A Quantitative Model of International Lending of Last Resort*

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Abstract

We analyze banking crises and lending of last resort (LOLR) in a quantitative model of financial frictions with bank defaults. LOLR policies generate a tradeoff between financial fragility (due to more highly leveraged banks) and milder crises since the policies are effective once in a crisis. In the calibrated model, the crisis mitigation effect dominates the moral hazard problem and the economy is better off having access to a lender of last resort. We characterize the conditions under which pools of small economies can be sustainable LOLRs. In addition, we assess the ability of China - a country with ample reserves - to be a sustainable international LOLR.

Keywords: Banking Crises, China, Financial Frictions, Lender of Last Resort
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1 Introduction

Following the last financial crisis, there has been a renewed interest in designing last-resort lending arrangements among countries. For example, since 2008, China has entered into more than 50 bilateral agreements that can be used to obtain lending of last resort (LOLR). Argentina, Pakistan and Venezuela have already used China's facilities.[1] While there exists a literature started by Bagehot (1878) analyzing the usefulness of lending of last resort, the issue of sustainability of international LOLR arrangements has not been explored within a quantitative macro framework. This paper fills the gap.

We study a small open economy whose banking system borrows from international financial markets to finance domestic production. Banks can default and a costly-state-verification friction generates an endogenous spread between banks' cost of funds and the exogenous risk free rate. The model has the "liability dollarization" channel surveyed in Mendoza (2016) as debt is denominated in units of tradables and collateral is posted in terms of nontradables (capital). Adverse financial shocks increase the probability of bank failures, lower banks' access to external funds and trigger a negative financial accelerator mechanism à la Bernanke et al. (1999), which is specially intense when banks are highly leveraged.[2] As in the data, systemic banking crises in the model are infrequent events, featuring a sharp rise in spreads, a reversal of the current account and a drop in aggregate output, investment and consumption.

In the model, the LOLR commits to partially finance the banks during the financial crises.[3] The LOLR allows the distressed banking sector to borrow at an interest rate lower than what private lenders would have charged without the intervention. This policy is effective at helping the banking sector to cope with financial distress and mitigates the negative financial accelerator. However, the anticipation of such interventions encourages banks to take more leverage ex-ante. We solve the model with global methods to capture this moral hazard.

LOLR policies generate a tradeoff between financial fragility (due to more highly leveraged banks) and milder crises since the policies are effective once in a crisis. For our calibration the crisis mitigation effect dominates the moral hazard problem and the economy is better off having access to a lender of last resort.

[1] Argentina has been actively negotiating a further extension of the swap line with China in an attempt to cope with recent economic turbulence (Wheatley 2018).

[2] In the model, banks are exposed to idiosyncratic asset quality shocks. The aggregate shock that triggers the financial crisis is an increase in the cross-sectional dispersion of the bank idiosyncratic shock. Alfaro et al. (2018), Christiano et al. (2014), Elenev et al. (2018), Faria-e-Castro (2018), among others, study financial crises driven by these shocks.

[3] See Jeanne and Wyplosz (2001) for a similar approach to modeling LOLR support to the domestic banking system.

The previous result takes us to the question of how to implement the LOLR. Bagehot proposed the central bank to be the LOLR. However, many central banks cannot act as successful last-resort lenders because their financial sector borrows in foreign currency (usually in dollars) and their reserves are not large enough.[4] Thus, we study international LOLR arrangements. First, we analyze pools of small economies as international LOLRs. In every period each member country pays participation premiums to the pool. Disbursements of the pool are payments made by the LOLR due to bank defaults in member countries. This is similar to a tax-financed LOLR, which in practice is how Ireland, Portugal and Spain supported their domestic financial systems during most of the 2008 financial crisis (Santos 2014, Zeissler et al. 2015). Second, we study whether a country with ample reserves like China can be a sustainable international LOLR.[5]

We show that without initial contributions of reserves, pools of small economies do not seem to be feasible arrangements for lending of last resort as they need an unrealistically large number of uncorrelated countries to have small probabilities of failure. We also show that for initial contributions of reserves of at least 4% of domestic output per-country, pools of as few as five highly correlated countries can be a sustainable LOLR.

In addition, we confirm the ability of China to be an international LOLR. We input into the model the ratio of China's foreign reserves to the total GDP of the countries that have signed lending agreements with China over the last nine years.[6] Model simulations show that, as long as China receives some compensation from the insured countries, it is able to provide the levels of liquidity support documented by Laeven and Valencia (2018) with zero probability of failure.

Obstfeld et al. (2009) hypothesized that the scale of reserves needed to backstop financial crises in emerging markets surpassed the resources of the multilateral organizations and all but the largest reserve holders in the world. We confirm that the largest reserve holders can play the role of international LOLR. Thus, the recent Chinese initiatives seem to benefit many countries that can avoid reserve accumulation as a costly self-insurance mechanism against domestic financial instability.[7] In fact, Aizenman et al. (2011, 2015) confirm that long-lasting

[4] Areas as Latin America are de facto mostly dollarized (Corbo 2001 and Salvatore 2001). Moreover, dollar-denominated debt keeps increasing rapidly. In 2014, non-U.S. debt issuers had $6.04 trillion in outstanding bonds, up nearly fourfold since 2008 (Talley and Trivedi 2014).

[5] The absence of conditionality may make China a popular LOLR because countries have been reluctant to use lending of last resort programs from the IMF to avoid the stigma and conditionality attached to them (Allen and Moessner 2015, Cecchetti 2014 or Landau 2014).

[6] At the end of 2015, China accounted for 85 percent of all global swap lines (Lagarde 2016). Aizenman et al. (2015) describe the strategy as a bundling of finance (lending, swap-lines and trade credit) in tandem with outward FDI to promote a new type of Chinese-outward mercantilism. Importantly, China seems to attach minimal conditions to its loans.

[7] Aizenman and Lee (2007) and Obstfeld et al. (2010) show that self-insurance is one of the main drivers of

LOLR agreements lead to lower reserve accumulation.

In terms of methodology, our paper contributes to the literature by developing a quantitative macro framework to think about the usefulness and sustainability of different types of LOLR arrangements. While most LOLR papers focus on setups with multiple equilibria and analyze qualitative properties (see, for example, Goodhart and Huang 2000, Corsetti et al. 2006, Morris and Shin 2006 or Bocola and Lorenzoni 2018), we study a financial frictions setup that allows a quantitative analysis of LOLR policy. Our paper connects with models of financial frictions between borrowers and lenders with endogenous accelerator mechanisms (like Bernanke et al. 1999, Christiano et al. 2014, Fernandez and Gulan 2015, Gertler and Karadi 2011 or Akinci and Queralto 2016 among many others). Like Bianchi (2016) or Bianchi et al. (2016) we solve the model with global methods to capture the trade-off between the ex-post benefits of liquidity support and the ex-ante moral hazard in the banking sector triggered by the LOLR.

The paper proceeds as follows: Sections 2 and 3 describe the model and the LOLR policies that we study. Section 4 discusses the calibration. Section 5 analyzes banking crises and lending of last resort policies. Section 6 studies the sustainability of an international LOLR with an application to China. Section 7 concludes. The appendices contain the optimality conditions of the model, the numerical algorithm, and the data sources.

2 Model

We consider a small open economy with households, financial intermediaries (banks), final goods producing firms and capital producers. There is a continuum of identical households of measure one. As in Gertler and Karadi (2011), at every point in time each household consists of a constant fraction of bankers and workers. Workers supply labor to final goods producing firms. Bankers manage financial intermediaries (banks) that borrow from international financial markets and lend to domestic firms. Only bankers have access to foreign debt markets. Banks can default and face an endogenous borrowing spread like the borrowers in Bernanke et al. (1999). There is a perfect consumption insurance within the household receiving wage income from her workers, and transfers from the bankers.

The model is real with consumption serving as numeraire. Only consumption goods are tradable. Below we describe the model ingredients in detail.

reserve accumulation. However, this accumulation comes at substantial costs (Reinhart et al. 2016 or Rodrik 2006).

2.1 Banks

At time t, an individual banker j purchases claims $K_{j,t+1}$ on final goods producing firms at unit price p_t. She uses her own net worth $N_{j,t}$ and debt $B_{j,t+1}$ bought by international lenders at price q_t.[8] Thus, the amount of external funds she obtains is $q_t B_{j,t+1}$. The balance sheet of an individual bank is

$$p_t K_{j,t+1} = N_{j,t} + q_t B_{j,t+1}. \tag{1}$$

After purchasing assets $K_{j,t+1}$, banks are hit by idiosyncratic i.i.d. shocks ω. This captures the idea that some banks hold high quality assets while others hold low quality assets. This is consistent with the evidence discussed in Bindseil and Laeven (2017) that interbank markets (banks' lenders in the model) ex-ante do not observe how credit losses are distributed across individual banks because the quality of banks' assets is opaque. Once an individual banker receives a shock ω, her time $t+1$ gross return on assets is $\omega R^k_{t+1} p_t K_{j,t+1}$, where R^k_{t+1} denotes the average return on capital.

The idiosyncratic shock ω has a unit-mean log normal distribution with cumulative distribution function $F(\omega, \sigma_t)$. It is subject to aggregate shocks to the volatility parameter σ_t as in Christiano et al. (2014). We use the notation $F_t(\omega)$ to indicate the time-varying nature of the distribution function. The distribution of the ω shocks satisfies

$$\mathbb{E}(\omega) = \mu_t + \frac{\sigma_t^2}{2} = 1, \forall t. \tag{2}$$

Equation (2) guarantees that the ω shocks are redistribution shocks to make banks' assets unevenly distributed across banks such that some banks cannot repay their borrowings.

After idiosyncratic and aggregate shocks are realized, some banks default while others repay their debt. The default threshold $\overline{\omega}_{t+1}$ is determined by the bank on the margin of default given its idiosyncratic shock,

$$\overline{\omega}_{t+1} R^k_{t+1} p_t K_{j,t+1} = B_{j,t+1}. \tag{3}$$

Banks with idiosyncratic shock $\omega \geq \overline{\omega}_{t+1}$ repay their debt, and those with $\omega < \overline{\omega}_{t+1}$ default. We assume that banks' lenders can observe the ω shocks only after paying the bankruptcy cost, which is a constant fraction μ of banks' assets. Thus, lenders recover a fraction $1 - \mu$ of the defaulting banks' assets.

[8] Throughout the text we use subscript j to refer to individual bank-specific variables. Their aggregate versions have no subscript.

An individual bank j's time $t+1$ realized earnings are

$$N_{j,t+1} = \omega R^k_{t+1} p_t K_{j,t+1} - B_{j,t+1}. \tag{4}$$

Banks' debt is priced in the international interbank markets such that, net of default, it ensures that banks' lenders, who we assume are risk-neutral, obtain an expected rate of return equal to the risk free rate $\frac{1}{q_f}$,

$$\frac{q_t B_{j,t+1}}{q_f} = \mathbb{E}_t \left\{ \int_{\overline{\omega}_{t+1}}^{\infty} B_{j,t+1} dF_{t+1}(\omega) + (1-\mu) \int_0^{\overline{\omega}_{t+1}} \omega R^k_{t+1} p_t K_{j,t+1} dF_{t+1}(\omega) \right\}. \tag{5}$$

That is, for an investor lending $q_t B_{j,t+1}$ today to the bank, the expected inflows, accounting for the probability of bank default, must equal the return of those funds in a risk-free investment $\left(\frac{q_t B_{j,t+1}}{q_f}\right)$.

We assume that at the end of the period a banker exits the business with an exogenous i.i.d. probability $1-\gamma$.[9] Upon exit, the bank transfers her retained earnings to the households in the form of dividends, and becomes a worker. Surviving banks reinvest all their net worth. Since bankers are members of households, they maximize the present discounted value of dividend payments to households.

Let $V_{j,t}$ denote the value function of a non-defaulting bank at the end of period t, before an exit shock is realized. Then the banker's problem is:

$$V_{j,t} = \max_{B_{j,t+1}, K_{j,t+1}} \left\{ (1-\gamma) N_{j,t} + \gamma \mathbb{E}_t \left[m_{t,t+1} \max \{ V_{j,t+1}, 0 \} \right] \right\}, \tag{6}$$

subject to the balance sheet constraint (1), the definition of default threshold (3), the evolution of individual net worth (4), and to the debt pricing equation (5). The continuation value of the Bellman equation (6) captures the possibility of future bank defaults and limited liability. The variable $m_{t,t+1}$ denotes the household's stochastic discount factor,

$$m_{t,t+1} \equiv \beta \frac{u_C(C_{t+1}, L_{t+1})}{u_C(C_t, L_t)}. \tag{7}$$

In the Appendix we show that, because of constant returns to scale technology, a bank's value function is linear in net worth, allowing for simple aggregation. The linearity of the value

[9] This assumption is common in the financial frictions literature (see, for example, Bernanke et al. 1999 or Gertler and Karadi 2011) and guarantees that banks never accumulate enough internal funds to avoid the need for external finance.

function implies that all banks have the same default threshold, leverage ratio, and face the same market price of debt.[10] Therefore, we only need to keep track of aggregate banking-sector variables to characterize the dynamics of our economy.

Banks that exit the business are replaced by an equal number of new bankers who receive a small initial start-up transfer T_b from the households. Thus, the aggregate banking-sector net worth N_t evolves according to

$$N_t = \gamma \int_{\overline{\omega}_t}^{\infty} \left[\omega R_t^k p_{t-1} K_t - B_t\right] dF_t(\omega) + T_b, \tag{8}$$

and total dividends Ω_t received by households from the banking sector are

$$\Omega_t = (1-\gamma) \int_{\overline{\omega}_t}^{\infty} \left[\omega R_t^k p_{t-1} K_t - B_t\right] dF_t(\omega), \tag{9}$$

where B_t and K_t denote banks' aggregate borrowings and claims on final firms, respectively.

2.2 Final goods producing firms

A representative final good producing firm combines capital with labor, supplied by households, to produce final goods according to the following Cobb-Douglas production function,

$$Y_t = A_t K_t^{\alpha} L_t^{1-\alpha},\ 0 < \alpha < 1, \tag{10}$$

where A_t is an aggregate productivity shock.

At the end of period t, the firm purchases new capital K_{t+1} at price p_t from capital producers for use in production in the next period. After production takes place in period $t+1$, the firm sells undepreciated capital back to capital producers. As in Gertler and Karadi (2011), we assume that the firms are penniless and have to finance all their capital purchases through bank loans. In order to acquire K_{t+1} units of capital, the firms issue Z_{t+1} claims to domestic banks, such that $Z_{t+1} = K_{t+1}$. Each claim is priced at the same price p_t as capital.[11] We assume that there are no financing frictions between firms and banks. Hence, the firms promise the bankers the realized return on a unit of capital in next period in exchange for borrowed

[10] In the Appendix we show that each bank has the same default threshold and faces the same market price of debt. We impose this condition from the outset and drop bank-specific subscript j from $\overline{\omega}_{t+1}$ and q_t.

[11] By arbitrage the price of claims issued by firms must be the same as a price of new capital goods.

funds today,[12]

$$R^k_{t+1} = \frac{r_{t+1} + (1-\delta)\, p_{t+1}}{p_t}, \tag{11}$$

where r_t is given by

$$r_t = \alpha \frac{Y_t}{K_t}. \tag{12}$$

2.3 Capital producing firms

At the end of period t, competitive capital producing firms build new capital by combining the undepreciated capital, bought from final goods producing firms, and new investment. They solve:

$$\max_{K_{t+1}, I_t} \left[p_t K_{t+1} - I_t - (1-\delta)\, p_t K_t\right], \tag{13}$$

subject to

$$K_{t+1} = (1-\delta)\, K_t + I_t - \frac{\phi}{2}\left(\frac{I_t}{K_t} - \delta\right)^2 K_t, \tag{14}$$

where δ is the depreciation rate of capital, and the parameter ϕ controls the capital adjustment cost that ensures that the price of capital varies endogenously, affecting banks' net worth.

2.4 Households

Households are hand-to-mouth and maximize utility over consumption C_t and labor hours L_t. They receive labor income from workers and dividend payments from banks and firms. The households' solve:

$$\max_{C_t, L_t} \mathbb{E}_0 \left[\sum_{t=0}^{\infty} \beta^t u(C_t, L_t)\right], \tag{15}$$

subject to the budget constraint,

$$C_t = W_t L_t + \Omega_t + \Phi_t - T_b, \tag{16}$$

where W_t is the wage per unit of labor, Ω_t are dividends from banks, Φ_t are firm profits, and T_b denotes transfers to bankers.

[12] This is as if banks own capital and rent it to firms at rental rate r_t.

2.5 Definitions

The current account is the negative of the change in banks' foreign debt,

$$CA_t = -\left(B_{t+1} - B_t\right). \tag{17}$$

We define the leverage of the banking sector as bank assets-to-equity ratio,

$$lev_t = \frac{p_t K_{t+1}}{N_t}. \tag{18}$$

The credit spread is the difference between banks' cost of funds and the risk free rate,

$$spread_t = \frac{1}{q_t} - \frac{1}{q_f}. \tag{19}$$

2.6 Aggregate shocks

There are two aggregate shocks in the economy: TFP shock and financial (risk) shock. The two shocks are independent from each other. The stochastic process for TFP shock follows an AR(1) process,

$$\log A_t = \rho_A \log A_{t-1} + \varepsilon_{t,} \tag{20}$$

with $\varepsilon_t \sim \mathcal{N}\left(0, \sigma_A^2\right)$.

The standard deviation of banks' idiosyncratic asset quality (σ_t) follows a two-state Markov process with high and low states, $\{\sigma_h > \sigma_l\}$.[13] We refer to states with σ_l as normal times, when domestic banks have regular access to private credit markets. States with σ_h are financial stress periods when banks' access to external financing is impaired and bank defaults are high. The transition probability matrix is given by

$$\Pi = \begin{bmatrix} \pi_{ll} & 1-\pi_{ll} \\ 1-\pi_{hh} & \pi_{hh} \end{bmatrix}, \tag{21}$$

where π_{ll} and π_{hh} denote the probability of remaining in the high and low-risk state, respectively.

[13] Christiano et al. (2010, 2014) refer to these shocks as "risk shocks" and attribute them most of the macro fluctuations in the U.S. and euro area. Akinci (2014) documents the importance of these shocks for emerging markets. This type of cross-sectional dispersion shocks have also been extensively used in the more recent macro-finance literature. See, for example, Alfaro et al. (2018), Elenev et al. (2018), Faria-e-Castro (2018).

3 Lending of last resort

We assume that in times of financial stress, that is, when $\sigma_t = \sigma_h$, there is a lender of last resort (LOLR). We discuss below two ways to finance this LOLR. In both cases, the LOLR operates in the same way that assumes full commitment: in case of financial stress the LOLR commits to financing a ψ fraction of the banks debt B_{t+1}. Thus, with LOLR, the banks' debt pricing equation becomes

$$\frac{q_t B_{t+1}}{q_f} = \psi \mathbb{I}_{\{\sigma_t=\sigma_h\}} B_{t+1} + \tag{22}$$

$$+ \left(1 - \psi \mathbb{I}_{\{\sigma_t=\sigma_h\}}\right) \mathbb{E}_t \left\{ \begin{array}{c} \int_{\overline{\omega}_{t+1}}^{\infty} B_{t+1} dF_{t+1}(\omega) + \\ \\ + (1-\mu) \int_0^{\overline{\omega}_{t+1}} \omega R^k_{t+1} p_t K_{t+1} dF_{t+1}(\omega) \end{array} \right\}.$$

That is, the first term in the right-hand side of (22) is the debt that the LOLR assumes in case of financial stress in the country. The second term is the expected repayments from the banks absent the LOLR policy like in equation (5). In fact, comparing (22) and (5) we can anticipate that LOLR policy, by committing to provide funds in the bad state of nature, also lowers banks' borrowing costs in the good state.

3.1 Financing the LOLR

The LOLR policy is costly because it involves a credit subsidy. The LOLR commits to financing a ψ fraction of the banks' debt B_{t+1} but for those banks that default the LOLR only recovers their assets, which by definition of default are lower than their debt. Thus, the expected costs of the LOLR policy are

$$\Xi_{t+1} = \psi \mathbb{I}_{\{\sigma_t=\sigma_h\}} \left[\int_0^{\overline{\omega}_{t+1}} \left[B_{t+1} - (1-\mu)\, \omega R^k_{t+1} p_t K_{t+1} \right] dF_{t+1}(\omega) \right]. \tag{23}$$

Next, we analyze two ways to finance Ξ_{t+1}. First, through taxes on the countries' households. Second, through an international organization.

3.1.1 Single-country LOLR

First we assume that the lender of last resort in country i is financed with taxes from the households of country i. This case gives us a benchmark to compare the international

LOLR. We refer to this case as the "single-country LOLR". This case applied to Ireland, Portugal and Spain during the 2008 financial crisis. Households in those countries paid higher taxes to support their domestic financial systems until the EU allowed the European Stability Mechanism and the ECB to exert as LOLR (Santos 2014, Zeissler et al. 2015).

Formally, in the single-country LOLR, the households' budget constraint (16) becomes

$$C_t = W_t L_t + \Omega_t + \Phi_t - \Xi_t - T_b \tag{24}$$

to incorporate the cost of the lending of last resort ($\Xi_t > 0$).

3.1.2 International LOLR

We refer to "international LOLR" when the lender of last resort is a pool of countries that starts with some endowment of reserves M_0 and every period charges a participation premium (ρ) to each country in the pool. Assuming that past reserves return the risk-free rate $\frac{1}{q_f}$, and that there are n countries paying the participation premium, then the reserves of the international LOLR evolve as

$$M_t = \frac{M_{t-1}}{q_f} + n\rho - \sum_{i=1}^{n} \Xi_{i,t}, \tag{25}$$

where $\Xi_{i,t} \geq 0$ are the losses incurred in country i. These losses are zero for country i if in period t the country's domestic banking system is not in financial distress.

The international LOLR fails if $M_t < 0$. That is, when the LOLR lacks resources to fulfill its role as LOLR. If the LOLR does not fail, (25) specifies that its reserves are the sum of the return on the past reserves, plus the insurance premiums paid by the countries in the pool $(n\rho)$, minus the sum of the losses incurred with the countries in the pool.

We use as participation premium the maximum amount that a country would be willing to pay for access to the international LOLR. This premium is the rate at which the households of the country obtain the same expected utility between the autarky single-country LOLR discussed in Section 3.1.1 and the international LOLR. That is, in the stationary distribution, ρ solves

$$\mathbb{E}\left[u(C_{\rho,t}, L_{\rho,t})\right] = \mathbb{E}\left[u(C_{T,t}, L_{T,t})\right], \tag{26}$$

where $C_{\rho,t}$ and $L_{\rho,t}$ are consumption and labor supply when the country pays ρ to belong to the international LOLR. $C_{T,t}$ and $L_{T,t}$ are consumption and labor supply as in the single-country

LOLR. An important remark is that the premium ρ has to be paid by the countries every period while the taxes Ξ_t in (24) only need to be paid when there is a financial turmoil and the LOLR must intervene.

4 Calibration

We calibrate the model to quarterly frequency. First, we set some parameters exogenously following standard values in the literature. Then we endogenously select the rest of the parameters to match some targets. Table 1 summarizes the parameter values and Table 2 contains the targets and moments of the model.

We use GHH preferences to avoid wealth effects on labor supply,

$$u(C_t, L_t) = \frac{1}{1-\eta}\left(C_t - \theta\frac{L_t^{1+\frac{1}{\xi}}}{1+\frac{1}{\xi}}\right)^{1-\eta},$$

where ξ is the elasticity of labor supply and η controls the curvature of the utility function. We choose the value of θ so that the long-run mean of hours worked equals 0.3. We assign standard values to the subjective discount factor $(\beta = 0.985)$, the risk-aversion parameter $(\eta = 2)$, the elasticity of labor supply $(\xi = 3)$, the annualized risk-free interest rate of 2.2% $\left(\text{i.e., } \frac{1}{q_f} = 1.0055\right)$, the capital share in production $(\alpha = 0.33)$, and the depreciation rate of capital $(\delta = 0.025)$. The parameters governing the persistence and volatility of the TFP shock process are set to the values in the range of values used in the RBC literature $(\rho_A = 0.9,\ \sigma_A = 0.008)$.[14] We set transfers to banks to be a very small positive number $(T_b = 0.0001)$. These transfers are a technical device to insure a non-zero equity of the banking sector and do not affect the quantitative results.

Next, we endogenously choose the values for the remaining parameters to match the following empirical targets:

(i) An annualized spread between banks' borrowing costs and the international risk free rate of about 4.5%. In the data average EMBI spread for emerging market economies is around 5 percentage points (see, for example, Fernandez and Gulan 2015). Akinci and Queralto (2016) estimate average country spreads of about 3 percentage points for 6 advanced OECD economies.

[14] We discretize (20) with $\rho_A = 0.9$ and $\sigma_A = 0.008$ into a three-state Markov process using Tauchen-Hussay (1991) methodology. The model generates the standard deviation and persistence of the HP filtered log output of 1.62% and 0.63, respectively, which are close to the corresponding values in the data (see, for example, Aguiar and Gopinath 2006)

(ii) An average leverage ratio of 3 and an average dividend payout-to-bank value ratio of 8%. These values are in the range of the values estimated by Fernandez and Gulan (2015) for 12 emerging market economies, and by Faria-e-Castro (2018) for the U.S. commercial banks.

In order to hit the above targets, we set μ to 0.22, σ_l to 0.24, and γ to a value of 0.92.

(iii) We choose the value of σ_h so that during a financial crisis interest rate spread rises by about 4.5 percentage points relative to its mean. This is consistent with the empirical evidence in Akinci and Queralto (2016). (iv) We set $\phi = 9.8$ so that in the no-LOLR economy investment is about 4 times more volatile than output.

(v) and (vi) We calibrate the transition probabilities of the financial risk process so that the frequency and average duration of banking crises in the no-LOLR economy are like in the empirical literature. Following Bianchi and Mendoza (2018) we define a financial crisis as an event in which current account is above 2 standard deviations from its long-run mean. This captures the well-established fact that financial crises in small open economies have large current account reversals because of disruptions in the banking sector and large drops in foreign financing of the domestic economy. We are also consistent with Laeven and Valencia's (2013) definition of a banking crisis. As we will discuss later, crises in our model feature a sharp jump in banks' bankruptcy rates and in the ex-post government losses associated with last-resort interventions. We set π_{ll} to 0.97 and π_{hh} to 0.85, which imply a frequency of banking crises of 5.58% percent, and an average duration of crises of about 1.2 years.[15] These values are in the range estimated by Bianchi and Mendoza (2018) and Laeven and Valencia (2013);

(vii) Finally, we set the LOLR parameter ψ to 0.108 so that the LOLR economy directly matches the liquidity support (as % of banks' total liabilities) of 10.8%, documented by Laeven and Valencia (2018).

We solve the model using global methods. We follow the policy function iteration algorithm developed by Colleman (1990). Thus, the decision rules take into account the moral hazard induced by the LOLR policy. Appendix B describes the numerical algorithm in detail.

[15] As in Bianchi and Mendoza (2018) the start date of a financial crisis event is set in the quarter within the previous 8 quarters in which the current account first rises above one standard deviation from its long-run mean. We set the end date of a crisis in the quarter within the 8 quarters following the event, in which the current account first falls below one standard deviation.

5 Quantitative results I. Banking crises with and without LOLR

5.1 Impulse responses

Figures 1 and 2 plot impulse responses to study how the economies with and without LOLR react to a financial shock. We focus on the single-country LOLR defined in Section 3.1.1. We follow the methodology of Bianchi (2016) in constructing the non-linear impulse response functions.[16] In all the panels, the solid line corresponds to the no-LOLR economy, and the dashed line refers to the economy with LOLR.

Figure 1 focuses on financial variables while Figure 2 displays the responses of investment, labor, output and consumption. An adverse shock increases the probability of bank defaults and banks' lenders price it with higher spreads (lower q_t). This increase in spreads leads to higher borrowing costs for banks forcing them to reduce their borrowings ($q_t B_{t+1}$ falls). The demand for capital decreases, as do the price of capital and investment. Falling asset prices further reduce banks' aggregate net worth and investment, through the standard financial accelerator of Bernanke et al. (1999). Households consumption falls because of lower bank dividends and wage income. Lending of last resort significantly mitigates the negative effects of the financial shock as banks can borrow at cheaper rates than otherwise.

5.2 Event-windows analysis

Since LOLR is an ex-post policy, it can induce a moral hazard problem. The lenders of the banks understand that the LOLR will mitigate both the banks' default and the fall in the price of capital (which serves as collateral in the loans), and lower the cost of banks' borrowings encouraging banks to leverage more. In addition, banks themselves anticipate that the LOLR will help them in a crisis and lower their precautionary savings motives to take higher risk through higher leverage.[17]

[16] We set the initial values of capital and debt in each economy at their corresponding unconditional mean values. We then simulate the shock processes of length 16 periods for 10,000 times and feed them into the policy functions to produce 10,000 paths for the endogenous variables. In each simulation, the TFP shock starts at its mean value. For each economy, we compute the average differences of the variables of interest between the paths that start with σ_h and those that start with σ_l, relative to the paths starting with σ_l.

[17] Even though banks are risk-neutral in our model, they use households stochastic discount factor to value future profit streams. Therefore, precautionary motive is present in banks' financial decisions.

Figure 4 confirms the moral hazard. It compares the long-run distributions of banks' debt with and without the LOLR policy. The ergodic distribution of bank debt puts larger mass at higher debt levels with LOLR policy, than without it.[18]

Due to the moral hazard problem, the economy with the LOLR may be more likely to move to states with large amount of debt, so that when an adverse financial shock hits the economy in these states, its negative effects are more amplified. Figures 1 and 2 do not fully capture the previous effect, since when deriving the impulse response functions, we fixed the initial debt levels to their corresponding unconditional mean values in the two economies. To fully account for the policy-induced moral hazard when evaluating the effectiveness of the LOLR in crises times, we study an average crisis episode in the two economies using the methodology of Mendoza (2010), Bianchi (2016) and Schmitt-Grohé and Uribe (2017).[19] Figure 3 plots the resulting event-windows.

Several results stand out in Figure 3: 1) In the model, like in the data, credit spreads rise sharply once in a financial crisis. There is a current account reversal as banks cannot borrow and asset prices fall sharply deteriorating banks' equity. Investment collapses as a result of lower bank credit to final goods firms that in turn demand less capital from capital producers. Lower capital and labor translate into lower output. Households cut back on consumption spending in response to a collapse in bank dividends and in wage income. 2) The LOLR significantly stabilizes the economy in a crisis because it provides funds to the banks and this weakens the negative financial accelerator. As a consequence, investment, output and consumption drop by less. Importantly, the consumption gains from LOLR are larger than the losses incurred by the LOLR during the crisis. Despite the increase in lump sum taxes the fall in household consumption is still about 0.5 percentage points lower with the last resort lending, than without it. This is because the disruptions in the banking sector are less severe under the LOLR.

5.3 Welfare

Next we look at the welfare implications of the LOLR policies. To compute welfare gains we solve for compensating consumption variations λ for each initial state that makes household indifferent between living in economies with and without LOLR. That is, for each initial state

[18] The unconditional average of bank leverage is also higher in the economy with the LOLR than without it.

[19] That is, we simulate economies with and without LOLR for 102,000 periods, discarding the first 2000 periods as burn-in. Then, we identify banking crises, center these crisis episodes at date 0, and take 15 periods before and after each crisis date. We compute averages for each variable across the entire set of the crises and associated time windows.

we compute λ such that

$$\mathbb{E}_0 \sum_{t=0}^{\infty} \beta^t u(C_{t,LOLR}, L_{t,LOLR}) = \mathbb{E}_0 \sum_{t=0}^{\infty} \beta^t u((1+\lambda)\, C_t, L_t), \tag{27}$$

where variables with $LOLR$ subscript denote policy functions in the LOLR economy. Figure 5 shows the welfare gains from the LOLR policy. Panel a) reports the simulated welfare gains around the average crisis episode that we analyzed on Figure 3. The welfare gains are highest (0.21% of permanent consumption) at the peak of the financial crisis. This is because the LOLR is most effective once the economy is hit by a financial crisis.

Panel b) evaluates the welfare gains as a function of initial debt levels and for different realizations of the financial shock. We fix the capital stock at its long-run mean value and the TFP shock at its low value. The figure illustrates that welfare gains are increasing in the level of debt. This is because when the level of debt is higher the economy is more vulnerable to financial crises and the LOLR becomes more valuable. Welfare gains are especially large for an adverse financial shock, since this is the state when the LOLR policy is actually triggered.

Interestingly, LOLR results in welfare losses for low enough initial debt levels and low value of risk shock. As Figure A2 in the online Appendix further illustrates, when the domestic banking sector is not under financial stress, the LOLR amplifies the effects of negative TFP shocks. This amplification effect, however, is quantitatively small.

Finally, we look at the unconditional welfare. That is, we compute the mean welfare gains using the stationary distribution of the no-LOLR economy. Table 3 has the results. Mean welfare gains from LOLR are small (0.008% of permanent consumption).[20] This result is due to the fact that financial crises, that is when the LOLR is most valuable, are infrequent events. In addition, as shown above, the LOLR is not effective at stabilizing the economy when it is hit by a productivity shock, which is the key shock driving output and consumption dynamics. Table 3 also compares unconditional averages of selected variables in the economies with and without LOLR. The effects of LOLR on output, capital and consumption are positive albeit quantitatively small. The frequency of financial crises is also slightly lower under the LOLR.

[20] The existing RBC literature based on a representative household and standard risk aversion parameter values generally finds small welfare gains from eliminating business cycle fluctuations. For example, Lucas (1987) finds that welfare gains from eliminating business cycles are about 0.01% of consumption for standard values of risk aversion parameter.

6 Quantitative results II. Sustainability of an international LOLR

This section analyzes the sustainability of an international lender of last resort that starts with some endowment of reserves contributed by the participating countries, and charges a participation premium every period to each country in the pool. We compare different cross-country correlations of the banking crises, different number of participating countries and different initial levels of reserves. Then we ask whether a country with ample reserves like China can be a sustainable international LOLR.

6.1 Probability of failure of an international LOLR

Figures 6 and 7 analyze the probability of failure of the international LOLR for different cases. In all of them the analysis is based on the benchmark calibration and a horizon of 50 years. The international LOLR fails when $M_t < 0$ in equation (25). In that case the disbursements due to the countries in crisis are larger than the sum of the inflows from new participation premiums and the existing stock of reserves.

Figure 6 focuses on the case when the initial level of resources is zero. That is, countries do not make any contribution of reserves to join the LOLR pool. However, they pay the participation premiums defined in (26). Figure 6 has two main results: 1) Without initial reserves, for the levels of liquidity support documented by Laeven and Valencia (2018), pools of small economies are unlikely to be sustainable LOLR. For example, even with 70 uncorrelated countries the probability of failure of the international LOLR is around 40%; 2) If banking crises are correlated then adding new countries does not help to reduce the probability of failure. The Law of Large Numbers fails to bring benefits from pooling risks for highly correlated financial shocks. In fact, Figure 6 shows that the higher the correlations, the more likely is the pool to fail.

Figure 7 plots the case when countries do make initial contributions of reserves to join the LOLR pool and in addition pay the participation premiums defined in (26). Figure 7 illustrates that with initial contributions of reserves, sustainability of the LOLR pool improves significantly even for highly correlated countries (Panel b). A pool with as few as five countries with each country contributing 4% of its annual output effectively eliminates the probability of failure. These results suggest that recent initiatives for pooling international reserves at the regional level (for example, Chiang Mai Initiative in Asian countries or the Latin American Reserve

Fund) can bring additional benefits through risk-sharing.

6.2 An application to China

In this subsection we evaluate whether it is feasible that a country with a large stock of reserves becomes the international LOLR. This country would receive benefits from being the LOLR that could be explicit (that is, collect insurance premiums) or implicit (for example, political influence or trade benefits). The insured countries would not need to contribute reserves, just to pay the participating premium.

The natural candidate to become the international LOLR is China because it is the country with the largest stock of foreign reserves. Figure 8 plots the dynamics of these reserves. Since December 2008, China has entered into more than 30 bilateral currency swap agreements. Moreover, China has created an even larger network of lending agreements through its development and export-import banks. Aizenman et al. (2015) describe the strategy as a bundling of finance dealing (lending, swap-lines and trade credit) to promote a new type of Chinese-outward mercantilism. Table 4 summarizes the evolution of these agreements.

China's lending agreements have multiple goals: facilitate settlement in renminbi, promote trade and also serve as a source of liquidity as a lender of last resort. For example, in 2013 Pakistan reportedly borrowed an equivalent of US$ 600 million to avert a domestic crisis (later it received a US$6.6 billion loan from the IMF).[21] In a similar move, in 2014 Argentina drew $2.7 billion upon its swap line with China to combat a shortage of dollar funding. China does not provide dollar liquidity but both Pakistan and Argentina were able to convert renminbi to dollars in the offshore market. Venezuela has also relied on China's lending of last resort. Contrary to the IMF, China seems to attach minimal conditions to its loans.

Figure 9a plots both the evolution of the number of countries with which China has a lending agreement, and the average correlation of output between China and the countries with which it has signed agreements. As pointed out by Aizenman et al. (2015), the correlation is relatively high because China has given preference to countries with natural resources or whose economies are strategic for the Chinese economy.[22] The correlation has fallen as more countries have signed agreements. Figure 9b plots the foreign reserves of China as % of the GDP in the pool of countries with an agreement with China. This ratio has decreased over time since China's foreign reserves have been flat or decreasing since 2012 while the number of agreements

[21] See Steil and Walker (2015) and O'Neil (2015).

[22] Morelli et al. (2015) show that during the recent financial crisis the U.S. lending was directed towards those countries more important for the stability of the U.S. financial system.

keeps increasing. Even so, in 2016, if we exclude the euro area from the covered countries, China has foreign reserves that are around 15% of the GDP of the pool of countries with an agreement.

We use the model to simulate the likelihood that China fails to be a sustainable LOLR. We calibrate the initial level of reserves in equation (25) to match the foreign reserves of China as percentage of poolwide GDP excluding the euro area, reported in Figure 9b. The simulation assumes that the cross-country correlation is 0.88, which is the average from Figure 9a, and the number of insured countries of 55 (that is, excluding the euro area). Countries pay the participation premium defined in (26).[23] China's reserves evolve as in equation (25). Reserves are invested at the international risk-free rate. Inflows are the participation premiums collected from the insured countries. Outflows are the lending of last resort subsidies provided to the countries in banking crises. We find that for the current levels of China's reserves, that is, 15% of total GDP of the insured pool, the probability that China fails as an international LOLR over the next 50 years is zero. Thus, given its large stock of foreign reserves, it seems that China can be a sustainable LOLR.

7 Conclusions

This paper studied banking crises and lending of last resort (LOLR) policies in a quantitative model in which banks can default and there is costly-state-verification. LOLR policies are beneficial in crises because they mitigate negative financial accelerators. We solved the model non-linearly to capture the moral hazard induced by the policies. Despite inducing higher bank leverage, LOLR seems beneficial for small open economies because it significantly mitigates banking crises.

Then we studied mechanisms to implement LOLR. Pools of small countries seem to be feasible lenders of last resort if they contribute to the initial stock of reserves. An economy with a large stock of reserves like China appears to be a sustainable international LOLR. Thus, through the lenses of the model, the recent Chinese initiatives to increase its clout as an international LOLR seem beneficial and long-lasting.

The model is real and has the "liability dollarization" channel surveyed in Mendoza (2016) as debt is denominated in units of tradables and collateral is posted in terms of the nontradable

[23] The calibration may be conservative in this regard because it is based on CRRA preferences with a risk aversion of two. This is a standard value in macro models but fails to generate the risk premiums implicit in asset prices.

sector. However, the model abstracts from monetary policy and nominal exchanges rates. An interesting avenue for future research is to integrate these nominal factors. We expect the core results to remain but this new framework would allow to study related questions like exposing the LOLR to exchange rate risk.

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Tables

Table 1. Parameters

Exogenously determined		
β	0.985	Discount factor
η	2	Risk aversion
θ	2.23	Labor disutility parameter
ξ	3	Frisch elasticity of labor supply
α	0.33	Capital share in production
δ	0.025	Capital depreciation rate
ρ_A	0.9	Persistence of TFP shock
σ_A	0.008	Std. deviation of TFP shock
T_b	0.0001	Transfers to banks
$\frac{1}{q_f}$	1.0055	Annual risk-free rate of 2.2%
Endogenously determined		
μ	0.22	Default cost parameter
γ	0.92	Bank survival rate
σ_l	0.24	Low value of risk shock
σ_h	0.2827	High value of risk shock
π_{ll}	0.97	Probability of staying in σ_l state
π_{hh}	0.85	Probability of staying in σ_h state
ϕ	9.8	Investment adjustment cost
ψ	0.108	LOLR parameter

Note: Calibration is at quarterly frequency. See Section 4 for the calibration strategy.

Table 2. Model moments and targets		
Moment	*Model*	*Target*
Credit spread (annual)	4.69%	3%-5%
Dividend payout rate	8%	5%-10%
Leverage ratio	2.76	3
Increase in credit spread during a crisis	4.52 p.p.	4.5 p.p.
Volatility of investment relative to output	4	4
Frequency of crises	5.58%	4%-10%
Duration of crises (years)	1.2	1-3
Liquidity support (as % of bank liabilities)	10.8%	10.8%

Note: See Section 4 for details. Percentage points are abbreviated as p.p.

Table 3. Comparing unconditional averages with and without LOLR	
	Change from No-LOLR to LOLR
Output	0.90%
Consumption	0.65%
Capital	1.36%
Bank equity	0.32%
Bank leverage	0.96%
Credit spread	0.06 p.p.
Frequency of a crisis	-0.75 p.p.
Welfare gains	0.008%

Note: Welfare is the unconditional average of compensating consumption variations (in %) computed over the stationary distribution of the No-LOLR economy. See Section 5 for details.

Table 4. China's lending programs

(Year of the agreement)

2007 and before	2008	2009
Angola, Argentina, Brazil, Equatorial Guinea, Ghana, Jamaica, Nigeria, Republic of Congo, Venezuela	Democratic Rep. of Congo, Ethiopia	*Belarus, Bolivia, Ecuador, *Hong Kong, *Indonesia, *Malaysia, Peru, *South Korea, Sudan
2010	**2011**	**2012**
*Iceland, *Singapore	Bahamas, *Kazakhstan, *Mongolia, *New Zealand, *Pakistan, *Thailand, *Uzbekistan, Zimbabwe	*Australia, Guyana, *Turkey, *Ukraine, *United Arab Emirates
2013	**2014**	**2015**
*Albania, *Euro Area, *Hungary, Mexico, Trinidad and Tobago, *United Kingdom	*Canada, *Qatar, *Russia, *Sri Lanka, *Switzerland	*Armenia, Barbados, *Chile, Costa Rica, *South Africa, *Suriname, *Tajikistan
Since 2016		
*Morocco, *Serbia, *Egypt		

Note: Countries with the symbol * only have currency swap agreements. See Appendix C for data sources.

Figures

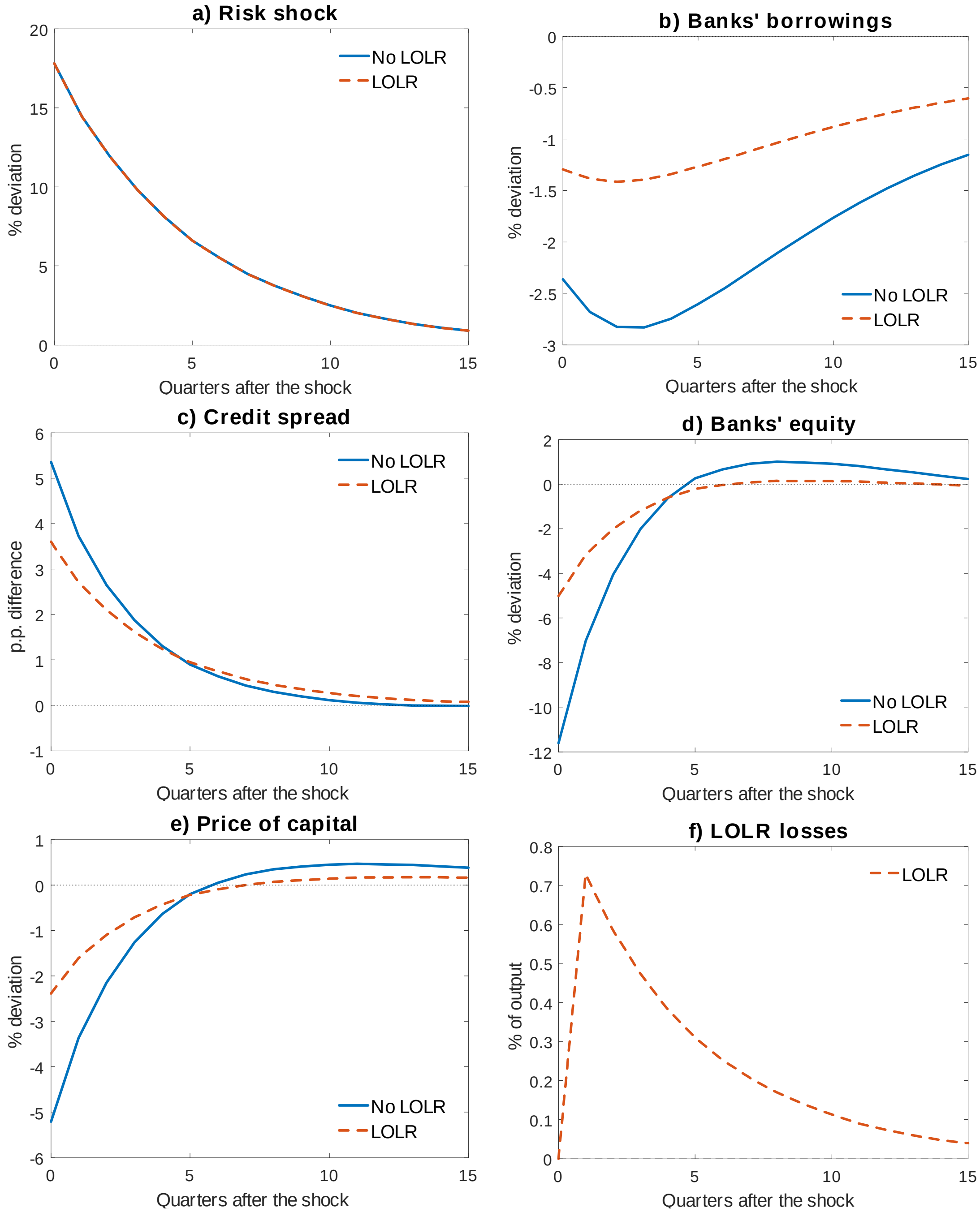

Figure 1. No-LOLR vs LOLR: Impulse responses I. This figure reports the responses to an increase in risk. Each panel plots the deviations between the simulated path that starts with high risk (σ_h) relative to the simulated path that starts with low risk (σ_l). Section 5 contains the numerical details, which follow Bianchi (2016).

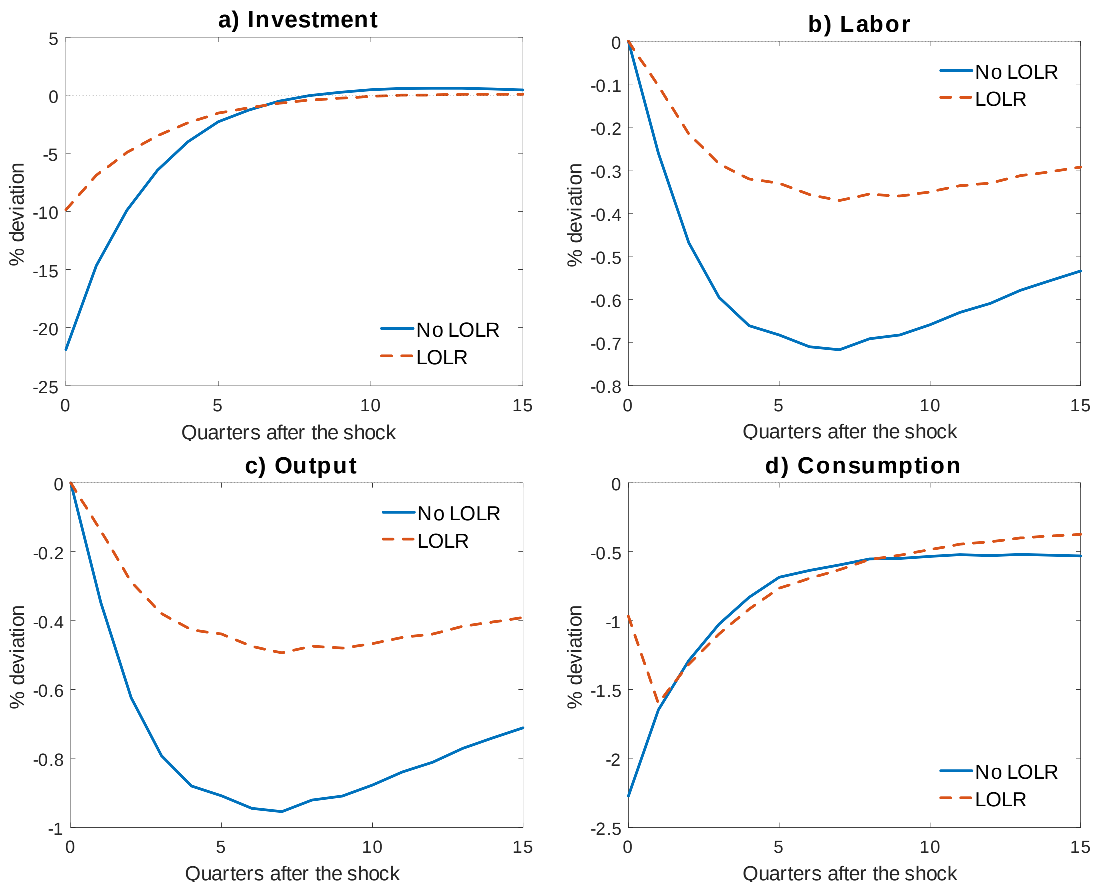

Figure 2. No-LOLR vs LOLR: Impulse responses II. This figure reports the responses to an increase in risk. Each panel plots the deviations between the simulated path that starts with high risk (σ_h) relative to the simulated path that starts with low risk (σ_l). Section 5 contains the numerical details, which follow Bianchi (2016).

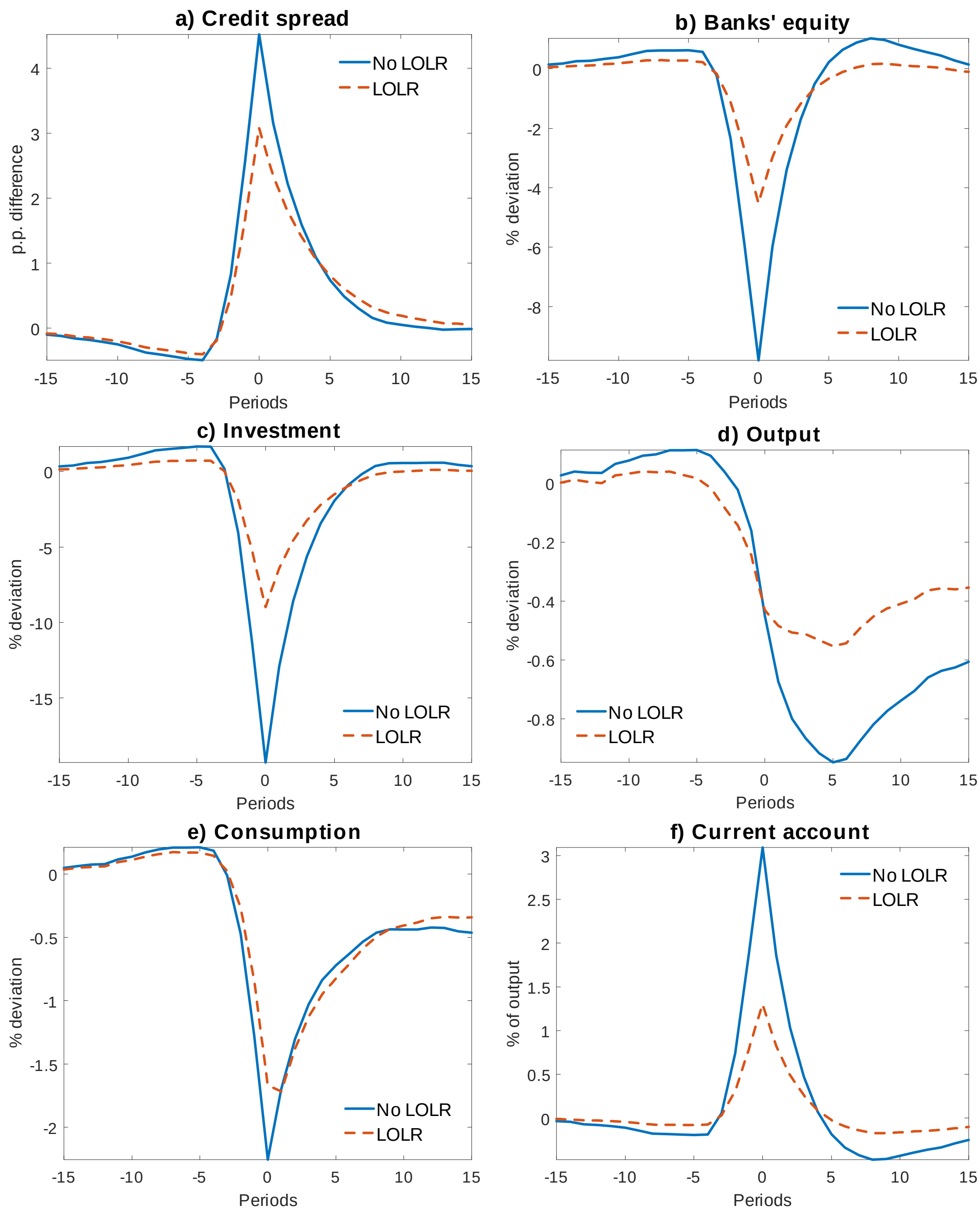

Figure 3. No-LOLR vs LOLR: Average crisis episode. This figure reports the crises in the economies with and without LOLR. Time 0 denotes the crisis date. The variables are in percent deviations (or in differences) relative to their respective unconditional mean values. Section 5 contains the details.

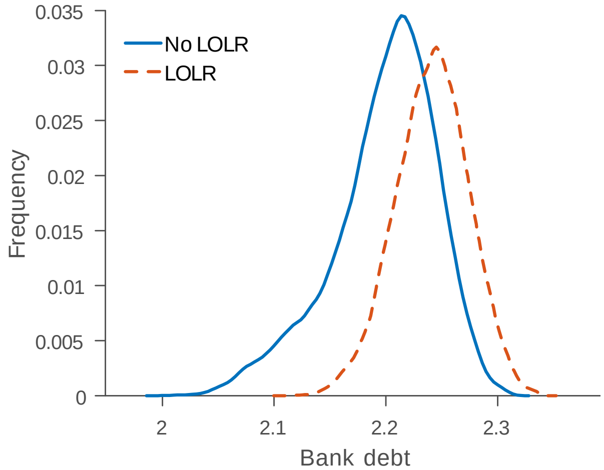

Figure 4. No-LOLR vs LOLR: Ergodic distribution of banks' debt. This figure plots the stationary distribution of banks' debt for the economies with and without LOLR.

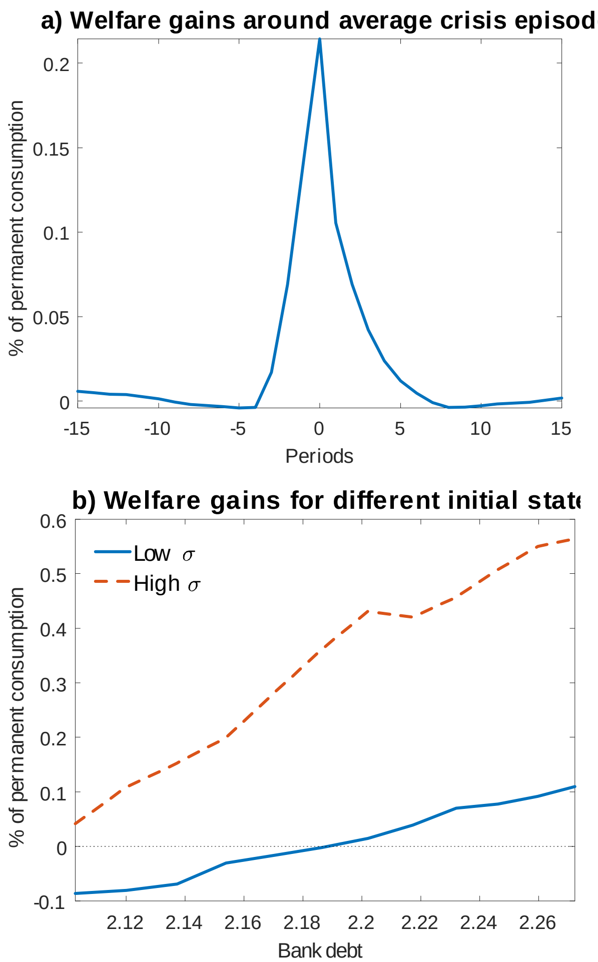

Figure 5. Welfare gains from LOLR. This figure illustrates welfare implications of the LOLR policy. Panel a) has the simulated welfare gains around an average crisis episode. Panel b) shows welfare gains as a function of initial debt levels and for high and low σ shock. Both lines of Panel b) are plotted for capital stock at its unconditional mean value, and for a low level of TFP.

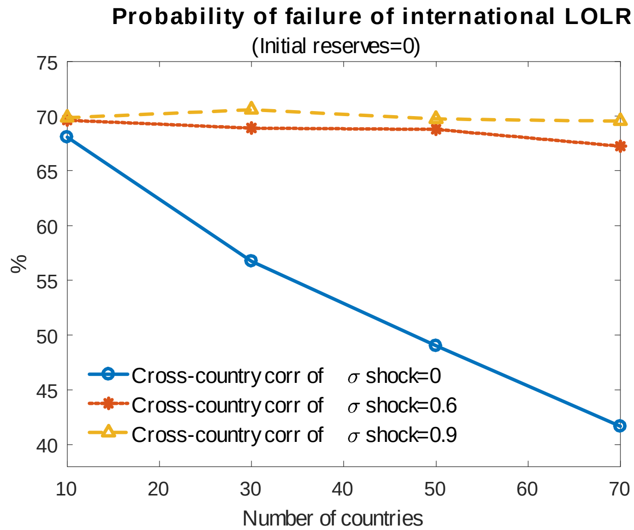

Figure 6. Sustainability of the international LOLR. The role of shock correlation and the number of participating countries. This figure plots the probability that the international LOLR fails for different cross-country correlations of risk shocks and different number of participating countries. Cross-country correlation of TFP shocks is zero. The figure assumes that participating countries pay the participation premium defined in Section 3.1.2. The LOLR starts with no initial reserves. The probability of failure is computed over a 50 years period.

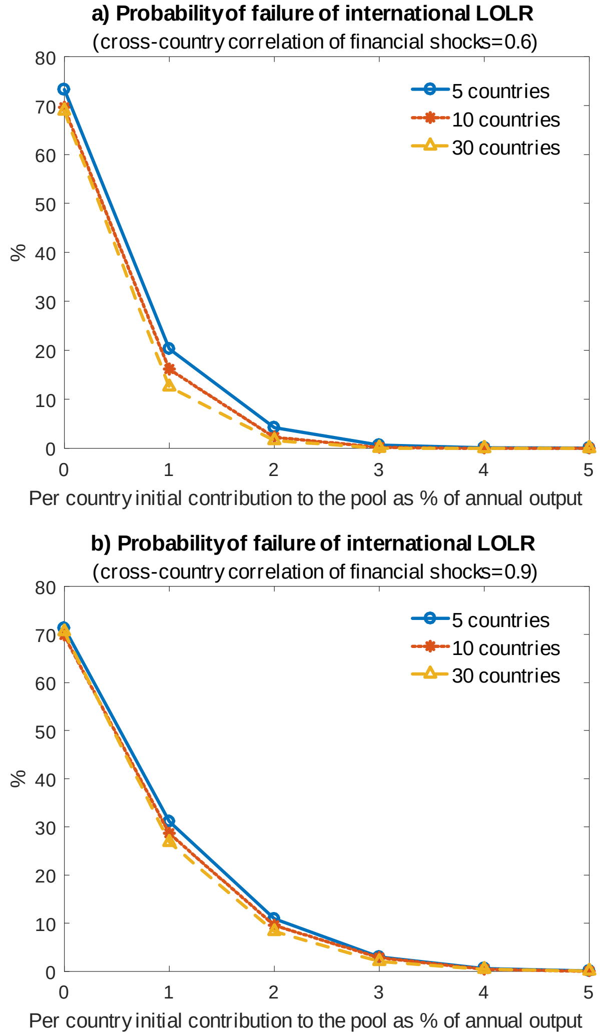

Figure 7. Sustainability of the international LOLR. The role of the initial level of reserves and the number of participating countries. This figure plots the probability that the international LOLR fails for different initial levels of reserves and different number of participating countries. Both panels assume that participating countries pay the participation premium defined in Section 3.1.2. Panel a) assumes the cross-country correlation of financial shocks of 0.6, and Panel b) has the correlation of 0.9. The cross-country correlation of TFP shocks is zero. The probabilities of failure are computed over a 50 years period.

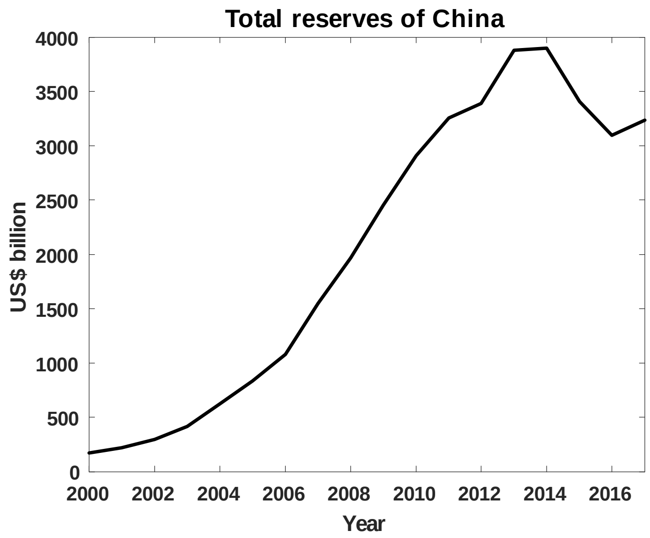

Figure 8. China's foreign exchange reserves. Data source: People's Bank of China.

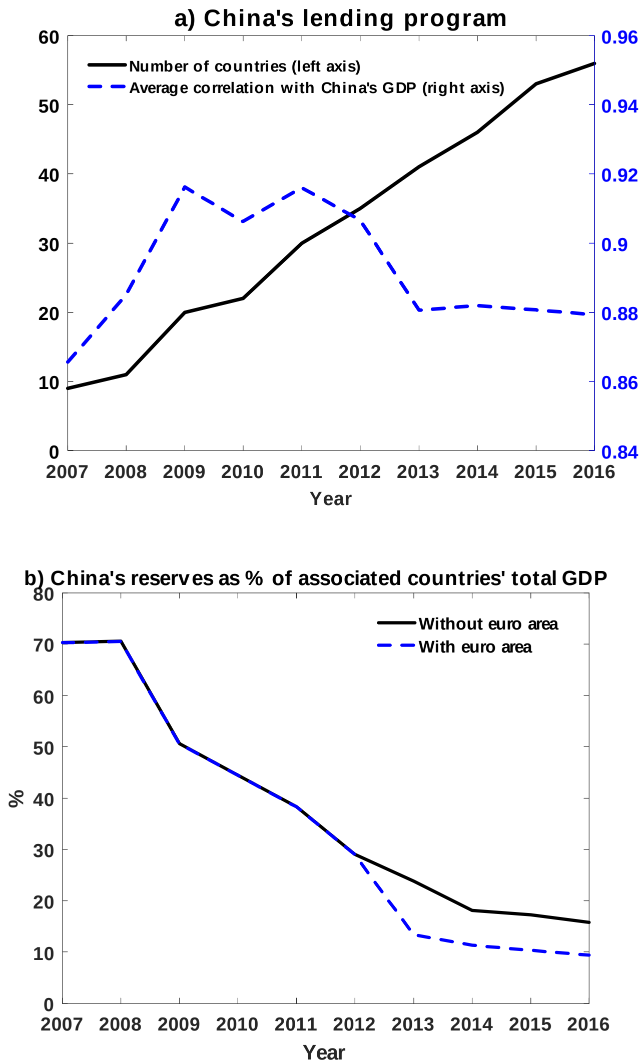

Figure 9. Evolution of China's lending programs. The top panel plots the number of countries with which China has signed lending agreements, and the average correlation over the 2000-2017 period between China's GDP and the GDP of the countries with signed agreements at a given date. Section 6.2 has more details. The bottom panel plots China's foreign exchange reserves as % of the total GDP of the countries that have signed lending agreements with China. One line excludes the euro area. For data sources see Appendix C.

Online Appendices-Not-For-Publication

A. Derivation of equilibrium conditions

A1 Banks

A1.1 Model without LOLR

Bank j faces the following dynamic optimization problem:

$$V_{j,t} = \max_{B_{j,t+1},K_{j,t+1}} \left\{ (1-\gamma) N_{j,t} + \gamma \mathbb{E}_t \left[m_{t,t+1} \max \left\{ V_{j,t+1}, 0 \right\} \right] \right\}, \tag{A1}$$

subject to

$$p_t K_{j,t+1} = N_{j,t} + q_t B_{j,t+1}, \tag{A2}$$

$$\frac{q_t B_{j,t+1}}{q_f} = \mathbb{E}_t \left(\begin{array}{c} \int_{\overline{\omega}_{t+1}}^{\infty} B_{j,t+1} dF_{t+1}(\omega) + \\ + (1-\mu) \int_0^{\overline{\omega}_{t+1}} \omega \left[r_{t+1} + (1-\delta) p_{t+1} \right] K_{j,t+1} dF_{t+1}(\omega) \end{array} \right), \tag{A3}$$

$$N_{j,t+1} = \omega \left[r_{t+1} + (1-\delta) p_{t+1} \right] K_{j,t+1} - B_{j,t+1}, \tag{A4}$$

$$\overline{\omega}_{t+1} \left[r_{t+1} + (1-\delta) p_{t+1} \right] K_{j,t+1} = B_{j,t+1}. \tag{A5}$$

where we explicitly replaced $R_{k,t+1}$ with the expression (11) in (3)-(5) to obtain (A3)-(A5).

Denote by $b_{j,t+1}$ an individual bank's debt-to-capital ratio,

$$b_{j,t+1} \equiv \frac{B_{j,t+1}}{K_{j,t+1}}. \tag{A6}$$

It is also convenient to denote the partial expectation of ω by

$$G_t(\overline{\omega}_t) \equiv \int_0^{\overline{\omega}_t} \omega dF_t(\omega). \tag{A7}$$

Using the definitions (A6) and (A7), we can rewrite the constraints (A2)-(A5) as follows:

$$\left(p_t - q_t b_{j,t+1} \right) K_{j,t+1} = N_{j,t}, \tag{A8}$$

$$q_t = q_f \mathbb{E}_t \left\{ \left[1 - F_{t+1}(\overline{\omega}_{t+1}) \right] - (1-\mu) \frac{\left[r_{t+1} + (1-\delta) p_{t+1} \right]}{b_{j,t+1}} G_{t+1}(\overline{\omega}_{t+1}) \right\}, \tag{A9}$$

$$N_{j,t+1} = \left(\omega \left[r_{t+1} + (1-\delta) p_{t+1} \right] - b_{j,t+1} \right) K_{j,t+1}, \tag{A10}$$

$$\overline{\omega}_{t+1} = \frac{b_{j,t+1}}{\left[r_{t+1} + (1-\delta)\, p_{t+1}\right]}. \tag{A11}$$

We guess and verify that a bank's value function is linear in individual net worth, with a time-varying coefficient υ_t that is common across banks,

$$V_{j,t} = \upsilon_t N_{j,t}. \tag{A12}$$

Using the guess (A12) together with equation (A10), and definitions (A6) and (A7), we can rewrite the Bellman equation (A1) as

$$\begin{aligned} V_{j,t} &= \max_{K_{j,t+1}, b_{j,t+1}} \left\{ (1-\gamma) N_{j,t} + \gamma \mathbb{E}_t \left[m_{t,t+1} \upsilon_{t+1} \int_{\overline{\omega}_{t+1}}^{\infty} \left[\left(\omega \left[r_{t+1} + (1-\delta)\, p_{t+1} \right] - b_{j,t+1} \right) K_{j,t+1} \right] dF_{t+1}(\omega) \right] \right\} = \\ &= \max_{K_{j,t+1}, b_{j,t+1}} \left\{ (1-\gamma) N_{j,t} + \gamma \mathbb{E}_t \left[m_{t,t+1} \upsilon_{t+1} \begin{pmatrix} \left[1 - G_{t+1}\left(\overline{\omega}_{t+1}\right)\right] \left[r_{t+1} + (1-\delta)\, p_{t+1} \right] + \\ - \left[1 - F_{t+1}\left(\overline{\omega}_{t+1}\right)\right] b_{j,t+1} \end{pmatrix} K_{j,t+1} \right] \right\}. \end{aligned} \tag{A13}$$

The bank's problem then is to maximize (A13) subject to the constraints (A8)-(A11).

Let Λ_t be the Lagrange multiplier associated with the bank's balance sheet constraint (A8). Then the Lagrangian function for this problem is

$$\begin{aligned} \pounds_{j,t} &= (1-\gamma) N_{j,t} + \gamma \mathbb{E}_t \left[m_{t,t+1} \upsilon_{t+1} \begin{pmatrix} \left[1 - G_{t+1}\left(\overline{\omega}_{t+1}\right)\right] \left[r_{t+1} + (1-\delta)\, p_{t+1} \right] + \\ - \left[1 - F_{t+1}\left(\overline{\omega}_{t+1}\right)\right] b_{j,t+1} \end{pmatrix} K_{j,t+1} \right] + \\ &\quad + \Lambda_t \left[N_{j,t} - K_{j,t+1} \left(p_t - q_t b_{j,t+1} \right) \right], \end{aligned}$$

with $\overline{\omega}_{t+1}$ and q_t given by (A11) and (A9), respectively.

The first order optimality conditions with respect to $K_{j,t+1}$ and $b_{j,t+1}$ are

$$\Lambda_t \left(p_t - q_t b_{j,t+1} \right) = \gamma \mathbb{E}_t \left\{ m_{t,t+1} \upsilon_{t+1} \left(\left[1 - G_{t+1}\left(\overline{\omega}_{t+1}\right)\right] \left[r_{t+1} + (1-\delta)\, p_{t+1} \right] - \left[1 - F_{t+1}\left(\overline{\omega}_{t+1}\right)\right] b_{j,t+1} \right) \right\}, \tag{A14}$$

and

$$\Lambda_t \left(q_t + \frac{\partial q_t}{\partial b_{j,t+1}} b_{j,t+1} \right) = \gamma \mathbb{E}_t \left\{ m_{t,t+1} \upsilon_{t+1} \left[1 - F_{t+1}\left(\overline{\omega}_{t+1}\right)\right] \right\}. \tag{A15}$$

Using (A14) and (A8) we can rewrite the value function (A13) as

$$\begin{aligned} V_{j,t} &= (1-\gamma) N_{j,t} + \Lambda_t \left(p_t - q_t b_{j,t+1} \right) K_{j,t+1} = \\ &= \left[(1-\gamma) + \Lambda_t \right] N_{j,t}. \end{aligned}$$

This verifies our initial conjecture that value function is linear in individual net worth,

$$\upsilon_t = (1-\gamma) + \Lambda_t, \tag{A16}$$

and implies that all banks will choose the same debt-to-capital ratio, and will face the same default threshold and debt pricing function.

Next we compute the partial derivative of debt pricing equation with respect to $b_{j,t+1}$ which appears in FOCs,

$$\frac{\partial q_t}{\partial b_{j,t+1}} = -q_f \mathbb{E}_t \left(\mu \frac{1}{b_{j,t+1}} f_{t+1}(\overline{\omega}_{t+1}) \overline{\omega}_{t+1} + (1-\mu) \frac{r_{t+1} + (1-\delta) p_{t+1}}{b_{j,t+1}^2} G_{t+1}(\overline{\omega}_{t+1}) \right). \tag{A17}$$

Using (A16) and (A17) we can further simplify the first order conditions (A14) and (A15):

$$\Lambda_t p_t = \gamma \mathbb{E}_t \left\{ m_{t,t+1} \left[(1-\gamma) + \Lambda_{t+1}\right] \left[\begin{array}{c} [1 - G_{t+1}(\overline{\omega}_{t+1})] \left[r_{t+1} + (1-\delta) p_{t+1}\right] + \\ - [1 - F_{t+1}(\overline{\omega}_{t+1})] \, b_{t+1} \end{array} \right] \right\} + \Lambda_t q_t b_{t+1}, \tag{A18}$$

$$\Lambda_t q_f \mathbb{E}_t \left\{ [1 - F_{t+1}(\overline{\omega}_{t+1})] - \mu f_{t+1}(\overline{\omega}_{t+1}) \overline{\omega}_{t+1} \right\} = \gamma \mathbb{E}_t \left\{ m_{t,t+1} \left[(1-\gamma) + \Lambda_{t+1}\right] [1 - F_{t+1}(\overline{\omega}_{t+1})] \right\}. \tag{A19}$$

A1.2 Model with LOLR

When there is LOLR, the debt pricing equation changes to

$$q_t = q_f \left\{ \psi \mathbb{I}_{\{\sigma_t = \sigma_h\}} + \left(1 - \psi \mathbb{I}_{\{\sigma_t = \sigma_h\}}\right) \mathbb{E}_t \left([1 - F_{t+1}(\overline{\omega}_{t+1})] + (1-\mu) \frac{r_{t+1} + (1-\delta) p_{t+1}}{b_{t+1}} G_{t+1}(\overline{\omega}_{t+1}) \right) \right\}. \tag{A20}$$

The rest of the bank's optimization problem is the same as in the no-LOLR case. The optimality conditions with respect to b_{t+1} and $K_{j,t+1}$ are

$$\begin{aligned} &\Lambda_t q_f \left[\psi \mathbb{I}_{\{\sigma_t = \sigma_h\}} + \left(1 - \psi \mathbb{I}_{\{\sigma_t = \sigma_h\}}\right) \mathbb{E}_t \left\{ [1 - F_{t+1}(\overline{\omega}_{t+1})] - \mu f_{t+1}(\overline{\omega}_{t+1}) \overline{\omega}_{t+1} \right\} \right] \\ &= \gamma \mathbb{E}_t \left\{ m_{t,t+1} \left[(1-\gamma) + \Lambda_{t+1}\right] [1 - F_{t+1}(\overline{\omega}_{t+1})] \right\}, \end{aligned} \tag{A21}$$

and

$$\Lambda_t p_t = \gamma \mathbb{E}_t \left\{ m_{t,t+1} \left[(1-\gamma) + \Lambda_{t+1}\right] \left[\begin{array}{c} [1 - G_{t+1}(\overline{\omega}_{t+1})] \left[r_{t+1} + (1-\delta) p_{t+1}\right] + \\ - [1 - F_{t+1}(\overline{\omega}_{t+1})] \, b_{t+1} \end{array} \right] \right\} + \Lambda_t q_t b_{t+1}, \tag{A22}$$

with q_t given by (A20).

A2 Capital producers

Capital producers' optimality condition is

$$p_t = \left[1 - \phi\left(\frac{I_t}{K_t} - \delta\right)\right]^{-1}. \tag{A23}$$

A3 Final goods producers

The final good producing firm's optimality condition with respect to labor is

$$W_t = (1-\alpha)\, A_t K_t^{\alpha} L_t^{-\alpha}. \tag{A24}$$

The zero profit condition then implies

$$r_t = \alpha A_t K_t^{\alpha-1} L_t^{1-\alpha}. \tag{A25}$$

A4 Households

The first order optimality condition for household's consumption-labor choice is given by

$$W_t = -\frac{u_L(C_t, L_t)}{u_C(C_t, L_t)}. \tag{A26}$$

The household's budget constraint in the economy without LOLR is

$$C_t = W_t L_t + \Omega_t - T_b. \tag{A27}$$

In the economy with LOLR the household's budget constraint becomes

$$C_t = W_t L_t + \Omega_t - T_b - \Xi_t, \tag{A28}$$

where Ξ_t is defined in (23).

With GHH preferences, the household's optimality condition with respect to labor $(A26)$ becomes

$$W_t = \theta L_t^{\frac{1}{\xi}}. \tag{A29}$$

Combining (A24) with the above labor supply equation yields

$$L_t = \left(\frac{1-\alpha}{\theta} \right)^{\frac{\xi}{1+\alpha\xi}} A_t^{\frac{\xi}{1+\alpha\xi}} K_t^{\frac{\alpha\xi}{1+\alpha\xi}}. \tag{A30}$$

B. Numerical appendix

The solution algorithm is backward time-iteration on equilibrium conditions. We formulate the equilibrium conditions in recursive form. The variables with prime superscript denote next period values.

There are two exogenous shocks in the model: a financial shock, σ, and a TFP shock, A. We discretize the AR(1) process for TFP shock into 3-state $\{A_l, A_m, A_h\}$ symmetric Markov chain using Tauchen-Hussey (1991) method. Since σ shock follows a two-state $\{\sigma_l, \sigma_h\}$ Markov chain, the discretized exogenous state space consists of 6 possible states: $(\sigma_l, A_l), (\sigma_l, A_m), (\sigma_l, A_h), (\sigma_h, A_l), (\sigma_h, A_m), (\sigma_h, A_h)$. By independence of σ and TFP shocks, the transition probability matrix for the exogenous state space is given by

$$\mathcal{P} = \Pi \otimes P_A,$$

where $\otimes$ denotes a Kronecker product, Π is given by (21) and P_A is a transition matrix associated with the discretized TFP process.

The model has two endogenous state variables: the beginning-of-period outstanding banking sector debt B and capital stock K. To improve the computational efficiency of the algorithm, we redefine the endogenous state space and instead of the level of debt B we use debt-to-capital ratio, $b \equiv \frac{B}{K}$, as a state variable.[24]

Let S be an exogenous state vector, $S = \{\sigma, A\}$. Denote today's aggregate state vector by X and tomorrow's state vector by X':

$$X \equiv \{b, K, S\}, \quad X' \equiv \{b'(X), K'(X), S'\}.$$

We are looking for time-invariant policy functions, $p(X), r(X), C(X), L(X), I(X), Y(X),$

[24] In our model bank debt and capital stock strongly co-move. Using the level of bank debt as a state variable, together with the level of capital stock, would imply solving the model on many grid points which are never visited in equilibrium. Redefining the state space in terms of debt-to-capital ratio avoids the above problem and improves computational efficiency. In addition, this way we also minimize extrapolating functions outside of the grid points, which in the case of linear interpolation can be problematic See Faria-e-Castro (2018) for a similar approach and more detailed discussion on this.

$b'(X), K'(X), \overline{\omega}(X), N(X), q(X), \Lambda(X), \Omega(X)$, that solve the equilibrium conditions:

Banks

$$[p(X) - q(X) b'(X)] K'(X) = N(X). \tag{A31}$$

$$\overline{\omega}(X) = \frac{b}{[r(X) + (1-\delta) p(X)]}. \tag{A32}$$

$$q(X) = q_f \mathbb{E}_{S'|S} \left[[1 - F(\overline{\omega}(X'))] + (1-\mu) \frac{G(\overline{\omega}(X'))}{\overline{\omega}(X')}) \right]. \tag{A33}$$

$$\Lambda(X) = \frac{\gamma\beta \mathbb{E}_{S'|S} \left\{ \frac{u_C(C(X'),L(X'))}{u_C(C(X),L(X))} [(1-\gamma) + \Lambda(X')] [1 - F(\overline{\omega}(X'))] \right\}}{q_f \mathbb{E}_{S'|S} [1 - F(\overline{\omega}(X')) - \mu \overline{\omega}(X') f(\overline{\omega}(X'))]}. \tag{A34}$$

$$\Lambda(X) p(X) = \gamma\beta \mathbb{E}_{S'|S} \left\{ \frac{u_C(C(X'), L(X'))}{u_C(C(X), L(X))} [1 - \gamma + \Lambda(X')] \begin{pmatrix} [1 - G(\overline{\omega}(X'))] [r(X') + (1-\delta) p(X')] + \\ - [1 - F(\overline{\omega}(X'))] b'(X) \end{pmatrix} \right. \tag{A35}$$

$$+ \Lambda(X) q(X) b'(X).$$

$$N(X) = \gamma \{ [1 - G(\overline{\omega}(X))] [r(X) + (1-\delta) p(X)] - [1 - F(\overline{\omega}(X))] b \} K + T_b. \tag{A36}$$

$$\Omega(X) = (1-\gamma) \{ [1 - G(\overline{\omega}(X))] [r(X) + (1-\delta) p(X)] - [1 - F(\overline{\omega}(X))] b \} K. \tag{A37}$$

Capital Producers

$$p(X) = \left[1 - \phi \left(\frac{I(X)}{K} - \delta \right) \right]^{-1}. \tag{A38}$$

$$K'(X) = (1-\delta) K + I(X) - \frac{\phi}{2} \left(\frac{I(X)}{K} - \delta \right)^2 K. \tag{A39}$$

Households and final goods firms

$$C(X) = (1-\alpha) Y(X) + \Omega(X) - T_b. \tag{A40}$$

$$Y(X) = A K^{\alpha} [L(X)]^{1-\alpha}. \tag{A41}$$

$$L(X) = \left(\frac{1-\alpha}{\theta} \right)^{\frac{\xi}{1+\alpha\xi}} A^{\frac{\xi}{1+\alpha\xi}} K^{\frac{\alpha\xi}{1+\alpha\xi}}. \tag{A42}$$

$$r(X) = \alpha A K^{\alpha-1} [L(X)]^{1-\alpha}. \tag{A43}$$

The algorithm follows these steps:

1. Generate a discrete grid for b and K, $g_b = \{b_1, b_2, ..., b_{N_b}\}$, $g_K = \{k_1, k_2, ..., k_{N_k}\}$, and

denote by $g_S = \{S_1, ..., S_{N_s}\}$ the exogenous state space. In order to evaluate functions on outside of the grid points we use piece-wise linear interpolation.

2. Conjecture $p_T(X)$, $\overline{\omega}_T(X)$, $q_T(X)$, $\Lambda_T(X)$, at time T, $\forall b \in g_b$ $\forall K \in g_K$ and $\forall S \in g_S$.

3. Set $j = 1$.

4. Given the conjecture $p_T(X)$ solve for $I_T(X)$ using (A38) and for $K'_T(X)$ from (A39). Compute $r(X)$ and $L(X)$ using (A42) and (A43). Given the conjectures, obtain $N_T(X)$, $\Omega_T(X)$ and $C_T(X)$ from (A36), (A37), and (A40), respectively. Given these solutions and the conjecture for $q_T(X)$, solve for $b'_T(X)$ using (A31). To evaluate expectations, interpolate functions given the solutions of $b'_T(X)$ and $K'_T(X)$, and the conjectures for $p_T(X)$, $\overline{\omega}_T(X)$ and $\Lambda_T(X)$. Compute updated $p_{T-j}(X)$, $\overline{\omega}_{T-j}(X)$, $\Lambda_{T-j}(X)$, and $q_{T-j}(X)$ using (A35), (A34), (A32) and (A33).

5. Evaluate convergence: If $\sup_X ||\Psi_{T-j}(X) - \Psi_T(X)|| < \epsilon$ for $\Psi = p, \overline{\omega}, q, \Lambda$, then stop since we have found the competitive equilibrium. Otherwise, go to $j+1$ and set $\Psi_{T-j+1}(X) = \Psi_{T-j}(X)$ and go to step 4.

When there is LOLR, equations (A33)-(A35) are replaced by (A20)-(A22), and consumption is given by (24).

C. Data sources

The data of foreign exchange reserves that Figure 8 plots are from the People's Bank of China (PBOC). The GDP data used in Figure 9 come from the World Bank.

We merged three databases to construct the set of countries with lending programs with China reported in Table 4:[25]

1) Countries that have signed bilateral currency swap agreements according to the PBOC. These countries are Albania, Argentina, Armenia, Australia, Belarus, Brazil, Canada, Chile, European Central Bank, Egypt, Hong Kong, Hungary, Iceland, Indonesia, Kazakhstan, Malaysia, Mongolia, Morocco, New Zealand, Nigeria, Pakistan, Qatar, Republic of Korea, Russia, Serbia, Singapore, South Africa, Sri Lanka, Suriname, Switzerland, Tajikistan, Thailand, Turkey, Ukraine, United Arab Emirates, United Kingdom, Uzbekistan.

2) The China-Latin America Finance Database gathered by Inter-America Dialogue (Gallagher and Myers 2017). This database contains data for Argentina, Bahamas, Barbados,

[25] For countries in several databases, like Argentina and Brazil, Table 4 records the date of the first agreement.

Bolivia, Brazil, Costa Rica, Ecuador, Guyana, Jamaica, Mexico, Peru, Trinidad and Tobago, Venezuela.

3) Brautigam and Gallagher (2014) database on agreements with African countries. These countries are Angola, Democratic Republic of Congo, Equatorial Guinea, Ethiopia, Ghana, Nigeria, Republic of Congo, Sudan, Zimbabwe.

Additional Figures

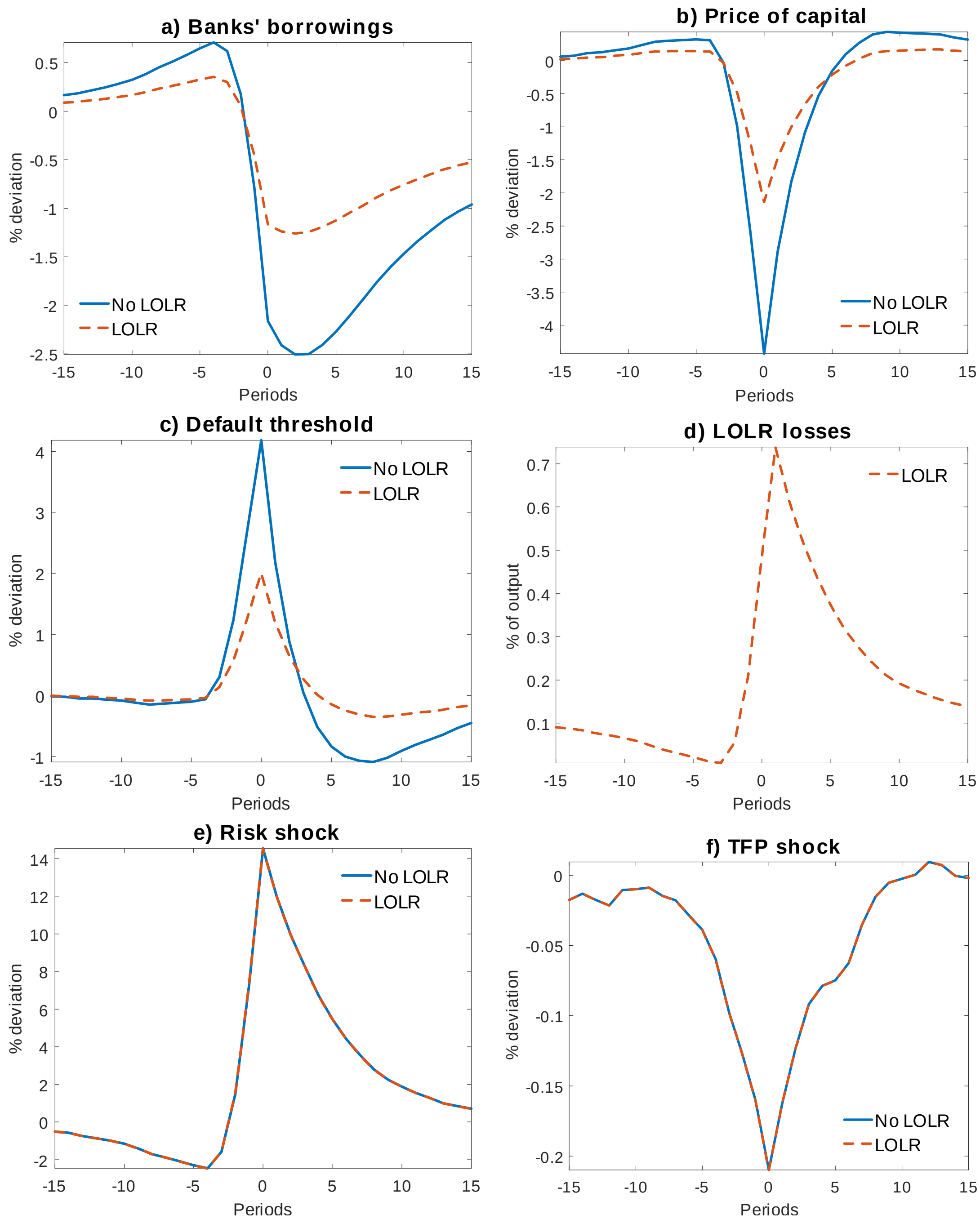

Figure A1. No-LOLR vs LOLR. Average crisis episode: Additional variables. This figure reports the crises in the economies with and without LOLR. Time 0 denotes the crisis date. The variables are in percent deviations (or in differences) relative to their respective unconditional mean values. Section 5 contains the details.

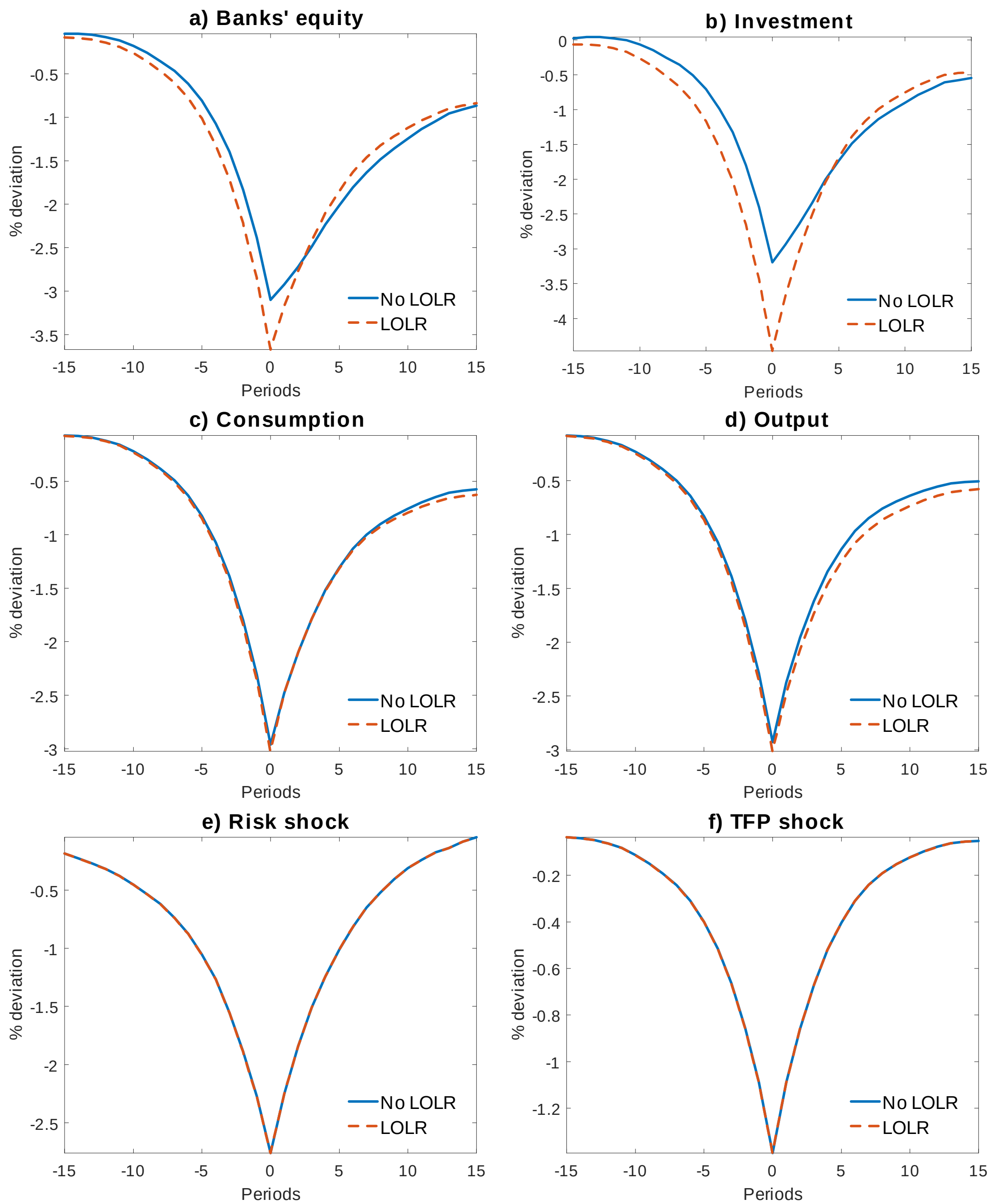

Figure A2. No-LOLR vs LOLR: Average episode with normal financial times and negative TFP shock. This figure reports times with no financial crisis and with productivity slowdown in the economies with and without LOLR. Time 0 denotes the date when TFP takes its lowest value and $\sigma = \sigma_l$. The variables are in percent deviations (or in differences) relative to their respective unconditional mean values. Section 5 contains the details.