Zero-Risk Weights and Capital Misallocation

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Abstract

Financial institutions, especially in Europe, hold a disproportionate amount of domestic sovereign debt. We examine the extent to which this home bias leads to capital misallocation in a real business cycle model with imperfect information and fiscal stress. We assume banks can hold sovereign debt according to a zero-risk weight policy and contrast this scenario to one in which banks weight the sovereign debt according to default probabilities. Banks are assumed to miscalculate the probability of a disaster state due to moral hazard and imperfect monitoring. This distortion pushes the economy away from the first-best allocation. We show that the zero risk weight policy exacerbates these distortions while a non-zero risk-weight improves allocations. The welfare costs associated with zero-risk weight policies are large. Households are willing to give up 3.2 percent of their consumption to move to the first-best allocation, whereas in the economy with non-zero risk-weights households are willing to give up only 1.2 percent of their consumption to move to the first-best allocation.

Keywords: Zero-Risk Weight, Fiscal Limit, Macroprudential Regulation, Sovereign-Bank Nexus, Fiscal Stress.

JEL Codes: E61, E62.

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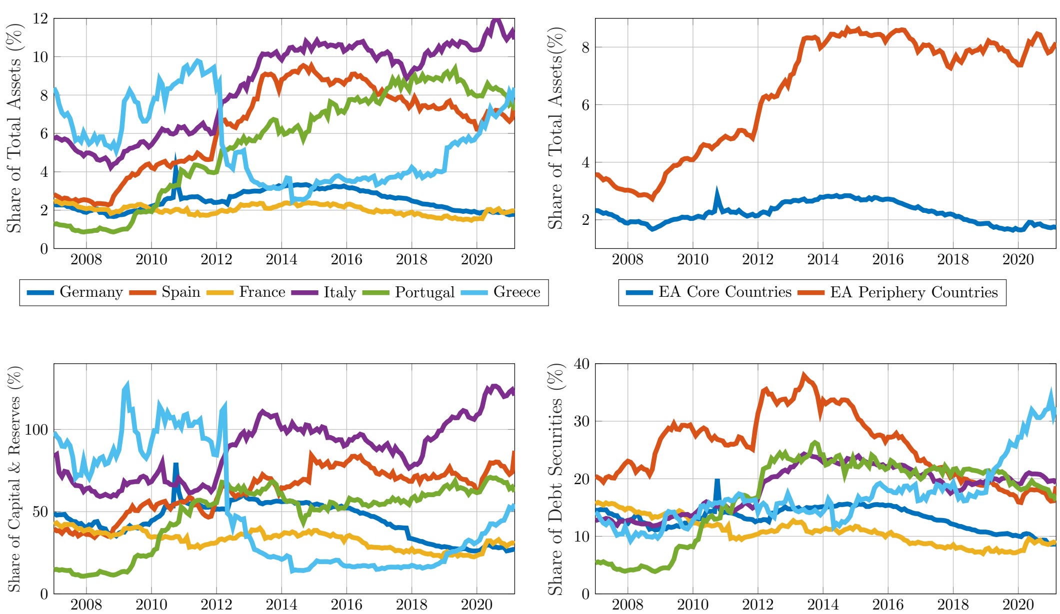
1 Introduction

The Global Financial Crisis and COVID-19 pandemic precipitated significant fiscal spending in many countries which, in turn, led to a substantial increase in sovereign debt. Not surprisingly, much of this sovereign debt ended up on the books of monetary financial institutions (MFIs). What is surprising, however, is the concentration of *domestic* sovereign debt held by MFIs. Figure 1 illustrates this phenomenon. The domestic sovereign debt held by MFIs in several European countries is plotted from 2007 through 2022 as a share of total assets, a share of capital and reserves, and a share of all debt securities. As a share of total assets, only Germany and France maintained relatively low and stable values. The debt restructuring in Greece in early 2012 explains the dramatic decline, but values have returned to pre-crisis levels by 2022. As a share of total assets, MFIs in Portugal, Spain and Italy hold nearly eight, four and two times, respectively, as much sovereign debt today as they did in 2009. The northeast plot separates the core euro area countries from the periphery, which highlights that the growth in domestic sovereign debt holdings is uniquely attributable to the periphery. These dynamics play out when comparing domestic sovereign debt holdings both as a share of capital and reserves and as a share of total debt securities. For Italy, the share of domestic sovereign debt held as a percentage of capital and reserves exceeds 100 percent; it exceeds 75 percent for Spain and 50 percent for both Greece and Portugal. As a share of total debt securities, Greek MFIs have seen a sharp increase since 2019.

Figure 1: Domestic Sovereign Debt Holdings of MFIs



Notes: ECB Statistical Data Portal.

The fiscal response to the pandemic has amplified current trends. This foretells increases in sovereign debt issuance, which — if current trends hold — will result in domestic sovereign debt encompassing an even greater share of the portfolios of MFIs.

One plausible explanation for this home bias is Article 89(1)(d) of the Capital Requirements Directive of the European Banking Authority, which permits European banks to assign a zero risk weight (ZRW) to bank exposures to sovereign debt issued by EU member states. Even sovereign debt from countries in relatively poor fiscal health is assigned a ZRW grade when calculating capital reserve requirements for the banking sector. The ZRW policy is implemented across many advanced economies in Europe and beyond.

The purpose of our paper is to assess the implications of a ZRW policy in a quantitative dynamic stochastic general equilibrium (DSGE) model. Our paper examines this issue from three vantage points. First, we study how financial regulation can correct misallocations and how banks respond to changes in risk weights. We show how a ZRW policy amplifies misallocations, although market-based risk weights improve allocations and can nearly attain the first-best allocations. Second, we analyze the quantitative consequences of financial regulations for the economy. When the ZRW policy is implemented, the recovery from disaster shocks – which can be interpreted as a financial crisis or an economic downturn due to the COVID-19 pandemic – is slower than in the case in which the risk weights are assigned correctly. Third, we investigate policy interactions and examine the extent to which fiscal policy is effective at mitigating recessions when financial regulation does not achieve first-best allocations. Since many advanced economies increased their fiscal spending in response to the pandemic, this exercise helps to improve our understanding of policy debates. We find that the effectiveness of fiscal policy is negligible when a ZRW policy is implemented, as asset substitutions and misallocations by banks dominate equilibrium outcomes.

Departing from rational expectations, our primary friction introduces inefficiencies due to imperfect information. We assume that the representative household and, by direct extension, the banks (which are managed by the household) are myopic in that they incorrectly assign probabilities to disaster states and future fiscal stress. We justify this assumption by appealing to moral hazard and bad monitoring technology. We assume that banks are overly optimistic with regard to the probability of receiving a bailout from the government. We also assume that disaster states suffer from the "peso problem" in that these states are more difficult to predict. Hence, banks and households misprice or underestimate risks concerning the disaster state. This myopia is then compounded by policy that applies ZRWs to sovereign debt, which pushes banks to over-accumulate sovereign debt relative to private capital. This forces the economy to deviate from first-best allocations.

We study these questions in a tightly calibrated DSGE model that is solved based on a non-linear time-iteration algorithm following Richter et al. (2014). The non-linear solution method allows us to capture more accurately the looming sovereign default risk far away from steady state, to take into account imperfect information, and to capture that banks in some states need to receive deposit insurance to prevent bankruptcy. We present a number of results, such as impulse responses conditional on scenarios of high and low fiscal stress, that benefit from using a non-linear solution method.

We have four primary results. First, the ZRW policy exacerbates deviations from first-best allocations, while non-ZRW policies move the economy much closer to first-best allocations. The ZRW policy causes a substantial distortion that results in nearly 20% less capital in the stochastic steady state (relative to the first-best allocation) and a substantial reduction in welfare. The welfare costs of households under ZRW policies are very large, as households are willing to give up 3.2 percent of their consumption to move to the first-best allocation. The economy with non-ZRWs is much closer to the first-best allocation (giving up 1.2 percent of consumption to move to the first-best allocation). The underlying mechanism works through the bank's balance sheet. Banks over-accumulate sovereign debt under the ZRW policy at the expense of private capital. Second, volatility and higher-order moments are reduced in all variables when the economy moves from the ZRW to the non-ZRW allocation. Volatility is reduced when policy of any sort is implemented because even the ZRW policy, whilst imposing a ZRW on government bonds, forces banks to hold equity against risky capital. These reserve holdings serve to mitigate the fluctuations because when a disaster state occurs banks have retained earnings to fall back on. Third, following a disaster shock, misallocations are much larger and more persistent under the ZRW policy vis-à-vis the non-ZRW policy due to a negative feedback loop. Since the government needs to provide deposit insurance to help banks after the disaster shocks, the probability of sovereign default increases. Rising sovereign debt worsens the banking sector's balance sheet through declining sovereign prices, which also causes increases in deposit insurance and reduces bank loans. This negative feedback loop leads to persistently slower recovery times from disaster shocks. Finally, fiscal stress amplifies all of our findings. The negative feedback loop is extremely sensitive to the sovereign's fiscal position. The extent to which a ZRW policy leads banks to misprice sovereign debt increases as fiscal positions deteriorate, which further distorts the allocations of the banks' balance sheet.

1.1 CONTACTS WITH THE LITERATURE

The extent to which the sovereign-debt bias translates into misallocations in the real economy is an increasingly important topic. A majority of the recent literature [e.g., Farhi and Tirole (2018), Brunnermeier et al. (2016)] refers to the interaction between sovereigns and the financial sector as a "diabolic loop" and "deadly embrace". Brunnermeier et al. (2016) claim that this interaction is the hallmark of the 2009-12 sovereign debt crisis in the periphery of the euro area. The literature has focused almost exclusively on determining the mechanisms through which sovereigns and the banking sector interact. These papers are concerned with the extent to which this interaction is a net positive or net negative one, with an overwhelming majority coming down on the side of the latter.

Our paper is closest in spirit and approach to Abad (2019), Aoki and Sudo (2013), Prestipino (2014), Nguyen (2015), Boz et al. (2014), Bocola (2016), Bi et al. (2015), Coimbra (2020), Sosa-Padilla (2018), Donadelli et al. (2019), and Darracq-Paries et al. (2016).[1]

Very few papers have examined the efficacy of a ZRW policy for macroeconomic aggregates through the lenses of a DSGE model. Abad (2019) calibrates a small-open economy RBC model to Spanish data with a different banking friction to ours and with a fiscal limit. Reassuringly, in line with our findings, he shows that introducing risk weights is welfare-improving. Our banking sector differs in important aspects, amongst these the information friction that endogenously determines the banks' portfolio decision and leads to overborrowing of government bonds. Furthermore, our analysis focuses on tail risk and the effect of financial regulation on higher moments. Donadelli et al. (2019) employ a linearized RBC model with a penalty function to model the regulatory constraint. Their focus is on the long-run effects of financial regulation. They find that risk weights on sovereign debt stabilize the macroeconomy in the long run.

Aoki and Sudo (2013) focus on the increased holding of sovereign debt by Japanese banks throughout the 1990s and 2000s. They first empirically document that private loans declined as banks increased their sovereign debt holdings. They find that imposing a value-at-risk constraint as in Adrian and Shin (2010), which requires banks to repay future commitments in all states of the world, leads to a rebalancing towards government debt. Banks lend less to the private sector, which dampens both output and inflation. One caveat of their results is that, while they have a rich financial sector, their model is linearized. This severely limits the ability of the model to assess the true risks associated with sovereign defaults, which are inherently nonlinear.

Prestipino (2014), Bocola (2016), Bi et al. (2015), and Coimbra (2020) incorporate the agency friction of Gertler and Karadi (2011) into a real business cycle model. Prestipino (2014) abstracts from bank holdings of sovereign debt, which is central to this paper, and examines alternative fiscal policies, such as bank bailouts and credit market interventions. Below, we argue that the efficacy of various policies depends critically on the fiscal health of the government.

[1] den Heuvel (2008) is one of the first papers to examine the welfare cost associated with bank capital requirements in a general equilibrium framework. He finds that the costs associated with capital requirements (reduction in liquidity services provided by the banking sector) outweigh the benefits (reduction in moral hazard problem associated with deposit insurance), which leads to a welfare cost of between 0.1% and 1% of permanent consumption. Taking into account the liquidity service provided by safe bank assets, Begenau (2020) argues that capital requirements have been too low in the United States. If households have sufficient demand for safe assets, an increase in the capital requirement causes a contraction in bank debt, lowering funding costs and increasing loans.

Bocola (2016) estimates the model using Italian bank-level data and convincingly argues that the banks' excessive holding of risky sovereign debt was strongly recessionary. He examines the longer-term refinancing operations (LTROs) implemented by the European Central Bank (ECB) in December 2011 and February 2012, finding that the effectiveness of such interventions is largely state-dependent. At the height of a financial crisis, these policies have significant effects, but the returns diminish significantly as the economy recovers. Bocola (2016) does not study the regulatory policies of interest in this paper.

Coimbra (2020), Bi et al. (2015), Hürtgen and Rühmkorf (2014) and Hürtgen (2021) model fiscal policy along the lines of Davig et al. (2010) and Bi (2012), as opposed to following the strategic default literature pioneered by Eaton and Gersovitz (1981).[2] Hürtgen and Rühmkorf (2014) show that households increase their precautionary savings when the economy approaches its fiscal limit. Hürtgen (2021) estimates the impact of the COVID-19 pandemic on state-dependent fiscal limits for several European countries, showing that fiscal stress increased markedly. Coimbra (2020) argues that one-time interventions — such as the LTROs — have limited effects if fiscal issues are not addressed. An important difference to our model is that he does not include capital and therefore cannot assess the trade-off between bank holdings of capital and sovereign debt. Bi et al. (2015) reinterpret the agency friction of Gertler and Karadi (2011) as a regulatory constraint. They find that the presence of sovereign default, coupled with an increase in bank holdings of sovereign debt, leads to a substantial reduction in capital, even though sovereign default risk by itself has a small impact on the economy. While we also highlight the crowding out of private capital, our paper differs from Bi et al. (2015) in that we focus on assessing a ZRW policy to mitigate these distortions.

Nguyen (2015) introduces a banking sector into the endogenous growth model of Romer (1989). The model contains a form of deposit insurance, which leads to the standard moral hazard problem (i.e., banks finance excessively risky projects) and a role for the regulation of bank capital. He calibrates the model using US data and finds that the higher capital requirement of Basel III yields welfare gains on the order of 1% of lifetime consumption. However, as in Prestipino (2014), Nguyen (2015) does not study the role of sovereign debt on banks' balance sheets.

Boz et al. (2014) and Sosa-Padilla (2018) study strategic sovereign default in a model in which the banking sector holds sovereign debt. A default event implies that the government cannot issue new bonds for a stochastic number of periods. This negatively impacts the assets held by the banks and leads to a credit crunch. Sosa-Padilla (2018) demonstrates that his model is able to replicate aggregate dynamics surrounding the Argentine default crisis, but does not examine

[2] Making default strategic would not qualitatively change the results, as it serves the same purpose, i.e. introducing sovereign default risk.

regulatory policies. In Boz et al. (2014), the banking sector holds loans and sovereign bonds as assets and pays a risk-free rate of return on deposits. The bank can issue equity to offset any shortfall in assets. They calibrate the model using Spanish data and examine alternative capital regulatory requirements (total leverage requirement and a risk-weight policy). They find that increasing the risk weight on sovereign debt and increasing the leverage requirement, consistent with the proposal of Basel III, marginally increases welfare. Anand and Mankart (2020) develop a static model of bank risk-taking with strategic sovereign default risk. In their model a rise in banks holdings of domestic government debt can be a market outcome.

Darracq-Paries et al. (2016) construct a six-region multi-country DSGE model with detailed modeling of the financial sector. They focus on Germany, France, Italy, Spain, and the rest of euro area. They argue that the adverse interactions between sovereigns and the banking sector can account for a majority of the poor performance of the euro area following the initial economic shock. Like Aoki and Sudo (2013), Darracq-Paries et al. (2016) linearize the economy around a deterministic steady state, which may omit important non-linear dynamics of sovereign default.

Several recent papers provide empirical support in favor of the crowding-out hypothesis (i.e. that sovereign debt crowds out private capital). De Marco (2019) shows that banks that were more exposed to sovereign debt tightened credit supply by more than banks that were less exposed. This happens through both credit quantities and prices, even when controlling for several factors. Small firms are most negatively impacted, even in countries that are not under sovereign stress. Düll et al. (2017) show that exposure is not limited to banks. They focus on insurance company holdings of sovereign debt and conclude that domestic sovereign risk significantly increases insurer risk. This risk is not as large as that faced by the banking sector, but is substantially larger than for non-financial corporation. Examining bank-level panel data for German banks, Buch et al. (2016) find substantial heterogeneity in asset holdings across banks. A majority of sovereign bonds are held by banks that are larger and less well-capitalized. Banks that hold a significant amount of liquid assets tend to have disproportionate holdings of German bonds. They conclude that there is "limited evidence for the impact of sovereign bond holdings on bank risk, measured through the banks' z-score." Kirschenmann et al. (2020) provide empirical evidence showing that the ZRW exemption for European sovereign debt amplifies the co-movement between sovereign CDS spreads and facilitates cross-border crisis spillovers.

We introduce inefficiencies through incomplete information in that households and banks misinterpret the probability associated with the disaster state. Recent papers argue that this assumption is a simpler way of analyzing the macroeconomic consequences of bounded rationality. For example, Farhi and Gabaix (2020) and Gabaix (2020) develop a behavioral macroeconomic DSGE model and find many consequences for aggregate outcomes of monetary and fiscal policy. We extend the literature in two ways. First, we introduce these behavioral factors into a model that includes a banking sector and study its implications for bank behavior. Second, we examine the effects of macroprudential policy and fiscal policy. We analyze how macroprudential policy can mitigate or exacerbate misallocations due to behavioral biases.

2 MODEL

This section outlines a real business cycle model extended with a banking sector, financial regulation, a fiscal sector with default risk and imperfect information whereby banks do not take into account disaster risk and fiscal stress. The model is solved globally using the time iteration method discussed in Richter et al. (2014). A complete description of the equilibrium conditions and the solution method is provided in Appendices A-C.

2.1 FIRMS Factor and product markets are perfectly competitive. Aggregate output (Y_t) is produced with a Cobb-Douglas technology, $Y_t = F(z_t, K_{t-1}, L_t) = z_t\left((1-\xi_t)K_{t-1}\right)^{\alpha} L_t^{1-\alpha}$, using the pre-determined capital stock K_{t-1} and labor L_t as inputs. The capital share is $\alpha \in [0,1]$ and the aggregate technology shock z_t can take on four values:

$$z_t = \begin{cases} \mathcal{Z}^H & \text{with } p^H \\ \mathcal{Z}^M & \text{with } p^M \\ \mathcal{Z}^L & \text{with } 1-p^H-p^M-p^D \\ \mathcal{Z}^D & \text{with } p^D\,, \end{cases} \tag{1}$$

with corresponding probabilities p^j $j \in \{H, M, L, D\}$ and where D is the disaster state. When the disaster shock hits the economy, a fraction ξ_t of capital is destroyed, as in Gourio (2012). Similarly, Gertler et al. (2012) and Akinci and Queralto (2022) also use capital quality shocks to simulate an economic downturn.

Profit maximization delivers the rental rate of capital (R_t^k) and the wage rate (W_t) as

$$R_t^k = z_t \alpha \left(\frac{(1-\xi_t)K_{t-1}}{L_t}\right)^{\alpha-1}, \tag{2}$$

$$W_t = z_t(1-\alpha)\left(\frac{(1-\xi_t)K_{t-1}}{L_t}\right)^{\alpha}. \tag{3}$$

2.2 HOUSEHOLDS Household preferences are given by a utility function with constant relative risk aversion

$$u(C_t, L_t) = \frac{c_t^{1-\sigma} - 1}{1-\sigma} - \chi \frac{L_t^{1+\eta}}{1+\eta} ,$$

where C_t denotes consumption, $\beta \in (0,1)$ is the discount factor, σ^{-1} is the intertemporal elasticity of substitution, and η^{-1} is the Frisch elasticity of labor supply. Households maximize lifetime utility subject to a budget constraint given by

$$C_t + \tau_t + D_t + E_t = W_t L_t + R_t^D D_{t-1} + R_t^E E_{t-1} ,$$

where τ_t is lump-sum taxes, D_t is bank deposits with return R_t^D and E_t is bank equity with return R_t^E. As we discuss in more detail below, households assume that bank deposits are risk-free, while bank equity has an uncertain return. Given the various shocks in the model, both assets are held in equilibrium.

2.3 FINANCIAL INTERMEDIATION Following Arellano et al. (2024) and Coimbra and Rey (2023), banks last for two periods. Initially, equity (E_t) is injected by households as start-up funds, while banks also collect deposits (D_t). Based on these funds, banks invest in loans to firms (K_t) and into a portfolio of long-term government bonds (B_t), which sells at price Q_t^B at time t. The government bond portfolio is composed of perpetuities with coupons that decay exponentially (see Eusepi and Preston, 2018; Leeper and Zhou, 2021). A government bond that is issued at time t pays π^{j-1} units of consumption at time $t+j$, for $j \geq 1$. The coupon decay factor $\pi \in [0,1]$ determines the average maturity of the debt portfolio. The duration of the long-term debt portfolio is $(1-\beta\pi)^{-1}$.

The balance sheet of bankers at the end of period t is

$$D_t + E_t = K_t + Q_t^B B_t = T_t , \tag{4}$$

with liabilities consisting of deposits and equity, and assets consisting of capital and bond holdings. Let T_t denote the total size of the balance sheet.

We assume bankers (and thereby households) are mildly "myopic" in that they incorrectly assign a probability of zero to the disaster state. An alternative interpretation is that bankers expect full deposit insurance from the from the Federal Government in the event of the disaster state. We justify this assumption by appealing to moral hazard (i.e. banks behave as if a bailout from the government is forthcoming in the disaster state) and bad monitoring technology (i.e. disaster states suffer from the "peso problem" in that these states are more difficult to predict).

Specifically, the households and bankers assign $p^D = 0$ and reallocate this probability to the low state, $p^L = 1 + p^D - p^H - p^M$. As explained below, this myopia is compounded by policy that applies ZRWs to sovereign debt, which pushes banks to over-accumulate sovereign debt relative to private capital, a misallocation and deviation from first-best.

The myopic behavior of bankers implies that they collect "risk-free" deposits so that the return is equal to the return on assets in the "low" state ($\mathcal{Z}^L$) instead of the "disaster" state ($\mathcal{Z}^D$). This implies that bankers misprice returns on capital and returns on government bonds, as shown in equation (5). Specifically, bankers collect deposits D_t to satisfy

$$\begin{aligned} R^D_{t+1} D_t &= K_t R^k_{t+1}(\mathcal{Z}^L) + B_t\left(1 + \pi Q^B_{t+1}(\mathcal{Z}^L)\right) \\ &= K_t R^k_{t+1}(\mathcal{Z}^L) + Q^B_t B_t \frac{1 + \pi Q^B_{t+1}(\mathcal{Z}^L)}{Q^B_t}, \end{aligned} \tag{5}$$

where $R^k_{t+1}(\mathcal{Z}^L) = \alpha \mathcal{Z}^L K_t^{\alpha-1} L_{t+1}^{1-\alpha}(\mathcal{Z}^L) + 1 - \delta$ represents the return on capital in the "low" state, and $Q^B_{t+1}(\mathcal{Z}^L)$ implies the price of government debts in the "low" state. To better understand this friction, suppose that banks set the guaranteed return on deposits to the disaster state instead of the low state. This is the natural debt limit of the bank (Acemoglu, 2008) and the expected difference between the return on deposits and the return on assets $\mathbb{E}_t(R^D_{t+1} D_t - (K_t R^k_{t+1} + B_t(1 + \pi Q^B_{t+1})))$ is equity. Because the bank optimizes asset holdings (i.e. sets the return on sovereign bonds equal to the return on capital), bank equity and deposits would replicate the first-best allocation or the allocation in which the banking sector allocates capital efficiently. In other words, the returns on deposits and bank equity would span the same space as the returns on sovereign bonds and capital, and the financial sector would be redundant.

When a disaster state occurs, banks must rely on deposit insurance and other regulatory sources of funds to meet their obligations. In addition, because sovereign default occurs almost always in disaster states, banks incorrectly assume that the government will not default on its debt. Hence, myopic households and bankers misprice the return on capital *and* the return on government bonds.

Bankers solve an asset allocation problem by choosing the optimal portfolio weight (ω_t) on each asset class (capital vs. sovereign debt),

$$V^*_{t+1} = \max_{\omega_t} \quad T_t \left[\mathbb{E}_t m_{t,t+1} \left(\omega_t (1 - \xi_{t+1}) R^k_{t+1} + (1 - \omega_t) \frac{(1 - \Delta_{t+1})(1 + \pi Q^B_{t+1})}{Q^B_t} - \zeta_t R^D_{t+1} \right) \right],$$

where $m_{t,t+1}$ represents the stochastic discount factor of households, $\omega_t = \frac{K_t}{T_t}$ is the capital share of the bank's total assets, and $\zeta_t = \frac{D_t}{T_t}$ is the deposit share of the bank's total assets. The first-order condition with respect to ω_t yields

$$\mathbb{E}_t\left[m_{t,t+1}(1-\xi_{t+1})R^k_{t+1}\right] = \mathbb{E}_t\left[m_{t,t+1}\frac{(1-\Delta_{t+1})(1+\pi Q^B_{t+1})}{Q^B_t}\right], \tag{6}$$

which gives the standard allocation that aligns expected returns across assets. Note that myopic mispricing factors can be interpreted as wedges distorting asset allocations of banks, an interpretation that we operationalize below.

Given an optimal value of ω_t, as in Gertler et al. (2012), the bank's equity value R^E_{t+1} can be defined as $R^E_{t+1} = V^*_{t+1}/E_t$, where $E_t = \mathbb{E}_t\left[m_{t,t+1}V^*_{t+1}\right]$. This condition determines equity injected to myopic bankers at time t, which implies that the equity value is equal to the expected discounted value of dividends (profits). Hence, this equation and equation (5) determine the liability side of the banks' balance sheet (the left-hand side of equation (4)). With respect to the asset side of the banks' balance sheet (the right-hand side of equation (4)), banks choose their optimal portfolio in equilibrium, based on equation (6).

2.4 GOVERNMENT The government finances unproductive spending (G_t) and deposit insurance (DIN_t) through lump-sum taxes (τ_t) and by issuing long-term debt (B_t). Deposit insurance is applicable when financial intermediaries cannot repay deposits in disaster states. Let Q^B_t be the price of debt in terms of time-t consumption units and π is a decay factor. A unit of bond is a promise to pay π units of consumption next period. The government may partially default on this promise and repay only a fraction $1-\Delta_t$ of the promised consumption. Therefore, the flow government budget constraint is given by

$$\tau_t + Q^B_t B_t = (1+\pi Q^B_t)(1-\Delta_t)B_{t-1} + G_t + DIN_t + cost_t\,. \tag{7}$$

Note that the term $cost_t$ captures real deposit issuance costs, such as management costs, social and political costs, or costs of collecting additionally taxes for deposit issuance. We assume that this cost is directly proportional to the amount of deposit insurance: $cost_t = \phi DIN_t$.

Following Bi (2012), we assume that government debt default depends upon the fiscal limit (s^*_t) of the economy. The fiscal limit is an increasing function of the debt-to-GDP ratio and is randomly drawn from an exogenous distribution $\mathscr{S}^*$. Following Davig et al. (2010), we assume that the probability of hitting the fiscal limit (P_t) is determined by a logistic function of the debt-to-GDP ratio s_{t-1}:

$$P_t = P(s_{t-1} \geq s^*_t) = \frac{\exp(\nu_1 + \nu_2 s_{t-1})}{1+\exp(\nu_1+\nu_2 s_{t-1})}\,.$$

The shape of the cumulative density function of the fiscal limit distribution is uniquely determined by the parameters ν_1 and ν_2. These two parameters provide sufficient flexibility in calibrating the fiscal limit for different countries or economies and accurately capture the non-linear interaction between sovereign debt and default risk.

When the economy reaches its fiscal limit, the government will default with probability one. The default scheme is defined as

$$\Delta_t = \begin{cases} 0 & s_{t-1} < s_t^* \\ \bar{\delta} & s_{t-1} \geq s_t^* \end{cases}$$

where $\bar{\delta}$ is the default rate. Lump-sum taxes are assumed to respond to debt, $\tau_t = \tau + \gamma^\tau((1-\Delta_t)B_{t-1} - B)$, while government spending remains constant at its steady state.

It is important to note that the banking sector cannot confiscate assets or cease operations. We do not take into account the possibility of bank runs. Our banking sector does not need a substantial government bailout at any time — even during "disaster" state realizations, when the bank must be compensated for the difference between the "disaster" and the "low" state, the bailout is not very large. Nonetheless, as we show below, the macroeconomic consequences can be substantial.

2.5 Financial Regulation

The key feature of our model is that the economy exhibits misallocations due to myopic behavior by households and banks. The objective of financial regulation is to mitigate the distortions caused by myopic households and banks in a way that improves welfare. We use our model to assess regulation policies that resolve these misallocations due to myopia. Our focus is on risk-weight policies and, in particular, the ZRW policy that is commonplace in developed economies and becoming more prevalent in developing economies. The financial regulator requires myopic banks to hold retained earnings (RE_t) equal to or greater than risk-weighted assets

$$RE_t = \tilde{\xi}\left[\tilde{a}^K K_t + \tilde{a}^B Q_t^B B_t\right], \tag{8}$$

where $\tilde{a}^K$ and $\tilde{a}^B$ represent risk weights for capital and government bonds, respectively. Equation (8) implies that banks need to retain $\tilde{\xi}$ of risk-weighted assets as earnings at the beginning of $t+1$. Let $\tilde{\xi}\tilde{a}^K = a^K$ and $\tilde{\xi}\tilde{a}^B = a^B$. Then, equation (5) becomes

$$R_{t+1}^D D_t = K_t\left(R_{t+1}^k(\mathcal{Z}^L) - a^K\right) + Q_t^B B_t\left(\frac{1 + \pi Q_{t+1}^B(\mathcal{Z}^L)}{Q_t^B} - a^B\right) \tag{9}$$

and the banker's optimization problem becomes

$$\max_{\omega_t} \quad T_t \left[\mathbb{E}_t m_{t,t+1} \left(\omega_t \left((1-\xi_{t+1}) R^k_{t+1} - a^K \right) + (1-\omega_t) \left(\frac{(1-\Delta_{t+1})(1+\pi Q^B_{t+1})}{Q^B_t} - a^B \right) - \zeta_t R^D_{t+1} \right) \right] ,$$

with Euler equation

$$\mathbb{E}_t \left[m_{t,t+1} \left((1-\xi_{t+1}) R^k_{t+1} - a^K \right) \right] = \mathbb{E}_t \left[m_{t,t+1} \left(\frac{(1-\Delta_{t+1})(1+\pi Q^B_{t+1})}{Q^B_t} - a^B \right) \right] . \tag{10}$$

The myopic behavior of banks leads to an improper assessment of risk. In the disaster state, the return on assets is insufficient to cover "guaranteed" deposits. We therefore ask: Can a government introduce risk weights on assets to move towards the first-best allocation? To what extent does a ZRW on sovereign debt worsen asset allocations? Does the extent to which the ZRW policy leads to misallocations depend on fiscal stress? Our nonlinear solution methodology allows us to address these questions via the welfare criterion and state-dependent impulse response functions. While we report other statistics (e.g. impulse response functions), the welfare of households is our object of interest.

2.6 CALIBRATION The model is calibrated at quarterly frequency. Table 1 lists the target values and the parameter values under the benchmark calibration. Many of our calibrated parameters come directly from Bi et al. (2013), who estimate a similar model using Bayesian methods and EU-14 data. Their model is similar to ours, but does not include a banking sector. They were interested in estimating fiscal limits in European economies and thus excluded the financial sector. Moreover, their estimation allowed for non-linear behavior, similar to our solution procedure. Given the overlap in both model structures and solution methods, using their estimated values serves to discipline our model parameters.

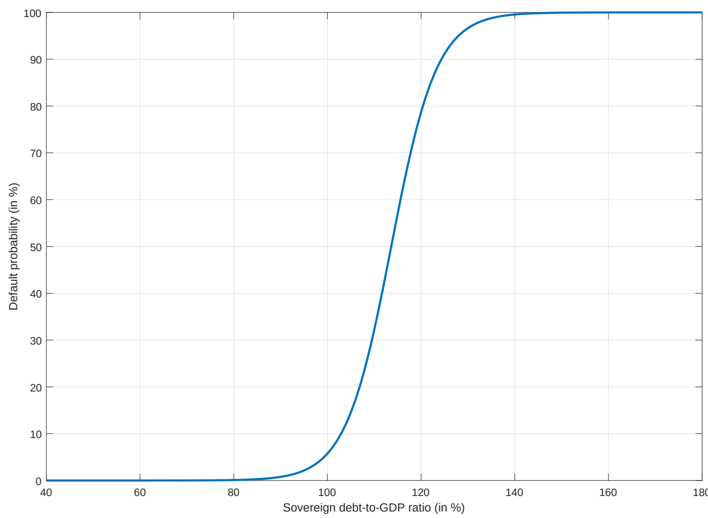
Turning to the calibration of financial regulation, banks are required to hold 3 percent of their risk-weighted assets in the form of retained earnings. We set the risk weight on capital to 40 percent and the risk weight on government debt to 0 percent (ZRW policy). We also present results for positive risk weights ranging from 0 to 50 percent. Furthermore, we set the annual debt-to-GDP ratio to 80 percent, deposit insurance costs to 0.9, and disutility of labor is fixed implying that households work 25 percent of their time.

Table 1: Parameterization

	Targeted Values	
$G/Y = 0.21$	Gov. spending/output	Bi et al. (2013)
$Q^B B/(4Y) = 0.8$	Gov. debt/output (annual)	Bi et al. (2013)
$\chi = 19.3166$	Steady state labor $\bar{L} = 0.25$	Bi et al. (2013)
	Calibrated Parameters	
β	Discount factor	0.99
δ	Depreciation rate for capital	0.025
α	Capital share	0.33
σ	Risk aversion	1
η	Inverse Frisch elasticity	1
γ_τ	Elasticity of government debt (tax rule)	0.5
$\bar{\delta}$	Haircut on government debt	0.035
ν_1	Determines default probability	−23.342
ν_2	Determines default probability	20.542
ϕ	Deposit insurance cost	0.9
$\mathcal{Z}^H$	Technology, good state	1.01
$\mathcal{Z}^M$	Technology, fair state	1.00
$\mathcal{Z}^L$	Technology, low state	0.99
$\mathcal{Z}^D$	Technology, disaster state	0.97
ξ	Capital quality disaster shock	0.02
π	Maturity of government debt	0.955
p^H	Prob. of good state	0.27
p^M	Prob. of fair state	0.4
p^L	Prob. of low state	0.27
p^D	Prob. of disaster state	0.06
$p^{*,H}$	Prob. of good state (myopic)	0.27
$p^{*,M}$	Prob. of fair state (myopic)	0.4
$p^{*,L}$	Prob. of low state (myopic)	0.33
$p^{*,D}$	Prob. of disaster state (myopic)	0
$\tilde{\xi}$	Capital requirement	0.03
$\tilde{a}^K$	Risk weight on capital	0 or 0.4
$\tilde{a}^B$	Risk weight on government debt	0 or 0.4

Our calibration implies that the probability of hitting the fiscal limit is negligible when the debt-to-GDP ratio is around its steady state of 80 percent. However, further away from steady state, the default probability rises. Thus, as we show below, an adverse sequence of shocks can bring the economy into an environment of high fiscal stress. In the first-best allocation, banks will demand higher risk premia on government bonds as the likelihood of default increases. In contrast, myopic banks ignore the possible risk of a government default, which can also be rationalized by the deposit insurance that is in place. Fiscal stress and the possibility of sovereign default manifest far away from steady and we capture this non-linearities more accurately using a global solution method.

Figure 2: Default Probability



2.7 POLICY SCENARIOS AND SOLUTION METHOD We examine three scenarios:

1. **First-best allocation:** In the first-best allocation, households and banks take the disaster state into consideration. Banks set guaranteed deposit rates at the disaster-state level. Households and banks formulate expectations correctly. Policy, in this environment, is not needed ($\tilde{a}^K = \tilde{a}^B = 0$). This is our benchmark.

2. **Non-ZRW:** Agents are myopic and a non-ZRW regulation is imposed ($\tilde{a}^B = 0.4$, $\tilde{a}^K = 0.4$). Households and banks ignore the possibility of the disaster state and the probability of government default.

3. **ZRW:** Agents are myopic and a ZRW regulation on sovereign debt ($\tilde{a}^B = 0$) is imposed, while the risk weight on capital remains at $\tilde{a}^K = 0.4$. Households and banks ignore the possibility of the disaster state and the probability of government default.

The model is solved using a global solution method and time iteration algorithm described in Richter et al. (2014). This method discretizes the state space and iteratively solves for updated policy functions until a tolerance ($\epsilon = 10^{-8}$) is met.[3] Linear interpolation is used to approximate future variables. The fully non-linear solution method allows us to accurately capture any non-linearities in the policy functions that may, for example, arise from fiscal stress, the banking sector or myopic expectation formation. A detailed description of the solution routine is laid out in Appendix C.[4]

[3]Reassuringly, we confirm that the Euler equation errors in base 10 logarithms are small across all four model scenarios. The median Euler equation errors are all between -5.3 and -4.2.

[4]We solve the model on 37,800 grid points each, often requiring more than 1,000 iterations. We used Amazon's Cloud service with 64 physical CPU cores and a run-time of roughly 50 minutes for each of the four cases.

3 Interaction of financial regulation and myopic expectations

In this section, we show how banks that do not internalize the disaster state create distortions compared to the first-best allocation. We illustrate how financial regulation using risk weights on capital and bonds can mitigate these distortions.

The model allows for the inclusion of the negative loop as described in Acharya et al. (2014) and many others in this literature. Banks misprice sovereign debt, which leads to over-accumulation relative to private capital. A ZRW policy serves only to *amplify* this over-accumulation. Because of the ZRW policy, this reallocation of the banks' portfolio constitutes an apparent shift in risk by under-capitalized banks. The sovereign debt may be increasingly risky, but the regulatory regime erroneously assumes that the sovereign debt buttresses the banking sector's balance sheet. The build up of sovereign debt risk on the banks' balance sheet crowds out other assets (e.g. loans to firms), leading to inefficient capital allocation and economic stagnation. Declining sovereign debt prices worsen the profitability of banks, which also reduces loans to firms. The weakened fiscal position and the spillover into the banking sector therefore makes the economy more susceptible to shocks.

Before turning to our numerical analysis, we inspect the channel through which financial regulation changes banks' behavior and (potentially) corrects the misallocations due to myopic behavioral biases of banks and households. Changes in retained earnings via the risk weight on capital ($\tilde{a}^K$) and risk weight on bonds ($\tilde{a}^B$) will impact the economy in both direct and indirect ways, a point which we now demonstrate.

3.1 Balance Sheet Misallocations: Assets

Let us first consider the asset side of the banks' balance sheet. Note that the first-best allocation replaces the myopic expectation operator with rational expectations. In order to make this explicit, in this section only, we use $\mathbb{E}_t^M$, M for "myopic" and $\mathbb{E}_t^R$, R for "rational". The first-best allocation sets the Euler equation as

$$\mathbb{E}_t^R\left[m_{t,t+1}(1-\xi_{t+1})R_{t+1}^k\right] = \mathbb{E}_t^R\left[m_{t,t+1}\frac{(1-\Delta_{t+1})(1+\pi Q_{t+1}^B)}{Q_t^B}\right]. \tag{11}$$

Here, the banker correctly internalizes the disaster state and the possibility of sovereign default. In contrast, myopic bankers equalize returns

$$\mathbb{E}_t^M\left[m_{t,t+1}(1-\xi_{t+1})R_{t+1}^k\right] = \mathbb{E}_t^M\left[m_{t,t+1}\frac{(1-\Delta_{t+1})(1+\pi Q_{t+1}^B)}{Q_t^B}\right], \tag{12}$$

where they internalize neither the disaster state nor the probability of sovereign default.

To clarify intuition, we define wedges τ_{t+1}^K and τ_{t+1}^B. These wedges capture myopic behavioral biases as follows

$$\mathbb{E}_t^M\left[m_{t,t+1}(1-\xi_{t+1})R_{t+1}^k\right] = (1+\tau_{t+1}^K)\mathbb{E}_t^R\left[m_{t,t+1}(1-\xi_{t+1})R_{t+1}^k\right],$$

$$\mathbb{E}_t^M\left[m_{t,t+1}\frac{(1-\Delta_{t+1})[1+\pi Q_{t+1}^B]}{Q_t^B}\right] = (1+\tau_{t+1}^B)\mathbb{E}_t^R\left[m_{t,t+1}\frac{(1-\Delta_{t+1})(1+\pi Q_{t+1}^B)}{Q_t^B}\right].$$

We can interpret τ_{t+1}^K and τ_{t+1}^B as equilibrium behavioral parameters, where first-best allocations assign $\tau_{t+1}^K = \tau_{t+1}^B = 0$, but the behavioral model generates τ_{t+1}^K and τ_{t+1}^B different from zero. These wedges distort the bank asset allocations and thus have adverse consequences for macroeconomic dynamics, which motivates financial regulation to correct these misallocations.

Mathematically, we can decompose these distortions through a covariance decomposition, noting that equation (12) implies

$$(1+\tau_{t+1}^K)\mathbb{E}_t^R\left[m_{t,t+1}(1-\xi_{t+1})R_{t+1}^k\right] = (1+\tau_{t+1}^B)\mathbb{E}_t^R\left[m_{t,t+1}\frac{(1-\Delta_{t+1})(1+\pi Q_{t+1}^B)}{Q_t^B}\right], \tag{13}$$

which becomes

$$\underbrace{\mathbb{E}_t^R\left[(1-\xi_{t+1})R_{t+1}^k - \frac{(1-\Delta_{t+1})[1+\pi Q_{t+1}^B]}{Q_t^B}\right]}_{\text{Expected excess return}} =$$

$$\underbrace{-Cov\left(\frac{m_{t,t+1}}{\mathbb{E}_t m_{t,t+1}},(1-\xi_{t+1})R_{t+1}^k\right) + Cov\left(\frac{m_{t,t+1}}{\mathbb{E}_t m_{t,t+1}},\frac{(1-\Delta_{t+1})[1+\pi Q_{t+1}^B]}{Q_t^B}\right)}_{\text{Risk adjustment}}$$

$$\underbrace{-\tau_{t+1}^K\mathbb{E}_t^R(1-\xi_{t+1})R_{t+1}^k}_{\text{Misperception wedge on expected return on capital}} + \underbrace{\tau_{t+1}^B\mathbb{E}_t^R\frac{(1-\Delta_{t+1})(1+\pi Q_{t+1}^B)}{Q_t^B}}_{\text{Misperception wedge on expected return on debt}}$$

$$\underbrace{-\tau_{t+1}^K Cov\left(\frac{m_{t,t+1}}{\mathbb{E}_t^R m_{t,t+1}},(1-\xi_{t+1})R_{t+1}^k\right)}_{\text{Mis-risk-adjustment wedge on capital}} + \underbrace{\tau_{t+1}^B Cov\left(\frac{m_{t,t+1}}{\mathbb{E}_t m_{t,t+1}},\frac{(1-\Delta_{t+1})(1+\pi Q_{t+1}^B)}{Q_t^B}\right)}_{\text{Mis-risk-adjustment wedge on debt}}.$$

The asset-side misallocations of banks enter through the last four terms. The goal of macroprudential policy is to mitigate these misallocations by changing a^K and a^B.

In a model with financial regulation and myopic expectations, banks determine the optimal portfolio shares as follows:

$$\mathbb{E}_t^M\left[m_{t,t+1}\left((1-\xi_{t+1})R_{t+1}^k - a^K\right)\right] = \mathbb{E}_t^M\left[m_{t,t+1}\left(\frac{(1-\Delta_{t+1})(1+\pi Q_{t+1}^B)}{Q_t^B} - a^B\right)\right].$$

As is clear from this condition, changes in a^K can affect returns on capital $(1-\xi_{t+1})R_{t+1}^k - a^K$. Through changes in a^B, financial regulation can also change the return on sovereign debt $\frac{(1-\Delta_{t+1})(1+\pi Q_{t+1}^B)}{Q_t^B} - a^B$. Intuitively, if a^K and a^B are correctly assigned, financial regulation can *directly* correct the expected return on assets, which mitigates the misallocation on the *asset* side of the banks' portfolio.

3.2 Balance Sheet Misallocations: Liabilities

In addition to the asset side of the banks' balance sheet, the liability side is also affected by myopic expectations. These misallocations can also be mitigated by changes in a^K and a^B *directly*.

The liability side of banks' balance sheet consists of deposits and equity injected. Changes in a^K and a^B correct the liability misallocations in two ways. First, a^K and a^B affect the return on deposits, which corrects leverage and liquidity crunches. Second, changes in a^K and a^B can impact bank profitability, which affects equity issuance and leverage. With respect to deposits, recall that banks, in the first-best allocation, collect deposits so that the guaranteed return is equal to the return on assets in the "disaster" state ($\mathcal{Z}^D$)

$$R_{t+1}^D D_t = K_t R_{t+1}^k(\mathcal{Z}^D) + (1-\Delta_t)Q_t^B B_t \frac{1+\pi Q_{t+1}^B(\mathcal{Z}^D)}{Q_t^B}.$$

Myopic banks collect deposits by replacing the disaster state with the "low" state,

$$R_{t+1}^D D_t = K_t R_{t+1}^k(\mathcal{Z}^L) + Q_t^B B_t \frac{1+\pi Q_{t+1}^B(\mathcal{Z}^L)}{Q_t^B}.$$

As is clear from these conditions, due to myopic behavior by banks, decisions on the extent to which banks finance assets via deposits are distorted.

In addition, since repayments on deposits are distorted, dividends to equity injected by households are also distorted. This affects the amount of equity injected. The financial regulation a^K and a^B can change the guaranteed return as follows:

$$R_{t+1}^D D_t = K_t\left(R_{t+1}^k(\mathcal{Z}^L) - a^K\right) + Q_t^B B_t\left(\frac{1+\pi Q_{t+1}^B(\mathcal{Z}^L)}{Q_t^B} - a^B\right).$$

This means that the guaranteed returns on capital and sovereign debt become $R_{t+1}^k(\mathcal{Z}^L) - a^K$

and $\frac{1+\pi Q^B_{t+1}(\mathcal{I}^L)}{Q^B_t} - a^B$, respectively. This corrects the size of deposits collected by banks, and changes in a^K and a^B can *directly* affect the banks' leverage ratio and liability structure.

In addition to deposits, dividends are also affected by the retained earning constraint. To see this, recall that expected dividends at $t+1$ under myopic expectations are as follows:

$$\mathbb{E}^M_t[V_{t+1}] = \mathbb{E}^M_t\left[\left((1-\xi_{t+1})R^k_{t+1} - a^K\right)K_t + \left(\frac{(1-\Delta_{t+1})[1+\pi Q^B_{t+1}]}{Q^B_t} - a^B\right)Q^B_t B_t - R^D_{t+1}D_t\right].$$

Then, the return on equity in the next period, R^E_{t+1}, can be defined as $\mathbb{E}^M_t[R^E_{t+1}] = \mathbb{E}^M_t\left[\frac{V^*_{t+1}}{E_t}\right]$. Thus, changes in financial regulation a^K and a^B can correct the return on equity.

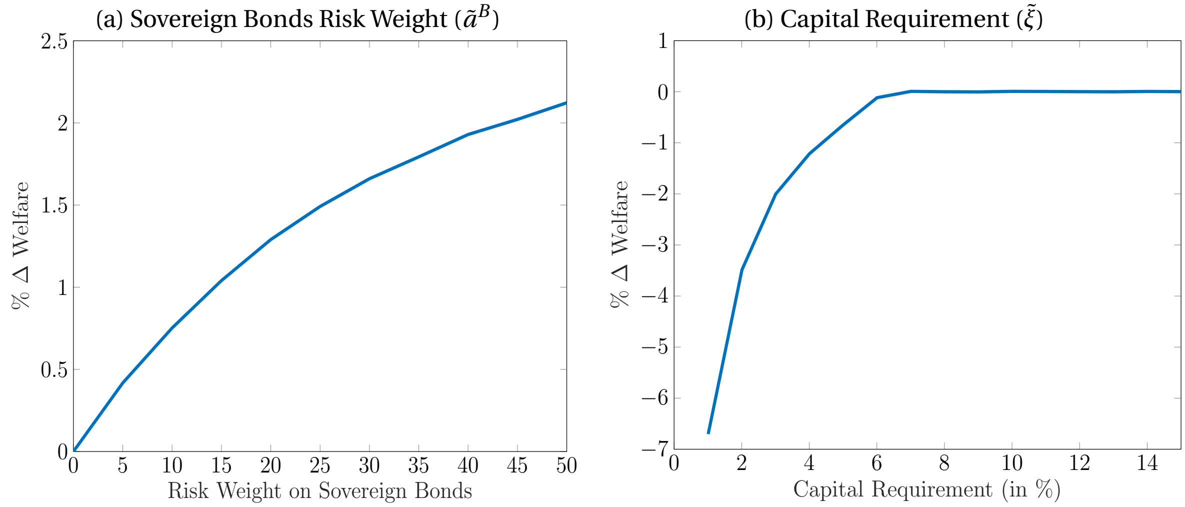
3.3 MISALLOCATION: HOUSEHOLD Finally, changes in the banks' balance sheet through changes in a^K and a^B affect household behavior *indirectly* via the two Euler equations $1 = \mathbb{E}^M_t m_{t,t+1}R^D_{t+1}$ and $1 = \mathbb{E}^M_t m_{t,t+1}R^E_{t+1}$. Changes in returns, R^D_{t+1} and R^E_{t+1}, affect the demand-side of the economy through household allocations. It is important to note that, while financial regulation – the setting of a^K and a^B – can restore first-best allocations when assigned correctly, it can also amplify inefficiencies. We show this to be true when ZRWs are assigned to risky sovereign debt. In what follows, we will examine the extent to which ZRW regulation distorts the economy.

4 RESULTS

This section presents our main results based on numerical simulations of the quantitative model. First, we compare the welfare implications of a ZRW policy to those of a non-ZRW policy. In particular, we show how changes in financial regulation affect these results. Second, we present impulse response functions (IRFs) to disaster shocks for different risk weights. Third, we turn to the long-run moments generated by a ZRW economy and a non-ZRW economy. Fourth, we show the tail distributions of the IRFs, taking into account different initial conditions when the shock hits the economy. Fifth, we show the IRFs in response to disaster shocks conditional on high and low sovereign default risk. Sixth, we conclude with a sensitivity analysis regarding the magnitude of capital destruction in the disaster state.

4.1 WELFARE RESULTS Recall our three policy scenarios: First-best allocation, ZRW economy, and non-ZRW economy. The most natural way assessing these alternative policy regimes is to examine their welfare implications. Following Schmitt-Grohé and Uribe (2005), we report the welfare costs as percentage of consumption equivalents. For example, to compare two different policy regimes, say A and B, we measure how much consumption households are willing to give up under policy regime A to be indifferent between both policy regimes. More precisely, $100\times\lambda^c$ measures the percentage of the consumption stream that agents are willing to forgo

Figure 3: Financial Regulation and Welfare



Notes: Panel (a) plots the change in welfare relative to the baseline ZRW case as the risk weight on bonds increases. Panel (b) plots the percentage change in welfare as the capital requirement percentage increases relative to the baseline non-ZRW case.

under policy regime A in order to be as well off as under policy regime B. Formally, we solve for λ^c in the following set of equations:

$$V_0^B = E_0 \sum_{t=0}^{\infty} \beta^t \left[\log((1-\lambda^c)C_t^A) - \chi \frac{L_t^{A^{1+\eta}}}{1+\eta} \right] \tag{14}$$

$$\lambda^c = 1 - \exp\{(V_0^B - V_0^A)(1-\beta)\}. \tag{15}$$

We simulate each economy for 200,000 periods (after a substantial burn-in period) and compute the absolute level of the value functions (V_0^A and V_0^B) and then solve for λ^c. Our benchmark economy is the first-best, rational expectations equilibrium, where welfare is naturally the highest.

Figure 3 depicts one of our primary findings, showing how financial regulation affects welfare outcomes. In the left-hand panel we solve for the non-ZRW economy for different risk weights on government debt ranging from 0% to 50%, while the other parameters are kept fixed to the baseline calibration. For each new value of sovereign risk weight, we solve the non-linear model and simulate the economy subject to random shocks. We calculate welfare relative to the ZRW economy. Introducing risk weights on sovereign debt ($\tilde{a}^B$) raises welfare by more than 2 percentage points relative to the ZRW economy.[5] Welfare is monotonically increasing in the risk weight. While we do not conduct optimal policy exercises, we show below that a risk weight

[5]Note that a value of 2% in welfare is quite substantial. While less appealing, recall that Lucas (1983) found a welfare cost of business cycles on the order of 0.2% for a similar utility function.

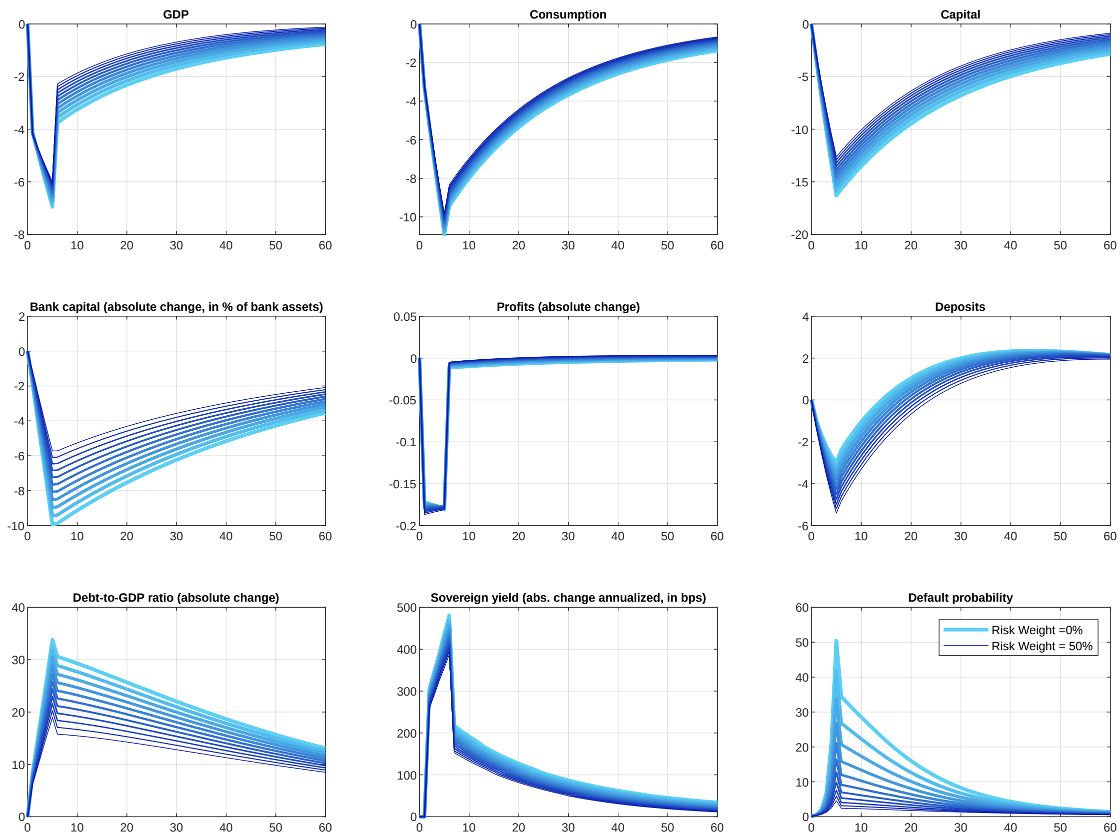
of roughly 50% is consistent with removing the wedge associated with myopic expectations.

The right-hand panel of Figure 3 shows how welfare responds in the non-ZRW economy to changes in the capital requirement or retained earnings of the bank. Welfare in the non-ZRW economy drops dramatically when the capital requirement ($\tilde{\xi}$) is set to a low value. For comparison purposes, a welfare decline of greater than 6.5% is consistent with substantial changes in growth rates in macro aggregates (see Barlevy, 2004); our welfare criteria are on par with changes in growth rates, which suggests a crucial role for regulatory policy in our environment. Welfare gains become negligible relative to the non-ZRW economy at a retained earnings requirement of around 7%. Thus, if retained earnings are high enough, this particular regulation can offset misallocations due to the ZRW on sovereign bonds. Recall that a ZRW policy, whilst imposing a ZRW on government bonds, still forces banks to hold equity against risky capital. These reserve holdings serve to mitigate the fluctuations because, if the disaster state occurs, banks can use the retained earnings (from equation (8)) to offset deposits that were guaranteed assuming (incorrectly) the worst case scenario was a "low" technology shock. The upshot here is that mitigating business cycle dynamics can be partly achieved through ZRW policies, although non-ZRW policies fully achieve this goal while simultaneously improving first-moment allocations. Thus, some macroprudential policy is better than none.

4.2 Impulse responses to disaster shocks

Figure 4 provides a broader view of the economy by plotting the IRFs to a sequence of four disaster shocks for different risk weights ranging from 0% to 50%. In the ZRW economy, capital and output decline to a much greater extent than in the economy with the highest risk weight on sovereign bonds. In addition, banks accumulate more sovereign debt in the ZRW economy, which results in a higher debt-to-GDP ratio, higher sovereign yields, and a 50% probability of default, compared to only a 10% probability of default for the 50% risk weight. With a higher risk weight, fiscal stress and the sovereign-bank nexus are less pronounced. Following a disaster shock, misallocations are much larger and more persistent under the ZRW policy vis-à-vis the non-ZRW policy due to the negative feedback loop. Since the government needs to provide deposit insurance to help banks after the disaster shocks, the probability of sovereign default rises. The sovereign debt worsens the banking sector's balance sheet through declining sovereign prices, which also causes increases in deposit insurance and reduces bank lending. This negative feedback loop leads to persistently slower recovery from disaster shocks. Finally, fiscal stress amplifies all of our findings. The negative feedback loop is very sensitive to the sovereign's fiscal position. The extent to which the ZRW policy leads banks to misprice sovereign debts increases as fiscal positions deteriorate, which further distorts the allocations of the banks' balance sheet.

Figure 4: IRFs to Disaster Shocks: Risk Weights on Sovereign Bonds



Notes: IRFs in percentage deviation from the stochastic steady state in response to a sequence of four disaster shocks for risk weights between 0% and 50% in increments of 5 pp. The default probability is shown in absolute terms.

4.3 LONG-RUN MOMENTS We assess the macroeconomic consequences of a ZRW policy and a non-ZRW policy in the longer run. Table 2 reports various moments of macroeconomic aggregates based on 200,000 simulations as percentage deviations from the first-best allocation. For example, the non-ZRW mean consumption value of -1.15 implies that consumption in the non-ZRW economy is 1.15% lower, on average, than in the rational or first-best economy. We exploit our non-linear solution methodology and examine higher-order moments of the stochastic steady state as well.

Table 2: Aggregates at the Stochastic Steady State (% Dev. from the First-Best Allocation)

	Non-ZRW				Zero-Risk Weight			
	Mean	Std. Dev.	Skewness	Kurtosis	Mean	Std. Dev.	Skewness	Kurtosis
Consumption	-1.15	27.5	-9.3	-6.1	-4.76	48.0	-12.3	-5.3
Capital	-2.92	29.3	2.1	-0.27	-19.1	55.6	-6.4	-0.29
Labor	0.14	10.3	253.0	9.4	-1.57	6.98	320.2	14.2
Output	-0.89	-1.17	-13.7	-7.7	-7.7	-0.49	-64.5	-16.1
Debt/Output	22.3	423.6	-0.51	9.2	33.2	801.6	58.1	24.9
Capital Ratio	-5.91	363.5	-16.8	-4.3	-11.6	681.8	9.4	2.02
Retained Earnings	-51.6	-51.6	-56.6	-11.6	-70.8	-20.0	-40.7	-21.5
Capital Return	-2.1	-24.0	-48.3	-8.5	-14.1	-78.2	-85.7	-19.1
Bond Return	-1.1	-1.2	-11.9	-13.0	-0.7	19.8	-25.6	-27.5
Deposit Return	-0.2	-34.5	0.6	-0.6	-0.2	-58.8	-17.9	-19.5
Default Probability	5.87	8.8	3.7	21.7	25.98	28.7	1.16	3.1

Notes: Table entries are percentage deviations from the first-best allocation based on simulations with 200,000 periods and a 1,000 burn-in period. Debt/Output = $Q^B B/(4Y)$, Capital Ratio = $K/(K+Q^B B)$, and Retained Earnings = $\tilde{\xi}\left[\tilde{a}^K K + \tilde{a}^B Q^B B\right]$. The default probability is reported in absolute terms, not as a deviation from first-best.

Several points are noteworthy: First, capital is substantially (19%) lower and much more volatile (55.6%) in the ZRW economy. In the ZRW economy, banks over-accumulate public debt (a much higher debt-output ratio), crowding out private capital. Conversely, capital is only 3% lower in the non-ZRW economy compared to the first-best allocation. This misallocation of capital leads to a decline in consumption of roughly 5% in the ZRW economy, as opposed to only 1% in the non-ZRW economy. Returns on bonds and capital in the ZRW economy deviate much stronger from first-best compared to in the non-ZRW economy. The ZRW economy has an average default probability of 26%, while the default probability is much lower in the non-ZRW economy (6%). Second, a non-ZRW policy substantially dampens higher-order moments for all macro aggregates, with the exception of labor (and the differences here are quite small). The higher-order moments reveal the extent to which the misallocations in the ZRW economy can increase the likelihood of low probability – and deleterious – outcomes. The debt-output ratio with ZRWs has a substantial standard deviation, skewness, and kurtosis. These misallocations are much larger and more persistent under the ZRW policy vis-à-vis the non-ZRW policy. With respect to the asset side of the banks' balance sheet, the capital-asset ratio is lower for the ZRW economy, though not substantially so. Finally, the skewness and kurtosis of the debt-output ratio speaks to one of the primary differences between these models and is explained, again, by the negative feedback loop. Since the deposit insurance provided by the government following disaster shocks increases the probability of sovereign default, the banking sector's balance sheet is negatively impacted through declining sovereign prices. This is a phenomenon that is clearly driving the default probabilities in Figure 4 and the higher-order moments of Table 2.

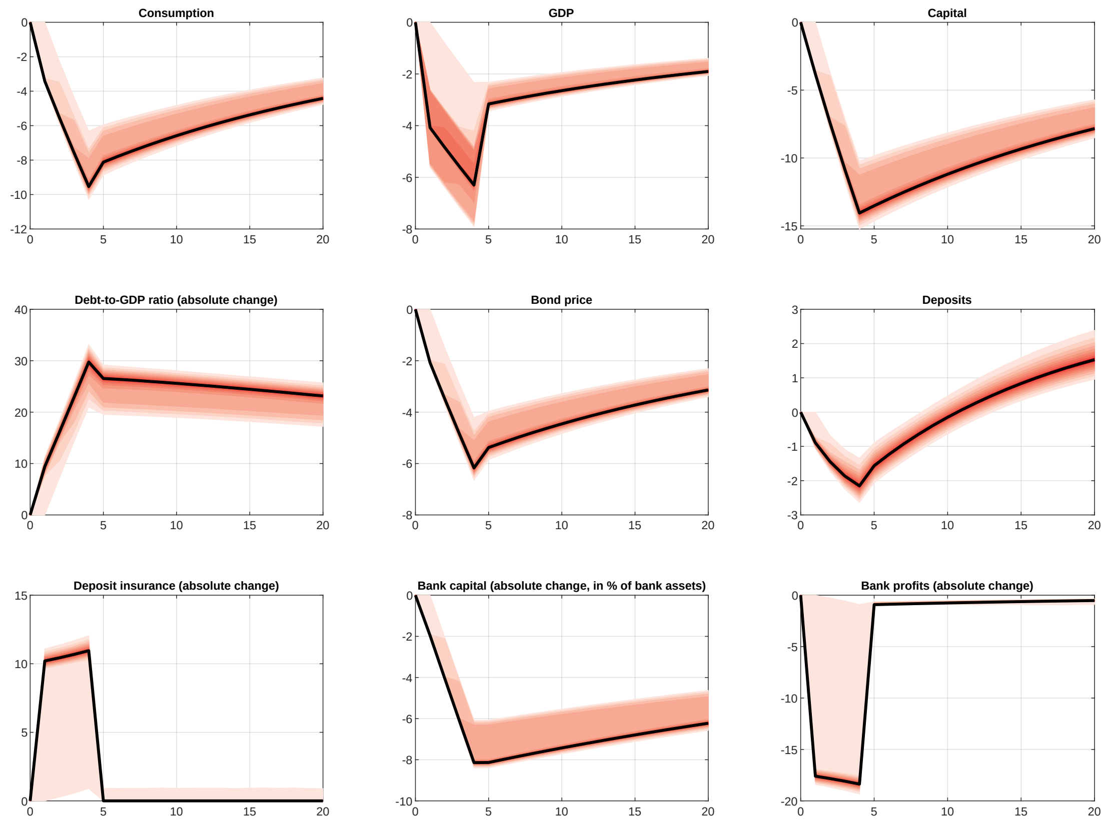
So far, we have shown that the macroeconomic consequences of a ZRW policy with myopic banks are substantial. As illustrated in the previous section, the distortions are also mirrored by the "misperception wedge" defined in the previous section:

$$\underbrace{-\tau^{K}_{t+1}\mathbb{E}^{R}_{t}(1-\xi_{t+1})R^{k}_{t+1}}_{\text{Misperception wedge on expected return on capital}} + \underbrace{\tau^{B}_{t+1}\mathbb{E}^{R}_{t}(1-\Delta_{t+1})(1+\pi Q^{B}_{t+1})Q^{B^{-1}}_{t}}_{\text{Misperception wedge on expected return on bonds}}$$

that is driving the deviation from the first-best allocation. The wedge mirrors that in the ZRW economy, the banks' balance sheet will under-accumulate capital and over-accumulate sovereign bonds. The mean wedge in the disaster state minus the mean wedge in non-disaster states is higher in the ZRW economy than in the non-ZRW economy. In the ZRW economy the wedges for capital and bonds are both 0.18, whereas the wedges in the non-ZRW economy are 0.13 for capital and 0.08 for bonds. We can also express the conditional wedges in percentage changes relative to the first-best allocation. The percentage change in the ZRW economy is 23.4% for the capital wedge and 23.0% for bonds wedge whereas, in the non-ZRW economy, it is 4.1% for the capital wedge and 6.5% for the bonds wedge. As expected, the wedge in the non-ZRW economy is closer to the first-best allocation compared to the ZRW economy. Even though some of the wedges appear numerically not very large, the macroeconomic effects and welfare implications are substantial. This is because even small deviations in the Euler equations (or first-order conditions) accumulate in present value, becoming more prominent in calculations such as welfare.

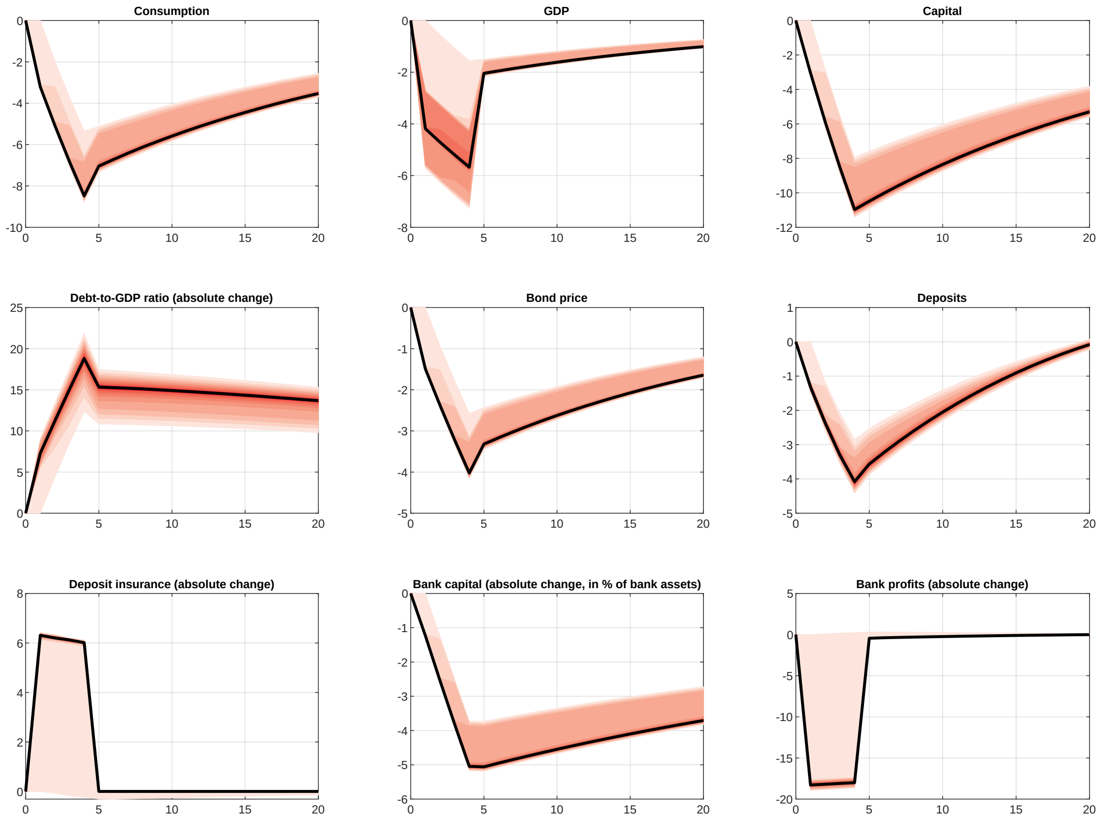
4.4 DYNAMIC TAIL RISK BEHAVIOUR Figures 5 and 6 speak to the dynamic tail risk associated with the non-ZRW and the ZRW economy. Here we simulate two economies with random shocks for 120 periods, where one economy is hit by an additional four consecutive disaster shocks starting in period 100. The difference between these two economies measures the IRF of a variable. We repeat this exercise 20,000 times to obtain 20,000 different IRF paths, where the state of the economy in period 100 ($t = 0$) differs in each simulation. The red-shaded area depicts the distribution of the IRFs in increments of 5 percentage points. The 5th and 95th per-

Figure 5: IRFs to Disaster Shocks: Tail Risk in ZRW economy



Notes: We simulate two economies with random shocks for 120 periods, where one economy is hit by an additional four consecutive disaster shocks starting in period 100. The difference between these two economies measures the IRF of a variable. We repeat this exercise 20,000 times to obtain 20,000 different IRF paths (with the state of the economy in period 100 differing in each simulation). The areas shaded in red depict the distributions of the IRFs in increments of 5 percentage points. The solid black lines show the median responses.

Figure 6: IRFs to Disaster Shocks: Tail Risk in the Non-ZRW Economy



Notes: We simulate two economies with random shocks for 120 periods, where one economy is hit by an additional four consecutive disaster shocks starting in period 100. The difference between these two economies measures the IRF of a variable. We repeat this exercise 20,000 times to obtain 20,000 different IRF paths (with the state of the economy in period 100 differing in each simulation). The areas shaded in red depict the distributions of the IRFs in increments of 5 percentage points. The solid black lines show the median responses.

centiles are the range. The solid black lines plot the median responses. Our ability to conduct such a thought experiment is a key advantage of solving the model globally.

The most pronounced distinction between the IRFs is the difference of deposit insurance and fiscal variables. In the non-ZRW economy, deposit insurance is roughly 50% below the equilibrium outcome in the ZRW economy. This induces substantial differences in fiscal variables. There is a 50% difference in the debt-to-GDP ratio and in the bond prices between the economies. Perhaps more importantly, these misallocations are persistent, especially in capital. Looking at the asset composition of banks, we know that the capital-total assets ratio is much lower in the ZRW economy, which implies that the economy has a severe misallocation of bank assets and capital is crowded out in favor of sovereign debt. This is because banks do not take fiscal stress risks into consideration. Thus, bank leverage increases beyond the optimal (constrained) allocation and leads to an increased probability of fiscal stress.

Based on the same set of 20,000 IRF simulations, we now turn to the most extreme model outcomes. Figure 7 shows the worst-case and best-case outcomes in each period in the ZRW economy and the non-ZRW economy. Intuitively, we sort the IRFs of each variable at each horizon across all simulations in descending order and then show the best and worst outcomes of each variable in each period. In this way, we can examine the most extreme outcomes generated by the model.[6] The figure provides a very clear depiction of how the ZRW policy can negatively impact the economy at all horizons. The macro aggregates (consumption, capital, debt-GDP ratio and GDP) are substantially worse in the ZRW economy in the worst-case simulations. The best-case simulations exhibit little difference. The bond price (and bank capital) in the ZRW economy has a maximum deviation that is nearly twice (1.5 times) as large as that in the non-ZRW economy. The upshot of this exercise is consistent with the main message of the paper: in good times, the differences between ZRW and non-ZRW policies are negligible but, in times of high fiscal stress, the ZRW policy substantially distorts the economy and worsens macro aggregates.

4.5 HIGH AND LOW FISCAL STRESS We compare the macroeconomic consequences of financial regulation in environments of high and low fiscal stress. These exercises shed light on the interactions between fiscal stress and financial regulation.[7] Similarly to before, we simulate the economy 20,000 times and compute the IRFs after a burn-in period. We then sort the simulations by the probability of default in the period when the last disaster shock hits the economy. In the high fiscal stress scenario we average across the simulations in the highest percentile of the default probability distribution. In the low fiscal stress scenarios we average across the lowest percentile of the distribution.

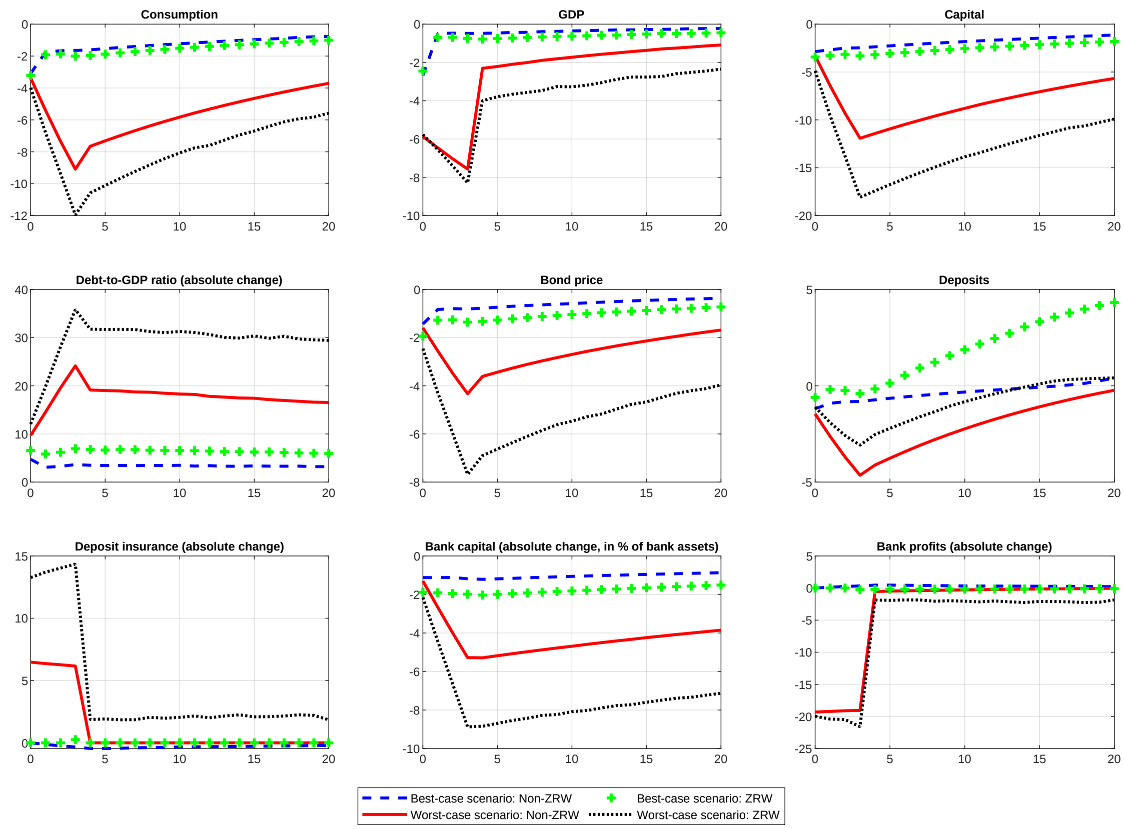
Figure 8 shows that, in the ZRW economy, the probability of default is fairly close to zero in the low fiscal stress scenario. In contract, the default probability is around 90 percent (at peak) in the high fiscal stress scenario. Capital, output and consumption contract more in the high fiscal stress environment. That said, even at low default risk, the disaster shock, of course, has substantial adverse consequences. The difference between the two scenarios illustrates the role played by fiscal stress. As expected the bank capital-total asset ratio declines more in the high fiscal stress scenario, so that, in times of high fiscal stress, banks over-accumulate sovereign debt and under-accumulate capital.

Figure 9 presents the exercise under a non-ZRW policy. As before, the high fiscal stress scenario exhibits more adverse effects than the low fiscal stress scenario. However, the bank

[6] Naturally, this exercise intentionally reports the worst and best outcomes at each period where the simulation may not be time-consistent.

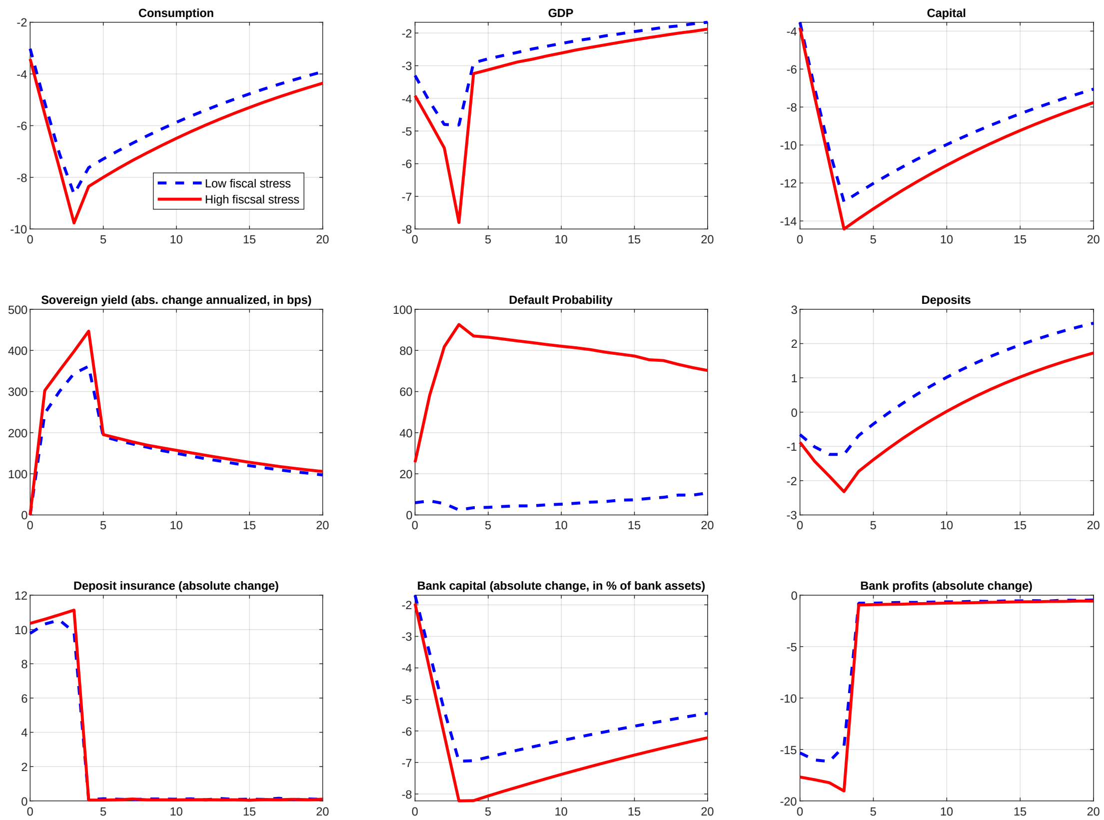
[7] We would like to thank an anonymous referee for suggesting this exercise.

Figure 7: Worst-Case and Best-Case Outcomes with ZRW and Non-ZRW regulation



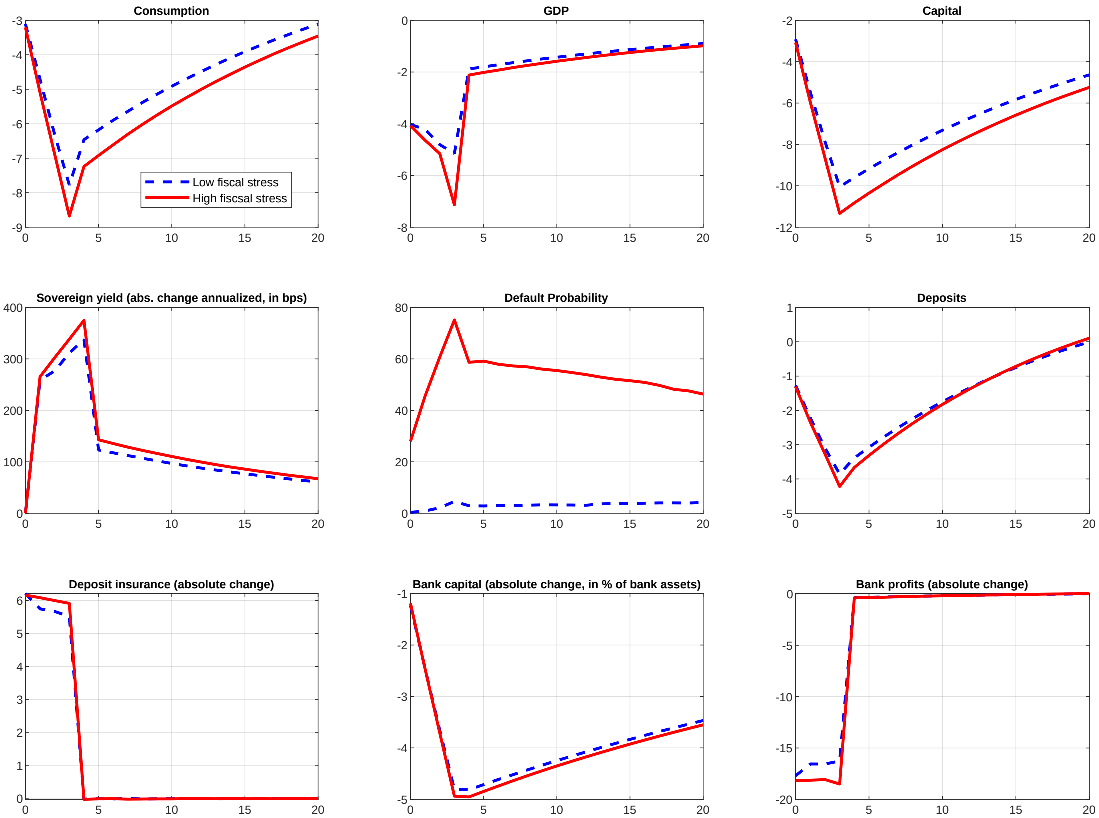
Notes: IRFs in % deviation from the stochastic steady state in response to a sequence of four disaster shocks. Based on 20,000 simulation, we show the worst-case and best-case outcomes in each period in the ZRW and non-ZRW economy.

Figure 8: IRFs to Disaster Shocks: High and Low Fiscal Stress in the ZRW Economy



Notes: We simulate two economies with random shocks for 120 periods, where one economy is hit by an additional four consecutive disaster shocks starting in period 100. The difference between these two economies measures the IRF of a variable. We repeat this exercise 20,000 times to obtain 20,000 different IRF paths (with the state of the economy in period 100 differing in each simulation). We show the average of the top and bottom percentiles sorted by the default probability.

Figure 9: IRFs to Disaster Shocks: High and Low Fiscal Stress in the Non-ZRW Economy



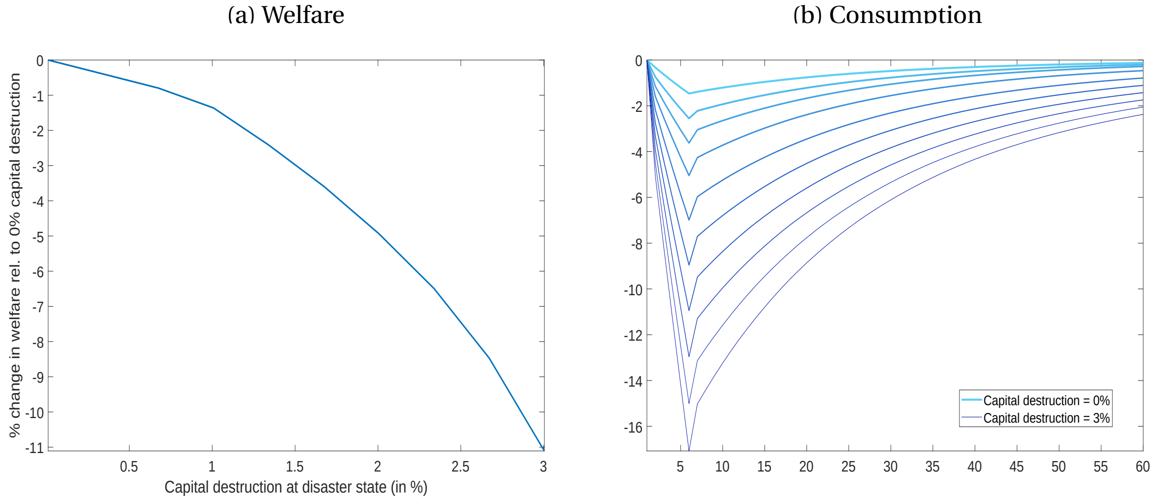
Notes: We simulate two economies with random shocks for 120 periods, where one economy is hit by an additional four consecutive disaster shocks starting in period 100. The difference between these two economies measures the IRF of a variable. We repeat this exercise 20,000 times to obtain 20,000 different IRF paths (with the state of the economy in period 100 differing in each simulation). We show the average of the top and bottom percentiles sorted by the default probability.

capital-total bank assets ratio differs very little between the two scenarios. Importantly, comparing the peak effects of capital (that mirrors the magnitude of the capital misallocation in the economy), we find that, at peak, capital declines by more than 14 percent in the ZRW economy and by around 11 percent in the non-ZRW economy. In other words, financial regulation in an environment of high fiscal stress can amplify the capital response by around 30 percent at peak.

4.6 SENSITIVITY OF CAPITAL DESTRUCTION IN DISASTER STATE

Our final point examines the severity of the recession that can be generated by our model and the extent to which welfare can fall. Figure 10 (a) focuses on how the degree of capital destruction in the disaster state impacts welfare. It plots the change in welfare (in percentage terms relative to first-best) for different magnitudes of the destruction shock (from 0 to 3%). Figure 10 (b) shows the consumption response to four disaster shocks and then a return to the steady state for different degrees of

Figure 10: Capital Destruction and Welfare



Notes: Panel (a) plots the change in welfare relative to the baseline case as the degree of the capital destruction (ξ_t) is increased. Panel (b) plots the consumption response in % change from the stochastic steady state to a sequence of four disaster shocks at different degrees of capital destruction ranging from 0% (light blue) to 3% (dark blue).

capital destruction.

A capital destruction shock of 3%, while seemingly large, is, in our view, no inconsistent with the magnitude of shocks during the Global Financial Crisis. There were many economies subject to such declines in consumption, and most, if not all, had banking sectors that held risky domestic sovereign debt. As motivated by Figure 1, many such economies have levels of debt that are disconcerting given their lack of diversification in bond holdings. As Figure 10 clearly demonstrates, a non-ZRW policy, coupled with a capital destruction shock, amplifies the decline in consumption and welfare in a non-linear fashion. In other words, doubling the capital destruction, from 1% to 2%, more than doubles the loss in welfare (from 1% to more than 4%). Figure 10 (b) paints a similar picture; the magnitude of the capital destruction shock amplifies the decline in consumption by a factor of roughly five.

Another interesting possibility is to reduce the probability of the disaster state.[8] Gourio (2012) uses a lower disaster probability of around one percent, but, conditional on the disaster state, he assumes that the capital destruction is much more severe than the magnitudes that we have shown here. For example, in his case. consumption drops by more than 25 percent (compared to roughly 10 percent in our setup). Naturally, for a given magnitude of capital destruction, a lower probability of the disaster state reduces the welfare implications, mirroring the effects shown in Figure 10.[9] However, in keeping with Gourio (2012), imposing a more severe

[8]We would like to thank an anonymous referee for this consideration.

[9]We show the welfare results for probabilities of the disaster state varying between 0.5% and 6.0% in Appendix D.

capital destruction shock would counterbalance the effect of a lower disaster state probability.

5 CONCLUSION

Financial institutions, especially in Europe, hold a disproportionate amount of domestic sovereign debt. We show how this home bias can arise and lead to capital misallocation in a real business cycle model with imperfect information and fiscal stress. A ZRW policy provides an incentive for banks to hold sovereign debt over private capital. In contrast, in a non-ZRW environment, banks optimally weight sovereign debt according to default probabilities. In our model, banks are assumed to miscalculate the probability of a disaster state due to moral hazard and imperfect monitoring. This distortion pushes the economy away from the first-best allocation. Moreover, as the economy approaches its fiscal limit, these distortions are amplified. The welfare costs associated with ZRW policies are very large, while they are substantially smaller in the economy with positive risk weights.

Future research could examine whether in a macroeconomic model with nominal rigidities and a central bank further trade-offs occur. These trade-offs could arise when monetary policy aims to mitigate the adverse economic effects using a potentially less efficient policy tool based on a Taylor-type rule. We can also investigate monetary, fiscal and financial regulation policy interactions. For example, to what extent is fiscal policy effective at mitigating recessions when financial regulation does not achieve first-best allocations? Since many advanced economies increased their fiscal spending in response to the pandemic, this exercise would help to improve our understanding of policy debates.

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A THE EQUILIBRIUM CONDITIONS

This section starts with the set of equilibrium conditions for the model under rational expectations. Then, the regulatory constraint in introduced and we explain how we solve the model under myopic expectations, the non-ZRW economy and the ZRW economy. Finally, we explain the global solution method for solving the model.

A.1 FIRMS The following optimality conditions are satisfied:

$$W_t = (1-\alpha) z_t \left((1-\xi_t) K_{t-1}\right)^{\alpha} L_t^{-\alpha} \tag{A.1}$$

$$R_t^k = \alpha z_t \left((1-\xi_t) K_{t-1}\right)^{\alpha-1} L_t^{1-\alpha} + 1 - \delta \tag{A.2}$$

$$Y_t = z_t \left((1-\xi_t) K_{t-1}\right)^{\alpha} L_t^{1-\alpha}\,. \tag{A.3}$$

The stochastic process of z_t is governed by:

$$z_t = \begin{cases} \mathcal{Z}^H = 1.01 \text{ and } \xi_t = 0 & \text{with } p^H \\ \mathcal{Z}^M = 1.00 \text{ and } \xi_t = 0 & \text{with } p^M \\ \mathcal{Z}^L = 0.99 \text{ and } \xi_t = 0 & \text{with } p^L \\ \mathcal{Z}^D = 0.97 \text{ and } \xi_t = \xi & \text{with } p^D\,. \end{cases}$$

A.2 HOUSEHOLDS Households solve the maximization problem defined in Section 2.4. The Euler equation and the intratemporal optimality condition are given by:

$$1 = \beta \mathbb{E}_t \left[\frac{C_t}{C_{t+1}}\right] R_{t+1}^D \tag{A.4}$$

$$W_t = \chi L_t^{\eta} C_t\,. \tag{A.5}$$

A.3 BANKS The balance sheet of banks is:

$$D_t + E_t = K_t + Q_t^B B_t \tag{A.6}$$

$$T_t = D_t + E_t\,. \tag{A.7}$$

Banks collect deposits so that the guaranteed return is equal to the return on assets in the "disaster" state ($\mathcal{Z}^D$):

$$R_{t+1}^D D_t = (1-\xi) K_t R_{t+1}^k(\mathcal{Z}^D) + Q_t^B B_t (1-\bar{\delta}) \frac{1 + \pi Q_{t+1}^B(\mathcal{Z}^D)}{Q_t^B}, \tag{A.8}$$

where $Q_{t+1}^B(\mathcal{Z}^D)$ denotes the price of government debt in the "disaster" state and $R_{t+1}^k(\mathcal{Z}^D)$

represents the return on capital in the "disaster" state:

$$R^k_{t+1}(\mathcal{Z}^D) = \alpha \mathcal{Z}^D((1-\xi)K_t)^{\alpha-1}\left(L_{t+1}(\mathcal{Z}^D)\right)^{1-\alpha} + 1 - \delta\,,$$

where $L_{t+1}(\mathcal{Z}^D)$ is labor supplied in the "disaster" state.

The optimization problem for bankers yields the standard allocation that aligns expected returns across assets as follows:

$$\mathbb{E}_t\left[\beta\frac{C_t}{C_{t+1}}(1-\xi_{t+1})R^k_{t+1}\right] = \mathbb{E}_t\left[\beta\frac{C_t}{C_{t+1}}\frac{(1-\Delta_{t+1})(1+\pi Q^B_{t+1})}{Q^B_t}\right]. \tag{A.9}$$

The equity value is equal to the expected discounted value of dividends (profits):

$$E_t = \mathbb{E}_t\left[\beta\frac{C_t}{C_{t+1}}V_{t+1}\right]. \tag{A.10}$$

Optimized profits (V_t) are given by:

$$\tilde{V}_t = (1-\xi_t)K_{t-1}R^k_t + \frac{(1-\Delta_t)(1+\pi Q^B_t)}{Q^B_{t-1}}Q^B_{t-1}B_t - R^D_t D_{t-1}\,, \tag{A.11}$$

$$V_t = \begin{cases} \tilde{V}_t & \text{if } \tilde{V}_t \geq 0 \\ 0 & \text{if } \tilde{V}_t < 0\,. \end{cases} \tag{A.12}$$

Deposits insurance is activated when profits are less than zero:

$$DIN_t = \begin{cases} 0 & \text{if } \tilde{V}_t \geq 0 \\ -\tilde{V}_t & \text{if } \tilde{V}_t < 0\,. \end{cases} \tag{A.13}$$

A.4 GOVERNMENT

The flow government budget constraint is given by:

$$\tau_t + Q^B_t B_t = (1+\pi Q^B_t)(1-\Delta_t)B_{t-1} + G_t + DIN_t + cost_t, \tag{A.14}$$

where deposit insurance costs are:

$$cost_t = \phi DIN_t\,. \tag{A.15}$$

Lump-sum taxes τ_t and government spending G_t follow fiscal rules:

$$\tau_t = \tau + \gamma^\tau((1-\Delta_t)B_{t-1} - B) \tag{A.16}$$

$$G_t = \bar{G}\,. \tag{A.17}$$

The probability (P_t) of hitting the fiscal limit is determined by a logistic function of the government debt-to-GDP ratio $s_{t-1} = \frac{Q^B_{t-1}B_{t-1}}{4Y_{t-1}}$:

$$P_t = P(s_{t-1} \geq s^*_t) = \frac{\exp(\nu_1 + \nu_2 s_{t-1})}{1+\exp(\nu_1 + \nu_2 s_{t-1})}\,.$$

When the fiscal limit hits, the government will default with probability one. The default scheme is defined as follows:

$$\Delta_t = \begin{cases} 0 & s_{t-1} < s^*_t \\ \bar{\delta} & s_{t-1} \geq s^*_t\,. \end{cases}$$

A.5 MARKET CLEARING The market clearing condition closes the model:

$$Y_t = C_t + K_t - (1-\delta)(1-\xi_t)K_{t-1} + G_t + cost_t\,. \tag{A.18}$$

A set of variables $(C_t, K_t, L_t, W_t, Y_t, R^K_t, R^D_{t+1}, Q^B_t, D_t, E_t, B_t, T_t, \tilde{V}_t, V_t, DIN_t, \tau_t, cost_t, G_t)$ is determined as a function of state variables $S_t = (K_{t-1}, B_{t-1}, Q^B_{t-1}, z_t, \Delta_t)$ in the equilibrium, which satisfies eighteen equations given by: (A.1) - (A.18).

B SCENARIOS

1. **First-best allocation:** The above conditions are satisfied under rational expectations. It is worth noting that the disaster state and the probability of government default are taken into consideration. Banks set guaranteed deposit rates at the disaster-state level. Households formulate expectations correctly. Policy, in this environment, is not needed. This implies that retained earnings, as defined in equation (B.2), are set to: $\tilde{a}^K = \tilde{a}^B = 0$ and the regulatory constraint is irrelevant.

2. **Myopia:** Agents are myopic and ignore the possibility of a disaster state and the probability of government default. The rational expectation operator $\mathbb{E}_t$ is replaced with the myopic expectation operator $\mathbb{E}^M_t$. In other words, households and banks assume that the default probability of government debt is zero ($p_t = 0$). In addition, they assign $p^D = 0$ and reallocate this probability to the low state, $p^{*,L} = 1 + p^D - p^H - p^M$. Myopic expecta-

tions are formed based on

$$\mathbb{E}_t^M z_{t+1} = \begin{cases} \mathcal{Z}^H \text{ and } \xi_t = 0 & \text{with } p^H \\ \mathcal{Z}^M \text{ and } \xi_t = 0 & \text{with } p^M \\ \mathcal{Z}^L \text{ and } \xi_t = 0 & \text{with } p^{*,L}\,. \end{cases}$$

The rational expectation operator $\mathbb{E}_t$ is replaced with $\mathbb{E}_t^M$ for all equilibrium conditions.

Banks collect deposits so that the guaranteed return is equal to the return on assets in the "low" state ($\mathcal{Z}^L$) instead of in the "disaster" state ($\mathcal{Z}^D$). Then, equation (A.8) is replaced with:

$$R_{t+1}^D D_t = K_t R_{t+1}^k(\mathcal{Z}^L) + Q_t^B B_t \frac{1 + \pi Q_{t+1}^B(\mathcal{Z}^L)}{Q_t^B}, \tag{B.1}$$

where $Q_{t+1}^B(\mathcal{Z}^L)$ represents the price of government debt in the "low" state, and $R_{t+1}^k(\mathcal{Z}^L)$ represents the return on capital when $\mathcal{Z}^L$ is in the "low" state

$$R_{t+1}^k(\mathcal{Z}^L) = \alpha \mathcal{Z}^L K_t^{\alpha-1} \left(L_{t+1}(\mathcal{Z}^L)\right)^{1-\alpha} + 1 - \delta\,,$$

where $L_{t+1}(\mathcal{Z}^L)$ is labor supplied in the "low" state.

The financial regulator requires myopic banks to hold retained earnings (RE_t) equal to or greater than risk-weighted assets

$$RE_t = \tilde{\xi}\left[\tilde{a}^K K_t + \tilde{a}^B Q_t^B B_t\right]\,, \tag{B.2}$$

where $\tilde{a}^K$ and $\tilde{a}^B$ represent risk weights for capital and government bonds, respectively. The capital requirement is denoted by $\tilde{\xi}$. For brevity, we define: $a^K = \tilde{\xi}\tilde{a}^K$ and $a^B = \tilde{\xi}\tilde{a}^B$.

3. **Non-ZRW:** The equilibrium conditions are the same as in the "Myopia" scenario, but a non-ZRW regulation is imposed ($\tilde{a}^B = 0.4$, $\tilde{a}^K = 0.4$, $\tilde{\xi} = 0.03$). Since financial regulation is imposed, equation (A.9) and equation (B.1) are replaced with

$$\mathbb{E}_t^M\left[\beta \frac{C_t}{C_{t+1}}\left((1-\xi_{t+1})R_{t+1}^k - a^K\right)\right] = \mathbb{E}_t^M\left[\beta \frac{C_t}{C_{t+1}}\left(\frac{(1-\Delta_{t+1})(1+\pi Q_{t+1}^B)}{Q_t^B} - a^B\right)\right],$$

$$R_{t+1}^D D_t = K_t\left(R_{t+1}^k(\mathcal{Z}^L) - a^K\right) + Q_t^B B_t\left(\frac{1+\pi Q_{t+1}^B(\mathcal{Z}^L)}{Q_t^B} - a^B\right).$$

4. **ZRW:** The equilibrium conditions are the same as in the "non-ZRW" scenario. However, a ZRW regulation on sovereign debt ($\tilde{a}^B = 0$) is imposed, while the risk weight on capital remains $\tilde{a}^K = 0.4$.

C Solution Method

The model is solved globally using the time iteration method as in Richter et al. (2014). This method discretizes the state space and iteratively solves for updated policy functions until a tolerance level is met. Linear interpolation is used to approximate future variables. The following provides an outline of the solution method:

1. The minimum set of state variables is denoted by $S_t = (K_{t-1}, B_{t-1}, Q^B_{t-1}, z_t, \Delta_t)$. Define the decision rules for $C_t(S_t)$, $Q^B_t(S_t)$, and $L_t(S_t)$. When reporting welfare results, we define an additional decision rule for the value function $VF_t(S_t)$.

2. Define the grid points by discretizing the state space. Make initial guesses for $C_t(S_t)$, $Q^B_t(S_t)$, and $L_t(S_t)$ over the state space. The deterministic steady state values are chosen as the initial guess.

3. Based on the initial guesses and the equilibrium conditions described above, solve the non-linear model to obtain the policy rules for all endogenous variables at each grid point. Along with this, the values of the endogenous state variables S_{t+1} are also obtained.

4. Based on the state vector S_{t+1}, use linear interpolation to obtain the values of the policy variables at $t+1$ for each possible realization of the state variables. Compute all endogenous variables at $t+1$ needed to compute time t expectations for each possible realization of the aggregate shocks and government defaults. Given the probability of each shock and government default, the expectations are calculated in the equilibrium equations.

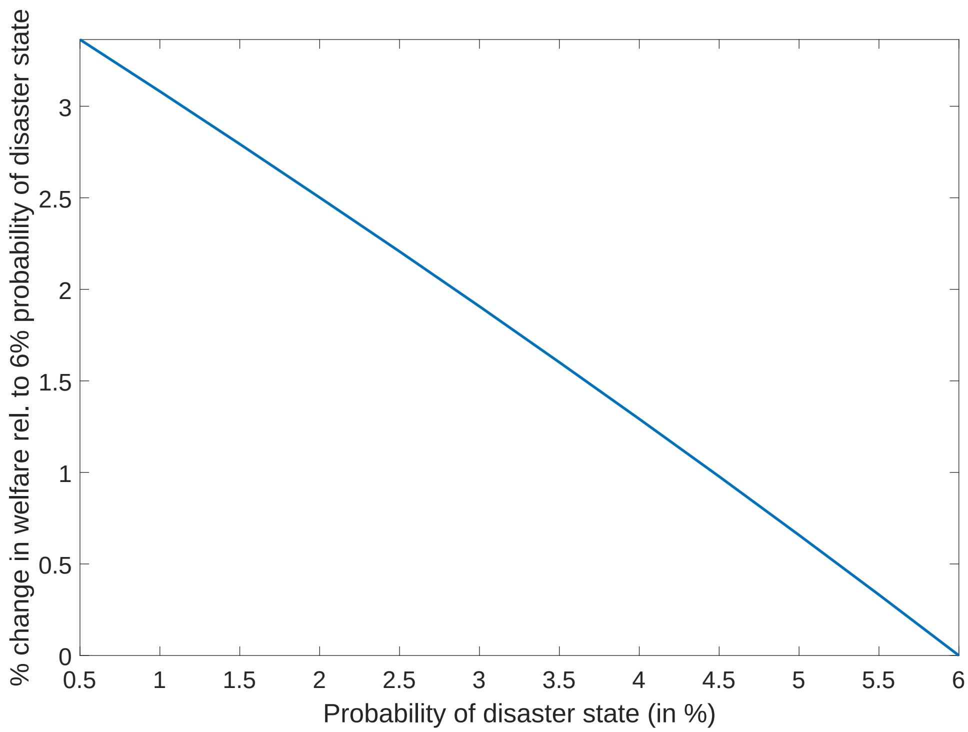
5. Solve for the residual equations using a numerical root-finding algorithm. The answers to the problem are a set of updated policy values for $C_t(S_t)$, $Q^B_t(S_t)$, and $L_t(S_t)$ at each grid point satisfying the equilibrium conditions.

6. Check convergence of the decision rules for $C_t(S_t)$, $Q^B_t(S_t)$, and $L_t(S_t)$. If the distance between the updated policy values and the policy values before updating at each grid point is above the desired tolerance (set to 10^{-8}), go back to step 3. Otherwise, the obtained policy values are our decision rules.

D FURTHER RESULTS

In this exercise, we show how welfare changes in the ZRW economy when we reduce the probability of the disaster state. Figure 11 shows the results for disaster state probabilities ranging from 0.5% to 6%. As expected, the welfare results improve as the probability of the disaster state declines (for a given capital destruction shock). Of course, the distortion of myopic banks would vanish completely if banks were to attach a probability of 0% to the disaster state.

Figure 11: Welfare and Disaster Probability



Notes: The figure plots the change in welfare in the ZRW economy relative to the baseline case (p^D = 6%) as the probability of the disaster state (p^D) varies.