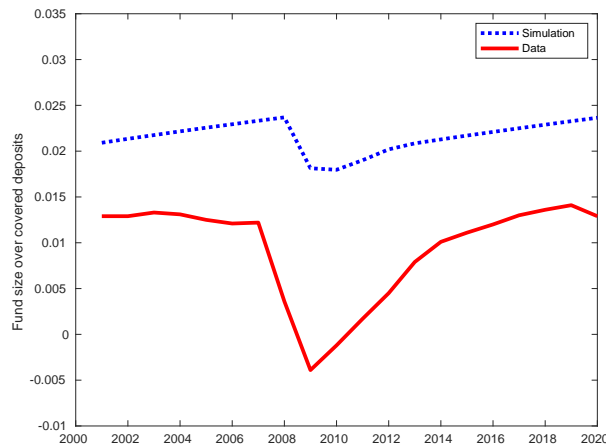


Figure 11: Comparison of simulated and U.S. fund sizes from 2001–2020. We simulate our model with an endogenous interest rate on deposits and late premiums only.

## 7 Quantitative Application: Funds by Income Level

In this section, we evaluate whether our model can replicate the decreasing fund-to-covered-deposits ratio along GDP per capita in Figure 1. We solve the model and obtain policy functions for three descending levels of average deposit balances,  $\mu_D$ . Varying these deposit balances will similarly affect depositors’ and taxpayers’ income levels (see Section 5 for details). The value functions and policy functions are solved over exogenous grids of the fund size and coverage level with optimal premiums.<sup>9</sup>

<sup>8</sup>The realized shock sequence is the failed-asset-to-domestic-deposit ratio as reported by the FDIC (2020) for 2000-2020. We draw the values of  $\rho_l$  from the calibrated distribution from the lowest 10% of  $\rho_l$  draws, to reflect the high, joint aggregate risk in this time period.

<sup>9</sup>To avoid default by taxpayers, we set their consumption to negative infinity if their consumption in failure states becomes negative.

## 7.1 Steady States and Welfare

We summarize the model results for all three income levels in Table 5. As income increases for depositors and taxpayers, deposit insurance coverage scales proportionately. Specifically, the coverage level increases but relative coverage, the covered-to-total-deposits ratio, remains constant. However, premiums will increase less than proportionately, causing the ratio of fund size to covered deposits to decrease in income.

Taxpayers' risk aversion is the reason that the fund size does not scale proportionately in depositor and taxpayer income. Agents with CRRA preferences are risk averse and exhibit decreasing absolute risk aversion (DARA). When taxpayers' income is low, taxpayers are more averse to banking crises that would potentially subject them to ex-post taxation. The policymaker considers taxpayers' welfare when assigning premiums to banks. As taxpayers' income increases, taxpayers become less risk averse to the possibility of ex-post taxation and assign a lower value to a deposit insurance fund. Because depositors' optimal share of insured deposits remains constant for various income levels, the policymaker optimally chooses not to scale the premium level with the coverage level.<sup>10</sup> Consequently, the fund size increases by less than the level of covered deposits, and the fund-to-covered-deposits ratio decreases in income.

	Low income	Middle income	High income
Total income	0.4879	0.5654	0.6547
Mean deposits	0.2440	0.2821	0.3274
Optimal coverage level	0.28	0.33	0.39
Maximum fund size over covered deposits (%) <sup>*</sup>	2.6691	2.3228	2.0587
Covered deposits to total deposits	0.5342	0.5309	0.5310
Expected share of failing banks <sup>**</sup>	0.16%	0.16%	0.16%

<sup>\*</sup>The maximum fund size is the maximum value obtained by the policy-functions when there are no bank failures. Optimal coverage given when the fund is empty. <sup>\*\*</sup>The expected bank failure is measured at the initial fund size,  $F_0$ .

Table 5: Comparison of model solution with multiple taxpayer income levels. We solve the model with an endogenous interest rate on deposits and late premiums only (i.e.,  $w_l = 1$ ).

In Figure 12, we plot cross-sectional evidence from the 2018 IADI data on the fund-to-covered-deposits ratio against income. We compare this trend with the model-implied counterpart. The de-

<sup>10</sup>The marginal cost of public funds remains constant across income levels because it scales with the ratio of the expected fiscal shortfall to income, which is also constant because the ratio of covered to total deposits is constant.

clining slopes of the two fund-to-covered-deposit ratios are very similar, indicating that our aforementioned explanation is plausible. Note again that the difference in fund levels in Figure 12 is immaterial to the analysis because our model implies a higher optimal fund size relative to covered deposits than reflected in the data.

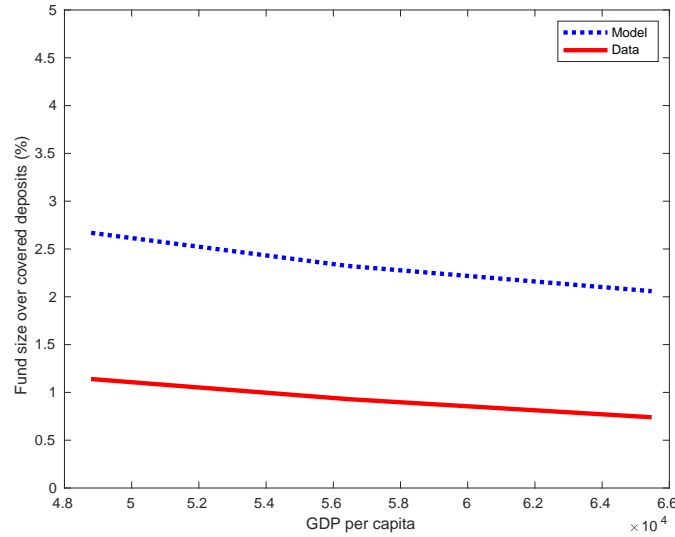


Figure 12: We compare the fund-to-covered-deposits ratio between the model and implied by the data. The data series is created via a quadratic regression of the fund-size-to-covered-deposits ratio on log GDP per capita in 2018.

Lastly, we examine welfare between the low and high income calibrations. Table 6 summarizes the conditional welfare changes, and Figure 13 displays agents' welfare gains relative to deposits for both calibrations.

	Regimes	Early depositors	Late depositors	Taxpayers	Total
Low income	1 to 2	0.1417	0.1325	-0.0014	0.0692
	1 to 3	0.1470	0.1347	-0.0024	0.0702
	2 to 3	0.0053	0.0022	-0.001	0.001
Middle income	1 to 2	0.1446	0.1350	-0.0013	0.0711
	1 to 3	0.1494	0.1376	-0.0024	0.0722
	2 to 3	0.0048	0.0026	-0.0012	0.0011

Table 6: Conditional welfare gains (%) by income level and regime. Regime 1 has no deposit insurance, regime 2 offers coverage without premiums, and regime 3 offers coverage and collects premiums. We solve the model with an endogenous interest rate on deposits and late premiums only (i.e.,  $w_l = 1$ ).

When we compare the conditional welfare gains between regimes 2 and 3, we observe that the low-income calibration delivers a higher welfare gain for early depositors but a lower welfare gain for

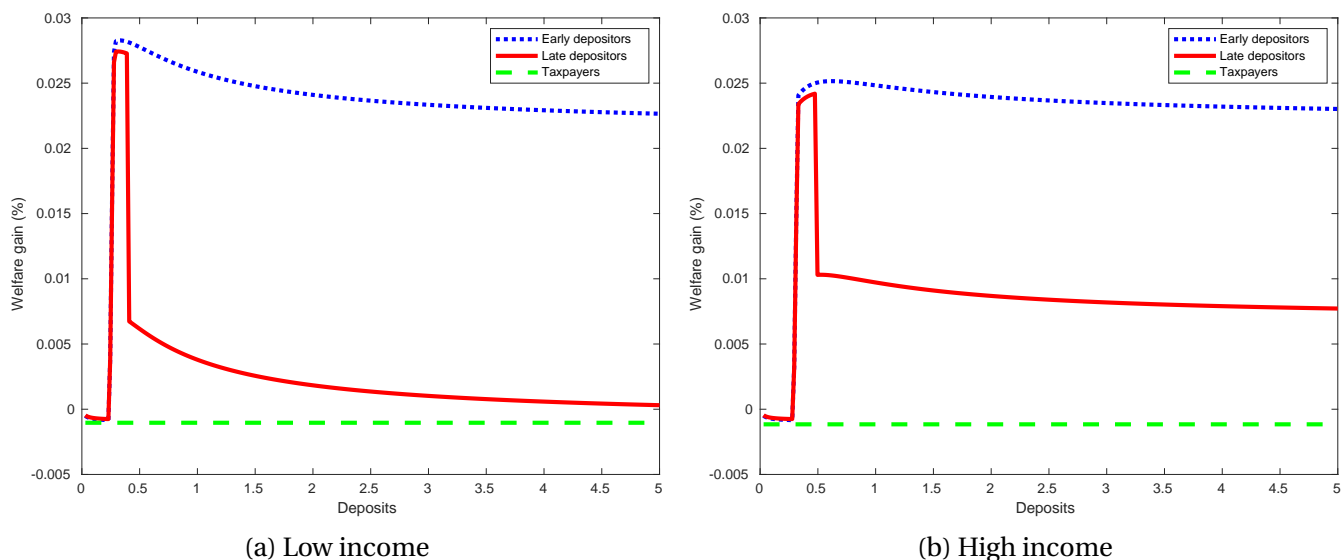


Figure 13: Conditional welfare gains from regime 2 to 3 by income level. We solve the model with an endogenous interest rate on deposits and late premiums only (i.e.,  $w_l = 1$ ).

late depositors. Taking stock of our findings in Table 2, we see that the welfare gain from premiums is constant in income for early depositors, increasing in income for late depositors, and decreasing (and negative) in income for taxpayers. Under either income level, depositors benefit from premiums while taxpayers' welfare is slightly lower. Overall, the welfare gains from a fund are constant in taxpayers' income.

## 8 Conclusion

We develop a quantitative model to characterize optimal funding for deposit insurance systems, emphasizing the role of premiums. Our analysis reveals how premiums can increase optimal coverage by insuring taxpayers against large fiscal shortfalls during bank failures and decrease the share of banks expected to fail annually. While premiums compensate taxpayers for fiscal shortfalls and discourage moral hazard by banks, premiums involve opportunity costs to the banking sector. The benefits of premiums depend on whether premiums are collected before or after the aggregate states are realized. Consequently, our results provide an important step towards understanding the welfare effects of deposit insurance schemes and the tradeoffs of ex-ante and ex-post financing.

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# Appendices

## A Calibration Data

We use a dataset from the International Association of Deposit Insurers (IADI) to understand how deposit insurance systems vary by country. We have data from 2014–2018, but we feature the 2018 data because it is the most complete and recent.

First, we show the ratio of fund size to total deposits across countries in 2018. We observe in Figure 14 that the fund to total deposits ratio over log GDP per capita has the same decreasing pattern as we observed in Figure 1:

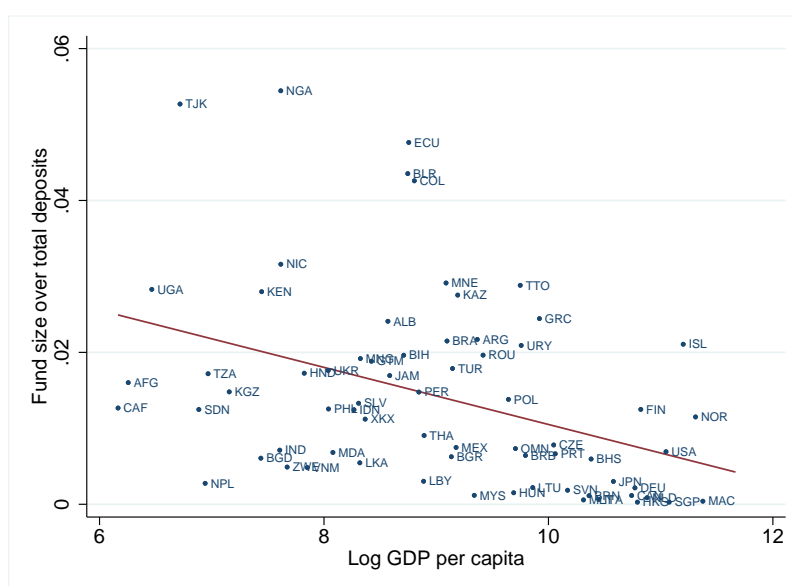


Figure 14: Fund size over total deposits (2018). GDP per capita is in U.S. 2018 dollars. Trend line is weighted by log population.

In Figure 15, we display the ratio of covered deposits to total deposits relative to log GDP per capita. We observe an increasing relationship between the ratio of covered deposits to total deposits in each country's banking system relative to each country's income. Intuitively, more developed countries are better able to stabilize their financial system by insuring a greater share of deposits.

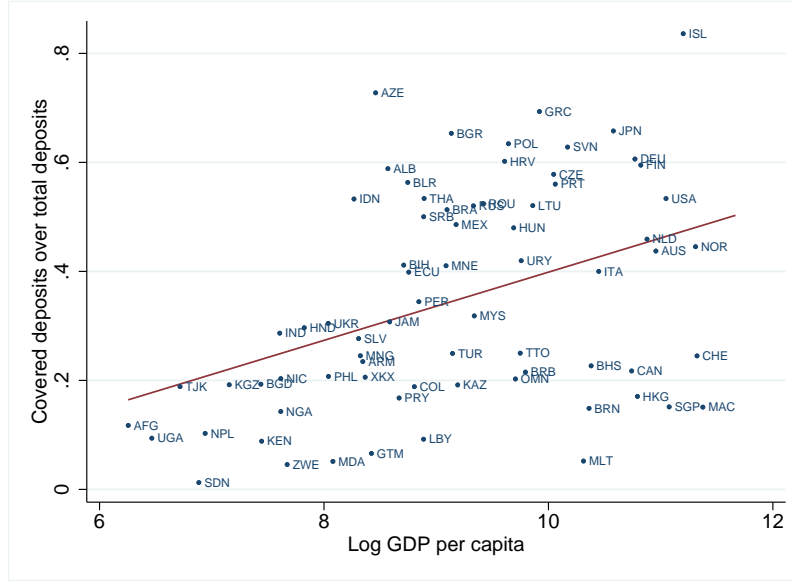


Figure 15: Covered deposits over total deposits in 2018. GDP per capita is in U.S. 2018 dollars. Trend line is weighted by log population.

## B Threshold Equilibria

We describe the threshold values,  $\hat{\rho}_l$  and  $\rho_l^*$ , that separate the unique failure, multiplicity, and no-failure regions for the value of the low-return state  $\rho_l$ . Starting with  $\hat{\rho}_l$ , we use the formulas from the Figure 3:

$$\frac{\rho_{2l}}{\rho_{2l} - 1} [D_0 R_1 - \rho_{1l} (D_0 - \pi_e)] = (1 - \lambda) D_0 R_1.$$

We also assume that  $\rho_{1l} = \rho_{2l} = \rho_l$ . Substituting, we get:

$$\frac{\rho_l}{\rho_l - 1} [D_0 R_1 - \rho_l (D_0 - \pi_e)] = (1 - \lambda) D_0 R_1.$$

Isolating  $\hat{\rho}_l$ , we arrive at:

$$\hat{\rho}_l = \frac{\sqrt{D_0} \sqrt{R_1} \sqrt{D_0 (\lambda^2 R_1 - 4\lambda + 4) + 4(\lambda - 1)\pi_e} + D_0 \lambda R_1}{2(D_0 - \pi_e)}.$$

Second, we solve for  $\rho_l^*$ , which is where  $\hat{D}_1$  intersects  $D_1^-$ . Let us define  $\xi \equiv \frac{\int_D^{\bar{D}} \min\{D_{0i} R_1, \delta\} dG(i)}{D_0}$ . Then

$$\frac{\rho_{2l}}{\rho_{2l} - 1} [D_0 R_1 - \rho_{1l} (D_0 - \pi_e)] = (1 - \lambda) \int_D^{\bar{D}} \min\{D_{0i} R_1, \delta\} dG(i).$$

Substituting in  $\rho_{1l}$  and  $\rho_{2l}$ , we arrive at:

$$\frac{\rho_l}{\rho_l - 1} [R_1 - \rho_l (1 - \frac{\pi_e}{D_0})] = (1 - \lambda)\xi.$$

Then we solve for  $\rho_l^*$ :

$$\rho_l^* = \frac{\sqrt{(\xi D_0 \lambda - \xi D_0 + D_0 R_1)^2 - 4(\pi_e - D_0)(\xi D_0 - \xi D_0 \lambda)} + \xi D_0 \lambda - \xi D_0 + D_0 R_1}{2(D_0 - \pi_e)}.$$

It is clear that both  $\hat{\rho}_l$  and  $\rho_l^*$  are increasing in the deposit rate  $R_1$ , and that  $\rho_l^*$  is decreasing in the coverage level  $\delta$ . In addition, note that if  $R_1 = 1$ , then both  $\hat{\rho}_l$  and  $\rho_l^*$  equal 1:

$$\hat{\rho}_l = \frac{\lambda + \sqrt{\lambda^2 + 4(1 - \lambda)}}{2} = \frac{\lambda + \sqrt{(\lambda - 2)^2}}{2} = \frac{\lambda + (2 - \lambda)}{2} = 1,$$

$$\rho_l^* = \frac{1 - \xi + \lambda\xi + \sqrt{(-1 + \xi - \lambda\xi)^2 - 4(\lambda\xi - \xi)}}{2} = \frac{1 - \xi + \lambda\xi + \sqrt{(\lambda\xi - \xi - 1)^2}}{2} = \frac{1 - \xi + \lambda\xi + (1 + \xi - \lambda\xi)}{2} = \frac{2}{2} = 1.$$

## C Optimal Deposit Insurance Coverage

In this appendix, we describe how we arrived at Equation (27) in more detail. The goal is to pin down the effect on welfare of a marginal change in the level of deposit insurance:

$$\frac{\partial W}{\partial \delta} = \int_{\underline{D}}^{\bar{D}} \frac{\partial V_i}{\partial \delta} dG(i) + \frac{\partial V_\tau}{\partial \delta} + \beta \frac{\partial W'}{\partial F'} \frac{\partial F'}{\partial \delta}. \quad (32)$$

We solve for each term separately. First, we solve for the marginal effect of a change in insurance coverage  $\delta$  on depositor welfare  $V_i$  where

$$\frac{\partial V_i}{\partial \delta} = \mathbb{E}_{s, \rho_l} \left\{ \lambda \frac{\partial U(C_{1i}(s, \rho_l))}{\partial \delta} + (1 - \lambda) \frac{\partial U(C_{2i}(s, \rho_l))}{\partial \delta} \right\}. \quad (33)$$

Using the Leibniz integral rule,  $\frac{\partial C_t^N}{\partial \delta} = 0$ , and the fact that only  $\rho_l^*$  depends on  $\delta$ , we have:

$$\begin{aligned} \frac{\partial E_{s, \rho_l}[U(C_t(s, \rho_l))]}{\partial \delta} &= \underbrace{\int_{\underline{\rho}_l}^{\hat{\rho}_l} \int_{\underline{s}}^{\bar{s}} U'(C_t^F) \frac{\partial C_t^F}{\partial \delta} dR(\rho_l) s dH(s) + \gamma \int_{\hat{\rho}_l}^{\rho_l^*} \int_{\underline{s}}^{\bar{s}} U'(C_t^F) \frac{\partial C_t^F}{\partial \delta} dR(\rho_l) dH(s)}_{q^F E_{s, \rho_l}^F \left[ U'(C_t^F) \frac{\partial C_t^F}{\partial \delta} \right]} \\ &+ \left[ U(C_t^F(\rho_l^*)) - U(C_t^N(\rho_l^*)) \right] \underbrace{E_s \gamma r(\rho_l^*) \frac{\partial \rho_l^*}{\partial \delta}}_{\frac{\partial q^F}{\partial \delta}}. \end{aligned} \quad (34)$$

Second, the marginal effect of varying the coverage level on taxpayer welfare is given by:

$$\frac{\partial V_\tau}{\partial \delta} = q^F E_{s, \rho_l}^F \left[ U'(C_\tau^F) \frac{\partial C_\tau^F}{\partial \delta} \right] + [U(C_\tau^F(\rho_l^*)) - U(C_\tau^N(\rho_l^*))] \frac{\partial q^F}{\partial \delta}. \quad (35)$$

Third, we solve for the effect of the coverage level on next period's aggregate welfare. We derive the marginal effect of varying the future fund size  $F'$  on future aggregate welfare  $W'$  by solving and iterating forward the envelope condition  $\frac{\partial W}{\partial F}$ . The fund size only affects taxpayer welfare  $V_\tau$  and not depositor welfare  $V_i$ . Using the Benveniste-Scheinkman theorem, we have that  $\frac{\partial \delta}{\partial F} = 0$  as  $\delta$  is already optimally chosen (Benveniste and Scheinkman, 1979).

$$\frac{\partial W}{\partial F} = \frac{\partial V_\tau}{\partial F} \Rightarrow \frac{\partial W'}{\partial F'} = \frac{\partial V_\tau'}{\partial F'}. \quad (36)$$

The only term remaining to pin down is the taxpayers welfare effect:  $\frac{\partial V_\tau}{\partial F}$ . Taxpayer welfare  $V_\tau$  will vary non-trivially with the fund size  $F$  in failure scenarios only. As before, we can use that  $\frac{\partial V_\tau}{\partial F} = \frac{\partial E_{s,\rho_l}[U(C_\tau(s,\rho_l))]}{\partial F}$ . Using the Leibniz integral rule, we have:

$$\frac{\partial E_{s,\rho_l}[U(C_\tau(s,\rho_l))]}{\partial F} = \underbrace{\int_{\rho_l}^{\hat{\rho}_l} \int_{\underline{s}}^{\bar{s}} U'(C_\tau^F) \left[ \frac{\partial C_\tau^F}{\partial F} \right] dR(\rho_l) sdH(s) + \gamma \int_{\hat{\rho}_l}^{\rho_l^*} \int_{\underline{s}}^{\bar{s}} U'(C_\tau^F) \left[ \frac{\partial C_\tau^F}{\partial F} \right] dR(\rho_l) sdH(s)}_{q^F E_{s,\rho_l}^F \left[ U'(C_\tau^F) \frac{\partial C_\tau^F}{\partial F} \right]} \quad (37)$$

Iterating forward yields:

$$\frac{\partial V_\tau'}{\partial F'} = q^F E_{s,\rho_l}^F \left[ U'(C_\tau'^F) \frac{\partial C_\tau'^F}{\partial F'} \right]. \quad (38)$$

Fourth, we derive the marginal effect of the insurance coverage on the next-period fund size,  $\frac{\partial F'}{\partial \delta}$ . If there is no bank failure, or if there is a bank failure and the proceeds from bank recovery are sufficient to recoup losses, or if the starting fund size is zero, then the marginal effect will be trivially zero. However, if there is a bank failure and  $F$  is used to cover the losses, then using Equation (3) we know that  $\frac{\partial F'}{\partial \delta} \leq 0$ .

The final expression is given by:

$$\begin{aligned} \frac{\partial W}{\partial \delta} &= \int_{\underline{D}}^{\bar{D}} \frac{\partial V_i}{\partial \delta} dG(i) + \frac{\partial V_\tau}{\partial \delta} + \beta \frac{\partial W'}{\partial F'} \frac{\partial F'}{\partial \delta} \\ &= q^F \int_j E_{s,\rho_l,\lambda}^F \left[ U'(C_j^F) \frac{\partial C_j^F}{\partial \delta} \right] dj - \frac{\partial q^F}{\partial \delta} \int_j \left[ U(C_j^N(\rho_l^*)) - U(C_j^F(\rho_l^*)) \right] dj \\ &\quad + \beta q^F E_{s,\rho_l}^F \left[ U'(C_\tau'^F) \frac{\partial C_\tau'^F}{\partial F'} \right] \frac{\partial F'}{\partial \delta}. \end{aligned} \quad (39)$$

## D Optimal Deposit Insurance Premium

We want to understand how a marginal change in the premium affects social welfare, that is, we want to characterize:

$$\frac{\partial W}{\partial \pi} = \int_{\underline{D}}^{\bar{D}} \frac{\partial V_i}{\partial \pi} dG(i) + \frac{\partial V_\tau}{\partial \pi} + \beta \frac{\partial W'}{\partial F'} \frac{\partial F'}{\partial \pi}.$$

Fortunately, it is convenient to derive this expression term by term while first assuming that  $R_1$  is predetermined. We can then amend the final expression with a simple substitution for the case in which  $R_1$  is endogenously chosen by banks.

Starting with depositors' welfare, recall that:

$$V_i = \mathbb{E}_{\lambda, s, \rho_l} [U(C_{ti}(s, \rho_l))] = \lambda \mathbb{E}_{s, \rho_l} [U(C_{1i}(s, \rho_l))] + (1 - \lambda) \mathbb{E}_{s, \rho_l} [U(C_{2i}(s, \rho_l))],$$

where

$$\begin{aligned} \mathbb{E}_{s, \rho_l} [U(C_{ti}(s, \rho))] &= s \left[ \int_{\underline{\rho_l}}^{\hat{\rho}_l(\pi, R_1)} U(C_{ti}^F(s, \rho_l)) dR(\rho_l) \right. \\ &\quad + \int_{\hat{\rho}_l(\pi, R_1)}^{\rho_l^*(\pi, \delta, R_1)} [\gamma U(C_{ti}^F(s, \rho_l)) + (1 - \gamma) U(C_{ti}^N(s, \rho_l))] dR(\rho_l) \\ &\quad \left. + \int_{\rho_l^*(\pi, \delta, R_1)}^{\bar{\rho}_l} U(C_{ti}^N(s, \rho_l)) dR(\rho_l) \right] \\ &\quad + (1 - s) U(C_{ti}^N(s, \rho_h)). \end{aligned}$$

Differentiating with respect to the premium  $\pi$ , we apply Leibniz integral rule and simplify to obtain the expression:

$$\begin{aligned} \frac{\partial \mathbb{E}_{s, \rho_l} [U(C_{ti}(s, \rho))] }{\partial \pi} &= s \left[ \overbrace{\int_{\underline{\rho_l}}^{\hat{\rho}_l(\pi, R_1)} U'(C_{ti}^F(s, \rho_l)) \frac{\partial C_{ti}^F}{\partial \pi} dR(\rho_l) + \gamma \int_{\hat{\rho}_l}^{\rho_l^*} U'(C_{ti}^F(s, \rho_l)) \frac{\partial C_{ti}^F}{\partial \pi} dR(\rho_l)}^{=q^F \mathbb{E}_{\rho_l} [U'(C_{ti}^F) \frac{\partial C_{ti}^F}{\partial \pi}]} \right. \\ &\quad + s \left[ [U(C_{ti}^F(s, \hat{\rho}_l)) - U(C_{ti}^N(s, \hat{\rho}_l))] (1 - \gamma) r(\hat{\rho}_l) \frac{\partial \hat{\rho}_l}{\partial \pi} + [U(C_{ti}^F(s, \rho_l^*)) - U(C_{ti}^N(s, \rho_l^*))] \gamma r(\rho_l^*) \frac{\partial \rho_l^*}{\partial \pi} \right] \\ &\quad \left. + s \left[ (1 - \gamma) \int_{\hat{\rho}_l}^{\rho_l^*} U'(C_{ti}^N(s, \rho_l)) \frac{\partial C_{ti}^N}{\partial \pi} dR(\rho_l) + \int_{\rho_l^*}^{\bar{\rho}_l} U'(C_{ti}^N(s, \rho_l)) \frac{\partial C_{ti}^N}{\partial \pi} dR(\rho_l) \right] + (1 - s) U'(C_{ti}^N(s, \rho_h)) \frac{\partial C_{ti}^N}{\partial \pi} \right. \\ &\quad \left. \underbrace{\hspace{10em}}_{(1-q^F) \mathbb{E}_{\rho_l} [U'(C_{ti}^N) \frac{\partial C_{ti}^N}{\partial \pi}]} \right] \end{aligned}$$



The sensitivity of depositors' welfare in response to a marginal change in  $\pi$  is given by:

$$\begin{aligned} \frac{\partial V_i}{\partial \pi} = & \mathbb{E}_\lambda \left\{ q^F \mathbb{E}_{\rho_l} \left[ U'(C_{ti}^F) \frac{\partial C_{ti}^F}{\partial \pi} \right] + (1 - q^F) \mathbb{E}_{\rho_l} \left[ U'(C_{ti}^N) \frac{\partial C_{ti}^N}{\partial \pi} \right] \right. \\ & \left. + \mathbb{E}_s [s] \left[ [U(C_{ti}^F(s, \hat{\rho}_l)) - U(C_{ti}^N(s, \hat{\rho}_l))] (1 - \gamma) r(\hat{\rho}_l) \frac{\partial \hat{\rho}_l}{\partial \pi} + [U(C_{ti}^F(s, \rho_l^*)) - U(C_{ti}^N(s, \rho_l^*))] \gamma r(\rho_l^*) \frac{\partial \rho_l^*}{\partial \pi} \right] \right\}. \end{aligned}$$

Second, we examine how a marginal change in the premium affects taxpayers' welfare. Recall that:

$$V_\tau(\delta, \pi, R_1) = \mathbb{E}_{s, \rho_l} [U(C_\tau(s, \rho_l))],$$

where

$$\begin{aligned} \mathbb{E}_{s, \rho_l} [U(C_\tau(s, \rho))] = & s \left[ \int_{\rho_l}^{\hat{\rho}_l(\pi, R_1)} U(C_\tau^F(s, \rho_l)) dR(\rho_l) \right. \\ & + \int_{\hat{\rho}_l(\pi, R_1)}^{\rho_l^*(\pi, \delta, R_1)} [\gamma U(C_\tau^F(s, \rho_l)) + (1 - \gamma) U(C_\tau^N(s, \rho_l))] dR(\rho_l) \\ & \left. + \int_{\rho_l^*(\pi, \delta, R_1)}^{\bar{\rho}_l} U(C_\tau^N(s, \rho_l)) dR(\rho_l) \right] \\ & + (1 - s) U(C_\tau^N(s, \rho_h)). \end{aligned}$$

Differentiating with respect to the premium  $\pi$ , we apply Leibniz integral rule, simplify, and use that  $\partial C_\tau^N / \partial \pi = 0$  to obtain:

$$\begin{aligned} \frac{\partial \mathbb{E}_{s, \rho_l} [U(C_\tau(s, \rho))]}{\partial \pi} = & \overbrace{s \left[ \int_{\rho_l}^{\hat{\rho}_l(\pi, R_1)} U'(C_\tau^F(s, \rho_l)) \frac{\partial C_\tau^F}{\partial \pi} dR(\rho_l) + \int_{\hat{\rho}_l}^{\rho_l^*} \gamma U'(C_\tau^F(s, \rho_l)) \frac{\partial C_\tau^F}{\partial \pi} dR(\rho_l) \right]}^{q^F \mathbb{E}_{\rho_l} \left[ U'(C_\tau^F) \frac{\partial C_\tau^F}{\partial \pi} \right]} \\ & + \mathbb{E}_s [s] \left[ [U(C_\tau^F(s, \hat{\rho}_l)) - U(C_\tau^N(s, \hat{\rho}_l))] (1 - \gamma) r(\hat{\rho}_l) \frac{\partial \hat{\rho}_l}{\partial \pi} + [U(C_\tau^F(s, \rho_l^*)) - U(C_\tau^N(s, \rho_l^*))] \gamma r(\rho_l^*) \frac{\partial \rho_l^*}{\partial \pi} \right]. \end{aligned}$$

The sensitivity of taxpayers' welfare in response to a marginal change in  $\pi$  is given by:

$$\frac{\partial V_\tau}{\partial \pi} = q^F \mathbb{E}_{\rho_l} \left[ U'(C_\tau^F) \frac{\partial C_\tau^F}{\partial \pi} \right] + \mathbb{E}_s [s] \left[ [U(C_\tau^F(s, \hat{\rho}_l)) - U(C_\tau^N(s, \hat{\rho}_l))] (1 - \gamma) r(\hat{\rho}_l) \frac{\partial \hat{\rho}_l}{\partial \pi} + [U(C_\tau^F(s, \rho_l^*)) - U(C_\tau^N(s, \rho_l^*))] \gamma r(\rho_l^*) \frac{\partial \rho_l^*}{\partial \pi} \right].$$

Third, we examine how a marginal change in the premiums affects the future fund size and its corresponding effect on future social welfare. We solve and iterate forward the envelope condition for  $\frac{\partial W}{\partial F}$ . Only taxpayers'

welfare is affected by changes in the fund size.

$$\frac{\partial W}{\partial F} = \frac{\partial V_\tau}{\partial F} \Rightarrow \frac{\partial W'}{\partial F'} = \frac{\partial V'_\tau}{\partial F'}, \quad (40)$$

where

$$\frac{\partial V'_\tau}{\partial F'} = \mathbb{E}_{s', \rho'_l} U'(C_\tau(s', \rho'_l)) \frac{\partial C_\tau(s', \rho'_l)}{\partial F'}. \quad (41)$$

Finally, we combine all terms to arrive at the final expression:

$$\begin{aligned} \frac{\partial W}{\partial \pi} = & \int_{\underline{D}}^{\overline{D}} \mathbb{E}_\lambda \left\{ q^F \mathbb{E}_{\rho_l} \left[ U'(C_{ti}^F(s, \rho_l)) \frac{\partial \widetilde{C_{ti}^F}}{\partial \pi} \right] + (1 - q^F) \mathbb{E}_{\rho_l} \left[ U'(C_{ti}^N(s, \rho_l)) \frac{\partial \widetilde{C_{ti}^N}}{\partial \pi} \right] \right. \\ & + \mathbb{E}_s[s] \left[ [U(C_{ti}^F(s, \hat{\rho}_l)) - U(C_{ti}^N(s, \hat{\rho}_l))](1 - \gamma)r(\hat{\rho}_l) \frac{\partial \widetilde{\hat{\rho}_l}}{\partial \pi} + [U(C_{ti}^F(s, \rho_l^*)) - U(C_{ti}^N(s, \rho_l^*))]\gamma r(\rho_l^*) \frac{\partial \widetilde{\rho_l^*}}{\partial \pi} \right] \Big\} dG(i) \quad (42) \\ & + \mathbb{E}_s[s] \left[ [U(C_\tau^F(s, \hat{\rho}_l)) - U(C_\tau^N(s, \hat{\rho}_l))](1 - \gamma)r(\hat{\rho}_l) \frac{\partial \widetilde{\hat{\rho}_l}}{\partial \pi} + [U(C_\tau^F(s, \rho_l^*)) - U(C_\tau^N(s, \rho_l^*))]\gamma r(\rho_l^*) \frac{\partial \widetilde{\rho_l^*}}{\partial \pi} \right] \\ & + q^F \mathbb{E}_{\rho_l} \left[ U'(C_\tau^F) \frac{\partial \widetilde{C_\tau^F}}{\partial \pi} \right] + \beta \mathbb{E}_{s', \rho'_l} U'(C_\tau(s', \rho'_l)) \frac{\partial C'_\tau}{\partial F'} \frac{\partial \widetilde{F'}}{\partial \pi}. \end{aligned}$$

To obtain  $\partial W/\partial \pi$  when  $R_1$  is endogenous (and depends on both  $\pi$  and  $\delta$ ), we make the following substitutions in Equation (42):

$$\frac{\partial \widetilde{X}}{\partial \pi} := \frac{\partial X}{\partial \pi} + \frac{\partial X}{\partial R_1} \frac{\partial R_1}{\partial \pi}, \quad X \in \{C_{ti}^F, C_{ti}^N, C_\tau^F, \rho_l^*, \hat{\rho}_l, F'\}. \quad (43)$$

## E Unconditional Welfare Gain (UWG)

The unconditional welfare gain (UWG) would act as an upper bound on welfare gain estimates of switching from policy regime  $a$  to policy regime  $b$  for each group:

$$UWG_{a \text{ to } b} = 100 \cdot \left[ \left( \frac{\int_{s,i} V_b(\cdot) dG(i) dH(s)}{\int_{s,i} V_a(\cdot) dG(i) dH(s)} \right)^{\frac{1}{1-\sigma}} - 1 \right].$$

The analogue to Table 2, now with the unconditional welfare gain, is:

	Regime	Early depositors	Late depositors	Taxpayers	Total
Unconditional welfare gain	1 to 2	0.1468	0.1374	-0.0011	0.0732
	1 to 3	0.1518	0.1403	-0.0027	0.0740
	2 to 3	0.0050	0.0030	-0.0016	0.0008

Table 7: Unconditional welfare gains (%) by income level and regime. Regime 1 has no deposit insurance, regime 2 offers coverage without premiums, and regime 3 offers coverage and collects premiums. We solve the model with an endogenous interest rate on deposits and late premiums only (i.e.,  $w_l = 1$ ).

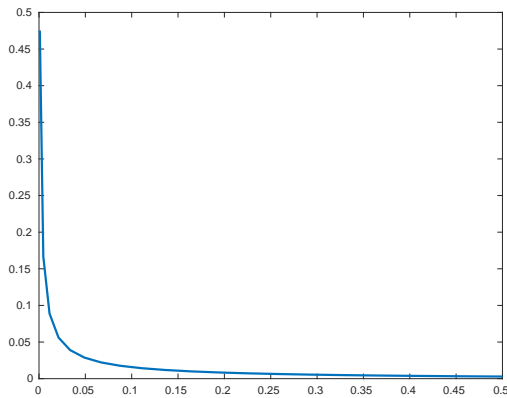
The analogue to Table 6, now with the unconditional welfare gain, is:

	Regimes	Early depositors	Late depositors	Taxpayers	Total
Low income	1 to 2	0.1416	0.1325	-0.0014	0.0692
	1 to 3	0.1470	0.1347	-0.0024	0.0702
	2 to 3	0.0053	0.0022	-0.001	0.001
Middle income	1 to 2	0.1446	0.1350	-0.0013	0.0711
	1 to 3	0.1494	0.1376	-0.0024	0.0722
	2 to 3	0.0048	0.0026	-0.0012	0.0011

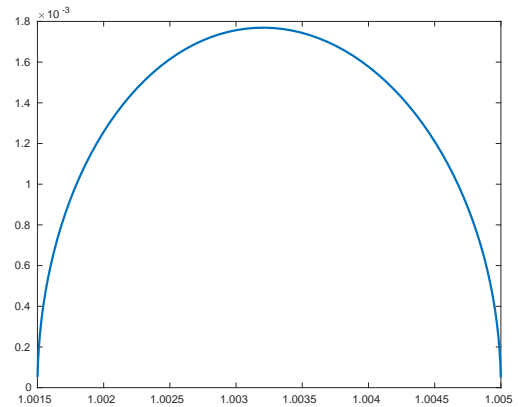
Table 8: Unconditional welfare gains (%) by income level and regime. Regime 1 has no deposit insurance, regime 2 offers coverage without premiums, and regime 3 offers coverage and collects premiums. We solve the model with an endogenous interest rate on deposits and late premiums only (i.e.,  $w_l = 1$ ).

## F Additional Figures From Calibration

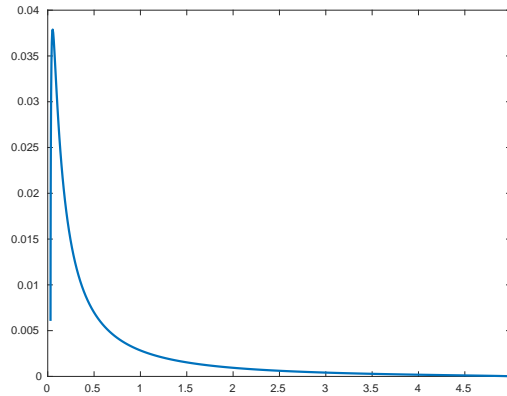
In this appendix, we show the PDF of the distribution of banks' low return on assets ( $\rho_l$ ), the PDF of the fraction of banks drawing the low return state ( $s$ ), and the PDF of the distribution of deposit accounts at date 0. Deposits are measured in hundreds of thousands of dollars.



(a) PDF of the distribution of fraction of banks drawing the low return  $s$ , where  $s \sim \text{LogN}(-9, 4.5)$ , truncated to  $[0, 1]$ .



(b) PDF of the distribution of low state return draws, where  $\rho_l \sim \text{LogN}(0, 0.015)$ , truncated to  $[1.0015, 1.005]$ .



(c) PDF of the distributions of deposits at date 0, where  $D \sim \text{LogN}(-3.6, 2.1)$ , Truncated to  $[0.03, 5]$ .

In addition, we show the expected ratio of bank failures over coverage levels  $\delta$  for  $R_{1,safe}$  and  $R_{1,risky}$ , keeping  $\pi = 0$ .

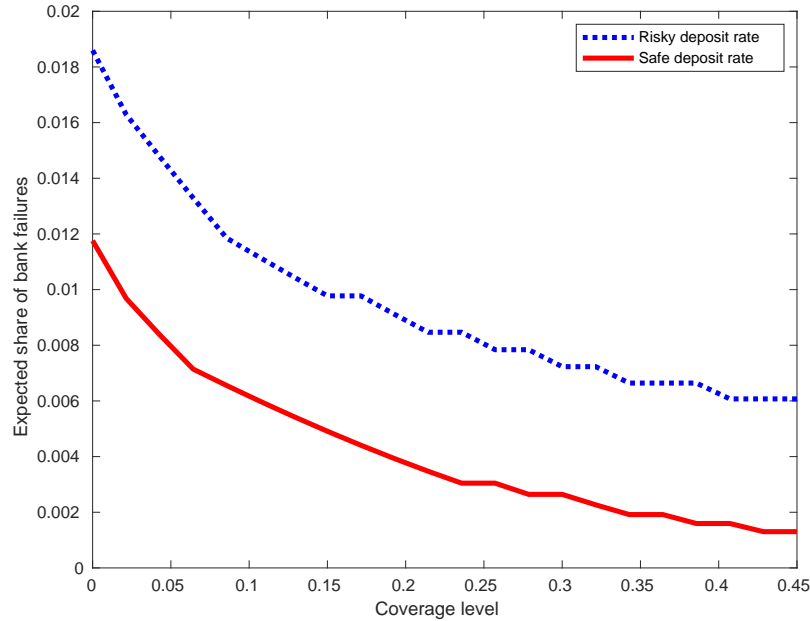


Figure 17: Share of banks expected to fail given coverage levels  $\delta$ , where both premiums and the fund size are zero. We use  $R_{1,safe} = 1.0025$  and  $R_{1,risky} = 1.0031$ .

Finally, we provide an overview of the most important data moments and the steady state counterparts: the optimal fund-to-covered-deposits ratio and the covered-to-total-deposits ratio.

Moment	Data	Model
Maximum fund size over covered deposits (%)*	1.41 (2008-2020)	2.059
Covered deposits to total deposits	0.6506 (2008-2020)	0.531

\*The maximum fund size is the maximum value obtained by the policy-functions when there are no bank failures.

Table 9: Key summary statistics of model solution. We solve the model with an endogenous interest rate on deposits and late premiums only (i.e.,  $w_l = 1$ ).

Table 9 shows that the model matches the U.S. data moments between 2008-2020 reasonably well. The fund-to-covered-deposits ratio is slightly overestimated by the model relative to the data, while the covered-to-total-deposits ratio is slightly underestimated by the model relative to the data.

## G Marginal Cost of Public Funds

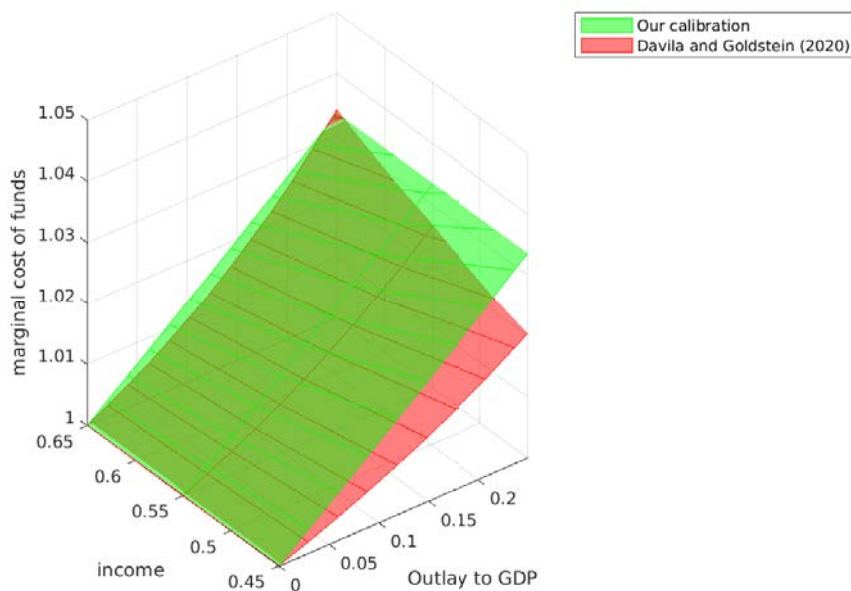
In this Appendix, we compare our calibration of the marginal cost of public funds  $\kappa(T, Y_\tau)$  to the one in [Dávila and Goldstein \(2021\)](#). We choose the following exponential-affine form:

$$\kappa(T, Y_\tau) = \frac{\kappa_1}{\kappa_2} \left( e^{\kappa_2 \frac{T}{Y_\tau}} - 1 \right), \quad \text{where } \kappa_1, \kappa_2 \geq 0,$$

The exponential-affine form chosen in [Dávila and Goldstein \(2021\)](#) is:

$$\kappa(T) = \frac{\kappa_1}{\kappa_2} \left( e^{\kappa_2 T} - 1 \right), \quad \text{where } \kappa_1, \kappa_2 \geq 0,$$

The parameters we choose are  $\kappa_1 = 0.13$  and  $\kappa_2 = 0.25$ , while [Dávila and Goldstein \(2021\)](#) set  $\kappa_1 = 0.13$  and  $\kappa_2 = 5.5$ . The main difference in the function chosen is how the marginal cost changes across  $Y_\tau$  for a given outlay to income ratio. We choose to scale outlay  $T$  by the available  $Y_\tau$  of taxpayers, thereby making sure that the marginal cost is constant across  $Y_\tau$ 's for a given  $\frac{T}{Y_\tau}$ .



Comparison social cost of taxation between our calibration and [Dávila and Goldstein \(2021\)](#). The parameters we chose are  $\kappa_1 = 0.13$  and  $\kappa_2 = 0.25$ . The parameters chosen by [Dávila and Goldstein \(2021\)](#) are  $\kappa_1 = 0.13$  and  $\kappa_2 = 5.5$

Figure 18: Calibration social cost of taxation  $\kappa(T, Y_\tau)$ .

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