RESERVE REQUIREMENTS AND OPTIMAL CHINESE STABILIZATION POLICY

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Abstract. We build a two-sector DSGE model of the Chinese economy to study the role of reserve requirement policy for capital reallocation and business cycle stabilization. In the model, state-owned enterprises (SOEs) have lower average productivity than private firms, but they enjoy government guarantees on bank loans. Private firms, in contrast, rely on "off-balance sheet" bank financing. Banks' on-balance sheet loans to SOEs face reserve requirement regulations, but off-balance sheet loans do not. Our framework implies a tradeoff for reserve requirement policy: Increasing the required reserve ratio acts as a tax on SOE activity and reallocates resources to private firms, raising aggregate productivity. This reallocation is supported by empirical evidence. However, raising reserve requirements also increases the incidence of costly SOE failures. Under our calibration, reserve requirement policy can be complementary to interest rate policy for stabilizing macro fluctuations and improving welfare.

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I. Introduction

China's central bank, the Peoples Bank of China (PBOC), frequently uses reserve requirements (RR) as a policy instrument for macroeconomic stabilization. Since 2006, the PBOC has adjusted the required reserve ratio at least 40 times. Changes have also been substantial. During the tightening cycles from 2006 to 2011, the required reserve ratio increased from 8.5 percent to 21.5 percent (see Figure 1). The literature has argued that these changes in reserve requirements are an important policy tool for the PBOC [e.g. Ma et al. (2013)].[1]

Under China's existing financial system, the Chinese government provides explicit or implicit guarantees for loans to State-owned enterprizes (SOEs) [e.g. Song et al. (2011)]. As a result, SOEs enjoy a borrowing advantage on formal bank loans despite their lower average productivity compared to China's private sector (POEs) (Elliott et al., 2015). Financing of private firms, especially small and medium-sized firms, largely relies on off-balance sheet lending by commercial banks and informal financial intermediaries, such as shadow banks (Lu et al., 2015).[2]

Since banks' on-balance sheet loans to SOEs are subject to RR regulations but their off-balance sheet loans are not, raising RR acts as a tax on SOE activity in China. When RR increases, this tax raises the incentive to move capital from the SOE sector to the private (POE) sector. Moreover, since private firms are on average more productive than SOEs

[1] Some studies in the literature suggest that the PBOC uses RR to help address external imbalances. For example, Ma et al. (2013) argues that the PBOC uses RR to mop up foreign exchange revenues under China's tightly controlled capital account. Following the global financial crisis, Chinas limited capital mobility combined with low foreign interest rates raised the fiscal cost of sterilizing capital inflows. Chang et al. (2015b) demonstrate that there is a tradeoff between sterilization costs and domestic price stability, raising the possibility of welfare gains through the use of RR as an alternative policy tool. China is not the only country that employs RR as a stabilization tool. Federico et al. (2014) find that about two-thirds of the emerging market countries in their study use RR for stabilization. Many of these other emerging market economies have open capital accounts, and primarily rely on RR policy as a mechanism for tightening activity without attracting further expansionary capital inflows, as conventional interest rate increases would do (Montoro and Moreno, 2011).

[2] In China, the government directly controls the volume of commercial bank loans (through "window guidance" of lending) and imposes caps on the loan-to-deposit ratio. These limitations on on-balance sheet lending, combined with sharp increases in the RR ratio, have contributed to a rapid expansion in shadow banking activity in the forms of wealth management products and entrusted loans. The bulk of this shadow banking activity was financed by commercial banks. See Hachem and Song (2015), Chen et al. (2016), and Wang et al. (2016) for some recent analyses. Lending by China's shadow banking sector increased by over 30 percent per year between 2009 and 2013. While shadow banks can help reduce intermediation costs, their unregulated activity raises risks to financial and macroeconomic stability (Gorton and Metrick, 2010; Verona et al., 2013; Elliott et al., 2015). See Funke et al. (2015) for a discussion of the implications of interest rate liberalization for China's monetary policy transmission in a DSGE model with shadow banking.

(Hsieh and Klenow, 2009; Hsieh and Song, 2015), this capital reallocation should improve aggregate productivity and therefore raise aggregate output.[3] This reallocation mechanism is supported by empirical evidence, as shown in Section II below. On the other hand, raising RR reduces aggregate demand and it also increase the incidence of bankruptcies for SOEs by raising their funding costs.

In this paper, we build a DSGE model to highlight this tradeoff for the use of reserve requirement policy. We develop a model in which a homogeneous intermediate good is produced by firms in two sectors—an SOE sector and a POE sector—using the same production technology. Consistent with empirical evidence, we assume that POEs have higher average productivity than SOEs.

To incorporate financial frictions, we build on the framework of Bernanke et al. (1999) (BGG) with costly state verification. We generalize the BGG framework to our two-sector environment by assuming that firms in each sector need to finance working capital with both internal net worth and external debt. Production and financing decisions are made after observing an aggregate productivity shock.

The non-financial sectors in our model are quite standard. There is a representative household who purchases a final good for consumption and capital investment, and supplies labor and capital to intermediate good firms. The final good is a composite of retail goods. Each retailer uses the homogeneous intermediate good as an input in producing a differentiated retail product. Retailers are price takers in the input markets, but monopolistic competitors in the product markets. Retail price adjustments are costly [e.g. Rotemberg (1982)]. As in BGG, we assume that loan contracts are signed before the realization of idiosyncratic shocks, implying that the loan rate is identical for all firms. In equilibrium, there is a threshold level of idiosyncratic productivity, above which firms repay the loan at the contractual rate, and earn nonnegative profits. Firms with productivity below the threshold level, however, will default. In the event of a default, the lender pays a cost to liquidate the project.

To capture the features of China's financial system, we deviate from the BGG framework in several dimensions. First, we assume that banking activity is segmented. On-balance sheet loans are provided to SOE firms only, while POE firms can obtain funding only through banks' off-balance sheet activity. This segmentation is adopted for analytical simplicity, but broadly consistent with evidence on banking lending practice in China (Elliott et al., 2015).

[3]Average productivity of SOEs is lower than that of private firms, but firm-level evidence also shows that there is substantial heterogeneity of productivity among firms within each sector. For example, Brandt (2015) shows that, in SOE-dominant industries, both SOEs and POES have lower productivity than firms in industries with less SOE presence.

Second, the government provides guarantees on bank loans to SOEs and, in the event of an SOE default, the government steps in to cover the bank's loan losses. This leaves SOE loans risk-free for banks, although government bailouts in the event of SOE defaults are socially costly. The guarantee acts as an implicit subsidy to SOEs that reduces their funding costs. In contrast, off-balance sheet loans to private firms are not guaranteed, and the financial frictions facing POEs mimic those in the standard BGG environment. In particular, the loan rate offered to POEs includes a default premium (or credit spread) that compensates the lender for expected bankruptcy losses.[4]

Third, on-balance sheet loans are subject to RR policy, so that a fraction of the on-balance sheet funds needs to be held as reserves at the central bank. Since banks do not earn any interest on reserves, RR policy drives a wedge between the deposit interest rate and the lending rate.

We study a calibrated version of our model to illustrate the tradeoff from adjusting required reserves. We first examine the steady-state effects of the RR ratio. Consistent with the mechanism described above, we find that an increase in the steady-state RR ratio improves aggregate TFP through reallocation of resources toward the more productive POE sector, but it also raises the social cost of SOE bankruptcies. As a consequence, there is an interior optimal steady-state level of the RR ratio that maximizes social welfare.

We then examine the implications of a simple reserve requirement rule for macroeconomic stability and social welfare when the economy is buffeted by an aggregate technology shock and an aggregate demand shock (in particular, a government spending shock). We compare the stabilizing performance of the RR rule to that of an interest rate rule. Under each rule, the policy instrument (the nominal deposit rate or the RR ratio) reacts to fluctuations in inflation and real GDP growth. We then optimize by searching for the coefficients in these reaction functions that maximize the representative household's welfare.[5]

Compared to our benchmark economy in which the monetary authority follows a Taylor rule and maintains a constant RR ratio, we find that following optimal RR and interest rate rules improve welfare. The optimal interest rate rule is more effective for stabilizing fluctuations in output and inflation than the optimal RR rule, although the optimal RR rule

[4]Chang et al. (2015a) provide evidence that China's credit policy favors capital-intensive (or heavy) industries at the expense of labor-intensive (or light) industries. Although not all heavy industries are state-owned, Chang et al. (2015a) find that the share of SOEs in capital-intensive industries has increased steadily since the large-scale SOE reform in the late 1990s. In any event, one could alternatively interpret the dichotomy of external financing in our model as illustrative of different treatments to firms favored by the Chinese government versus those not favored.

[5]We restrict the planner's problem to simple rules because the model proved too complex to solve for the full Ramsey equilibrium numerically.

is more effective for reallocating resources between the SOE sector and the POE sector. Since the government provides guarantees for SOE loans, lenders (banks) face no default risks. The financial accelerator mechanism of the BGG framework is thus muted for the SOE sector, but not for the POE sector, rendering the POE sector more responsive to macroeconomic shocks. By shifting resources between the two sectors, adjustments in the RR ratio can help stabilize aggregate fluctuations.

As a result, when the planner is allowed to optimally choose the coefficients in both policy rules, social welfare can be further improved relative to each individual optimal rule. In the case of jointly optimal policy rules, the effectiveness of interest rate policy for stabilization is enhanced by also pursuing optimal RR policy. This result suggests that RR policy can be complementary to the conventional interest rate policy. Under our calibration, however, the welfare gain is quite modest when we add reserve requirements as an additional stabilization tool relative to the case with optimal interest rate policy alone.

Our work is related to earlier literature on the implications of sectoral preferences in China. Brandt and Zhu (2000) examine the implications of commitment by the Chinese government for maintaining employment in its less efficient state sector. They find that the cost of fulfilling this commitment has implications for monetary policy and inflation. Song et al. (2011) study China's transition dynamics in a two-period overlapping generations model with SOEs and POEs. As in our paper, SOEs have lower productivity, but enjoy superior access to bank credit. Their model's transition dynamics explain some puzzling characteristics about the Chinese economy, such as high growth being accompanied by high saving rates.

Our model differs from the earlier literature in three dimensions. First, we investigate an infinite-horizon DSGE model, which accommodates the study of both the steady-state equilibrium and business cycle dynamics. Second, we model financial frictions for both the SOE sector and the private sector in the spirit of Bernanke et al. (1999) (BGG). Off-balance sheet lending to POE firms are exactly in keeping with the framework in BGG. On balance sheet lending to SOEs are guaranteed by the government, but failures of low productivity SOEs still incur costly government bail out of lenders. Third, we study the implications of RR policy relative to the conventional interest rate policy in an environment with nominal rigidities and financial frictions. Our finding suggests that, in this second-best environment, RR policy is useful for not just steady-state reallocation, but also for business cycle stabilization.

II. The reallocation effects of reserve requirement policy: Some evidence

Our model implies that an increase in reserve requirements reallocates capital from SOEs to POEs because it raises the relative cost of on-balance sheet banking activity. In this section, we demonstrate that this reallocation mechanism in the model is supported by empirical evidence at both the macro level and the micro level.[6]

II.1. **Some VAR evidence of reallocation effects of RR policy.** We first consider the macroeconomic effects of a shock that raises reserve requirements (RR) in a Bayesian vector-autogression model (BVAR) estimated using aggregate Chinese data. We include 4 variables: the required reserve ratio, the three-month nominal deposit rate, real GDP (in log units), and the share of business fixed investment in the SOE sector in aggregate business fixed investment, in that order. The time-series data that we use are taken from Chang et al. (2015a), with a sample ranging from 1995:Q1 to 2013:Q4. The BVAR is estimated with four quarterly lags and Sims-Zha priors, and with the required reserve ratio ordered first for Choleski identification. Under this identification assumption, the RR responds to all shocks in the impact period, while the other three variables do not respond to the RR shock in the impact period.[7]

Figure 2 shows the estimated impulse responses following a positive shock to the reserve requirement ratio in our BVAR model. The impulse responses suggest that, following an increase in RR, the share of SOE investment falls significantly, although the shock has ambiguous effects on real GDP and the nominal interest rate. Since capital moves from the less productive SOE sector to the more productive POE sector, the reallocation should raise aggregate productivity and lead to an increase real GDP holding all else equal.[8] However, the increase in RR has also contractionary effects on aggregate demand. Thus, the net increase in real GDP following the shock to RR is small, as shown in the figure.

II.2. **Firm-level evidence of reallocation effects of RR policy.** We next consider some firm-level evidence of the reallocation effects of changes in RR. Our model suggests that an increase in RR directly raises the cost of external financing for SOEs, since they borrow primarily through on-balance sheet channels. On the other hand, an increase in RR should have a smaller adverse impact on POE activity since POEs borrow mainly through off-balance sheet activity. We take this general implication to Chinese equity data, and investigate whether an increase in RR lowers the stock returns of SOE firms relative to POE firms.

[6]The evidence presented in this section is illustrative, and should not be viewed as formal tests of the empirical implications of our theory.

[7]The qualitative results do not change if RR is ordered last.

[8]The reallocation of capital may be costly, as in our model. However, if the productivity gain dominates, then aggregate productivity should rise.

We consider the announcement effects of changes in RR policy on the relative stock returns of SOE firms. In particular, we estimate the regression model

$$\sum_{h=-H}^{H} R^e_{j,t+h} = a_0 + a_1 \Delta RR_{t-1} + a_2 SOE_{jt} \times \Delta RR_{t-1} + a_3 SOE_{jt} + bZ_{jt} + \varepsilon_{jt}. \quad (1)$$

In this equation, the variable R^e_{jt} denotes risk-adjusted excess returns for firm j in period t, defined as $R^e_{jt} = R_{jt} - \hat{\beta}_j R_{mt}$, where R_{jt} denotes the firm's stock return, R_{mt} the market return, and $\hat{\beta}_j$ the firm's "market beta" (i.e.. the estimated slope coefficient in the regression of the firm's return on a constant and the market return). The term ΔRR_{t-1} denotes changes in RR. The term SOE_{jt} is a dummy variable indicating whether the firm is an SOE; that is, whether the firm is directly controlled by the state or has the state as its majority shareholder. The variable Z_{jt} is a vector of control variables, including firm size, book-to-market value ratio, industry fixed effects, and year fixed effects. The term ε_{jt} denotes regression errors. The left hand side of the regression model is cumulative risk-adjusted excess returns within the window of time from H days before to H days after a given date t.

Our parameter of interest is a_2, the coefficient of the interaction term. It captures the relative effects of RR changes on the stock returns of SOEs. If an increase in RR reduces the relative stock returns for SOE firms, then we should observe that $a_2 < 0$.

We estimate the model in equation (1) using daily data from nonfinancial firms listed in the Shanghai and Shenzhen stock exchanges for the period from 2005 to 2015. Under China's current regulations, a change in RR policy is not to be signaled or leaked before the actual announcement. Thus, within a relatively short window of time around the announcement date, changes in RR policy are likely to contain some surprise component that can potentially affect stock returns.

Table 1 shows the estimation results for three different window lengths around the RR change announcements: the same day of the announcement ($H = 0$), a three-day window ($H = 1$), and a five-day window ($H = 2$). The regression results show that the estimated value of a_2 is negative and statistically significant at the 99% level for all 3 different window lengths. The negative estimates of a_2 is also economically significant. For example, on the same day of the RR policy change, a one percentage point increase in the required reserve ratio would reduce the daily stock return of an average SOE firm relative to a non-SOE firm by about 0.0012%. This corresponds to a 2.43% reduction in SOE *relative* monthly returns, or an annualized reduction of about 33%.[9] The estimates of a_2 using the cumulative excess returns in the three-day and five-day windows are even larger.

[9]This calculation is based on 20 trading days per month. The PBOC typically changes in the required reserve ratio by 50 basis points, although in some occasions, the size of the change can be as large as 100 basis points.

Our finding that an increase in RR has a more adverse impact on SOE firms than on POE firms supports the reallocation mechanism featured in our DSGE model below. An increase in RR raises the funding costs for SOEs who borrow mainly on-balance sheet, which exposes commercial banks to RR regulations. As RR increase, banks increase the relative share of their off-balance sheet activities, benefiting POEs at the expense of SOEs.

In China, demand for off-balance sheet loans expanded rapidly following the large-scale fiscal stimulus plan that was announced in November 2008 and implemented in 2009-2010, because local governments needed to raise funds to finance new investment projects partly supported by the central government's stimulus funds. Since the capital reallocation mechanism in our model works through credit reallocation between on-balance sheeting lending and off-balance sheeting activity, we would expect a stronger role for the reallocation channel in the sample after the fiscal stimulus plan was adopted. This is indeed confirmed by the data.

Table 2 shows the regression results for two subsamples: the pre-stimulus period (2005-2008) and the post-stimulus period (2009-2015). The estimates of a_2 were not significantly different from zero in the pre-stimulus period, but became significantly negative at the 99% level in the post-stimulus sample. Moreover, the value of a_2 estimated in the post-stimulus sample is about twice as large (in absolute terms) as our full-sample estimate in Table 1.[10] Thus, an increase in RR reduces stock returns for SOEs relative to non-SOEs primarily during the post-stimulus period, when shadow banking activity was expanding rapidly.

Overall, both our BVAR macro evidence and our firm-level evidence support the reallocation mechanism featured in our DSGE model below.

III. The model

The economy is populated by a continuum of infinitely lived households. The representative household consumes a basket of differentiated goods purchased from retailers. Retailers produce differentiated goods using a homogeneous wholesale good as the only input. The wholesale good is itself a composite of intermediate goods produced by two types of firms: SOEs and POEs. The two types of firms have identical production technologies ex-ante except that the average productivity of SOEs is lower than POEs.

Firms face working capital constraints. Each firm finances wages and rental payments using both internal net worth and external debt. Following Bernanke et al. (1999), we assume that external financing is subject to a costly state verification problem. In particular,

[10]To conserve space, we display here only the estimation results for the one-day and three-day windows. The results for the five-day window are similar. In particular, the estimate of a_2 is insignificant in the pre-stimulus period but becomes large and significantly negative in the post-stimulus sample.

each firm can observe its own idiosyncratic productivity shocks. Firms with sufficiently low productivity relative to their nominal debt obligations will default and be liquidated. The lender suffers a liquidation cost when taking over the project to seize available revenue.

We generalize the BGG framework to a two-sector environment with SOEs and POEs that have access to different sources of external financing. In particular, we assume that SOEs can borrow through banks' on-balance-sheet transactions, and are thus subject to regulations such as reserve requirements. Consistent with China's reality, we assume that SOE loans are backed by government guarantees. POEs can borrow only through off-balance-sheet transactions, which are not regulated, but are also not backed by the government. Therefore, banks face no default risk for their on-balance sheet loans to SOEs; but they need to incorporate expected default costs for off-balance sheet loans extended to POEs, as in the BGG framework.[11]

III.1. **Households.** There is a continuum of infinitely lived and identical households with unit mass. The representative household has preferences represented by the expected utility function

$$U = \sum_{t=0}^{\infty} \beta_t \left[\ln(C_t) - \Psi \frac{H_t^{1+\eta}}{1+\eta} \right], \tag{2}$$

where C_t denotes consumption and H_t denotes labor hours. The parameter $\beta \in (0, 1)$ is a subjective discount factor, $\eta > 0$ is the inverse Frisch elasticity of labor supply, and $\Psi > 0$ reflects labor disutility.

The household faces the sequence of budget constraints

$$C_t + I_t + \frac{D_t}{P_t} = w_t H_t + r_t^k K_{t-1} + R_{t-1} \frac{D_{t-1}}{P_t} + T_t, \tag{3}$$

where I_t denotes capital investment, D_t denotes deposit in banks, w_t denotes the real wage rate, r_t^k denotes the real rent rate on capital, K_{t-1} denotes the level of the capital stock at the beginning of period t, R_{t-1} is the gross nominal interest rate on household savings determined from information available in period $t-1$, P_t denotes the price level, and T_t denotes the lump-sum transfers from the government and earnings received from firms based on the household's ownership share.

[11]For simplicity, we model all off-balance sheet activity as taking place through the commercial bank, but the framework could be extended to allow separate non-banks to borrow from commercial banks off-balance sheet and extend loans to the POEs without loss of generality. Off balance sheet lending in this model is an example of a broad set of nonbank financing activity in China, including private loans and corporate bonds. Large and profitable Chinese private firms typically have no difficulties accessing bank loans, but they rely more on non-bank channels such as equity and corporate bond markets for raising funds to avoid implicit taxes through reserve requirements on bank loans.

The capital stock evolves according to the law of motion

$$K_t = (1-\delta)K_{t-1} + [1 - \frac{\Omega_k}{2}\left(\frac{I_t}{I_{t-1}} - g_I\right)^2]I_t, \tag{4}$$

where we have assumed that changes in investment incur an adjustment cost reflected by parameter Ω_k. The constant g_I denotes the steady-state growth rate of investment.

The household chooses C_t, H_t, D_t, I_t, and K_t to maximize (2), subject to the constraints (3) and (4). The optimizing conditions are summarized by the following equations:

$$\Lambda_t = \frac{1}{C_t}, \tag{5}$$

$$w_t = \frac{\Psi H_t^\eta}{\Lambda_t}, \tag{6}$$

$$1 = \mathrm{E}_t \beta R_t \frac{\Lambda_{t+1}}{\Lambda_t \pi_{t+1}}, \tag{7}$$

$$1 = q_t^k \left[1 - \frac{\Omega_k}{2}\left(\frac{I_t}{I_{t-1}} - g_I\right)^2 - \Omega_k \left(\frac{I_t}{I_{t-1}} - g_I\right)\frac{I_t}{I_{t-1}}\right] + \beta \mathrm{E}_t q_{t+1}^k \frac{\Lambda_{t+1}}{\Lambda_t}\Omega_k \left(\frac{I_{t+1}}{I_t} - g_I\right)\left(\frac{I_{t+1}}{I_t}\right)^2 \tag{8}$$

$$q_t^k = \beta \mathrm{E}_t \frac{\Lambda_{t+1}}{\Lambda_t}[q_{t+1}^k(1-\delta) + r_{t+1}^k], . \tag{9}$$

where Λ_t denotes the Lagrangian multiplier for the budget constraint (3), $\pi_t = \frac{P_t}{P_{t-1}}$ denotes the inflation rate from period $t-1$ to period t, and $q_t^k \equiv \frac{\Lambda_t^k}{\Lambda_t}$ is Tobin's q, with Λ_t^k being the Lagrangian multiplier for the capital accumulation equation (4).

III.2. **Retail sector and price setting.** There is a continuum of retailers, each producing a differentiated retail product indexed by $z \in [0,1]$. The retail goods are produced using a homogeneous wholesale good, with a constant-returns technology. Retailers are price takers in the input market and face monopolistic competition in their product markets. Retail price adjustments are subject to a quadratic cost, as in Rotemberg (1982).

The production function of retail good of type z is given by

$$Y_t(z) = M_t(z), \tag{10}$$

where $Y_t(z)$ denotes the output of the retail good and $M_t(z)$ the intermediate input.

The final good for consumption and investment (denoted by Y_t^f) is a Dixit-Stiglitz composite of all retail products given by

$$Y_t^f = \left[\int_0^1 Y_t(z)^{(\epsilon-1)/\epsilon} dz\right]^{\epsilon/(\epsilon-1)}, \tag{11}$$

where $\epsilon > 1$ denotes the elasticity of substitution between retail goods.

The optimizing decisions of the final good producer lead to a downward-sloping demand schedule for each retail product z:

$$Y_t^d(z) = \left(\frac{P_t(z)}{P_t}\right)^{-\epsilon} Y_t^f, \tag{12}$$

where $P_t(z)$ denotes the price of retail product z.

The zero-profit condition for the final good producer implies that the price level P_t is related to retail prices by

$$P_t = \left[\int_0^1 P_t(z)^{(1-\epsilon)} dz\right]^{1/(1-\epsilon)}. \tag{13}$$

Each retailer takes as given the demand schedule (12) and the price level P_t, and sets a price $P_t(z)$ to maximize profit. Price adjustments are costly, with the cost function given by

$$\frac{\Omega_p}{2}\left(\frac{P_t(z)}{\pi P_{t-1}(z)} - 1\right)^2 C_t,$$

where Ω_p measures the size of the adjustment cost and π is the steady-state inflation rate. Retailer z chooses $P_t(z)$ to maximize its expected discounted profit

$$\sum_{i=0}^{\infty} \beta^i \mathrm{E}_t \Lambda_{t+i}\left[\left(\frac{P_{t+i}(z)}{P_{t+i}} - p_{w,t+i}\right) Y_{t+i}^d(z) - \frac{\Omega_p}{2}\left(\frac{P_{t+i}(z)}{\pi P_{t+i-1}(z)} - 1\right)^2 C_{t+i}\right], \tag{14}$$

where p_{wt} is the relative price of the wholesale good (expressed in consumption units) and $Y_{t+i}^d(z)$ is given by the demand schedule (12).

We focus on a symmetric equilibrium in which $P_t(z) = P_t$ for all z. The optimal price-setting decision implies that

$$p_{wt} = \frac{\epsilon - 1}{\epsilon} + \frac{\Omega_p}{\epsilon}\frac{1}{Y_t}\left[\left(\frac{\pi_t}{\pi} - 1\right)\frac{\pi_t}{\pi} C_t - \beta \mathrm{E}_t \frac{\Lambda_{t+1}}{\Lambda_t}\left(\frac{\pi_{t+1}}{\pi} - 1\right)\frac{\pi_{t+1}}{\pi} C_{t+1}\right]. \tag{15}$$

III.3. **The wholesale goods sector.** The wholesale goods used by retailers as inputs are a composite of intermediate goods produced by firms in the SOE sector and the POE sector. Denote by Y_{st} and Y_{pt} the products produced by SOE firms and POE firms, respectively. The quantity of the wholesale good M_t is given by

$$M_t = \left(\phi Y_{st}^{\frac{\sigma_m - 1}{\sigma_m}} + (1-\phi) Y_{pt}^{\frac{\sigma_m - 1}{\sigma_m}}\right)^{\frac{\sigma_m}{\sigma_m - 1}}, \tag{16}$$

where $\phi \in (0,1)$ measures the share of SOE goods and $\sigma_m > 0$ is the elasticity of sbustitution between goods produced by the two sectors.

Denote by p_{st} and p_{pt} the relative price of SOE products and POE products, respectively, both expressed in final consumption good units. Cost-minimizing by the wholesale good producer implies that

$$Y_{st} = \phi^{\sigma_m}\left(\frac{p_{st}}{p_{wt}}\right)^{-\sigma_m} M_t, \quad Y_{pt} = (1-\phi)^{\sigma_m}\left(\frac{p_{pt}}{p_{wt}}\right)^{-\sigma_m} M_t. \tag{17}$$

The zero-profit condition in the wholesale sector implies that the wholesale price is related to the sectoral prices through

$$p_{wt} = \left(\phi^{\sigma_m} p_{st}^{1-\sigma_m} + (1-\phi)^{\sigma_m} p_{st}^{1-\sigma_m}\right)^{\frac{1}{1-\sigma_m}}. \tag{18}$$

III.4. **The intermediate goods sectors.** We now present the environment in the SOE and POE intermediate goods sectors. We focus on a representative firm in each sector $j \in \{s, p\}$.

A firm in sector j produces a homogeneous intermediate good Y_{jt} using capital K_{jt} and two types of labor inputs— household labor H_{jt} and entrepreneurial labor H_{jt}^e, with the production function

$$Y_{jt} = A_t \bar{A}_j \omega_{jt} (K_{jt})^{1-\alpha} \left[(H_{jt}^e)^{1-\theta} H_{jt}^{\theta}\right]^{\alpha}, \tag{19}$$

where A_t denotes an aggregate productivity shock, $\bar{A}_j$ measures the average level of total factor productivity (TFP) of sector j, and the parameters $\alpha \in (0,1)$ and $\theta \in (0,1)$ are input elasticities in the production technology. The term ω_{jt} is an idiosyncratic productivity shock that is i.i.d. across firms and time, and is drawn from the distribution $F(\cdot)$ with a nonnegative support. We assume that the idiosyncratic productivity shocks are drawn from a Pareto distribution with the cumulative density function $F(\omega) = 1 - (\frac{\omega_m}{\omega})^k$ over the range $[\omega_m, \infty)$, where $\omega_m > 0$ is the scale parameter and k is the shape parameter.

Aggregate productivity A_t contains a deterministic trend component g^t and a stationary component A_t^m. In particular, we assume that $A_t = g^t A_t^m$, with the stationary component A_t^m following the AR(1) stochastic process

$$\ln A_t^m = \rho_a \ln A_{t-1}^m + \epsilon_{at}, \tag{20}$$

where we normalize the steady-state level of A^m to unity, $\rho_a \in (-1,1)$ is a persistence parameter, and the term ϵ_{at} is an i.i.d. innovation drawn from a log-normal distribution $N(0, \sigma_a)$.

Firms face working capital constraints. In particular, they need to pay wage bills and capital rents before production takes place. Firms finance their working capital payments through their beginning-of-period net worth $N_{j,t-1}$ and through borrowing, B_{jt}. The working capital constraint for a firm in sector $j \in \{s, p\}$ is given by

$$\frac{N_{j,t-1} + B_{jt}}{P_t} = w_t H_{jt} + w_{jt}^e H_{jt}^e + r_t^k K_{jt}. \tag{21}$$

where w_{jt}^e denotes the real wage rate of managerial labor in sector j.

Given the working capital constraints in Eq. (21), cost-minimization implies that factor demand satisfies

$$w_t H_{jt} = \alpha\theta \tfrac{N_{j,t-1}+B_{jt}}{P_t}, \tag{22}$$

$$w^e_{jt} H^e_{jt} = \alpha(1-\theta) \tfrac{N_{j,t-1}+B_{jt}}{P_t}, \tag{23}$$

$$r^k_t K_{jt} = (1-\alpha) \tfrac{N_{j,t-1}+B_{jt}}{P_t}. \tag{24}$$

Substituting these optimal choices of input factors in the production function (19), we obtain the firm's revenue (in final good units)

$$p_{jt} Y_{jt} = \tilde{A}_{jt} \omega_{jt} \frac{N_{j,t-1}+B_{jt}}{P_t}, \tag{25}$$

where the term $\tilde{A}_{jt}$ is given by

$$\tilde{A}_{jt} = p_{jt} A_t \bar{A}_j \left(\frac{1-\alpha}{r^k_t}\right)^{1-\alpha} \left[\left(\frac{\alpha(1-\theta)}{w^e_{jt}}\right)^{1-\theta} \left(\frac{\alpha\theta}{w_t}\right)^{\theta}\right]^{\alpha}. \tag{26}$$

We interpret $\tilde{A}_{jt}$ as the rate of return on the firm's investment financed by external debt and internal funds.

III.5. **Financial intermediaries and debt contracts.** The only financial intermediary in our model is banks. At the beginning of each period t, banks obtain household deposits D_t at interest rate R_t. They lend an amount B_{st} on-balance sheet to the SOE sector, and B_{pt} off-balance sheet to the private sector. On balance sheet loans are subject to reserve requirements, but off-balance sheet loans are not. In addition, since SOE loans are guaranteed by the government, banks do not face default risks for on-balance sheet loans. For the off-balance sheet loans to POEs, banks need to incorporate the expected cost of default in the loan interest rate, and therefore a credit spread arises, as in the BGG framework.

The banking sector is perfectly competitive with free entry. Thus, the representative bank earns zero profit in equilibrium. The bank decides the share of funds allocated to on-balance sheet activity, i.e., SOE loans, denoted by ζ_t. The amount of SOE loans is thus given by

$$B_{st} = (1-\tau_t)\zeta_t D_t. \tag{27}$$

Since the government guarantees repayments of SOE loans, there is no default risk on bank loans and banks charge a risk-free loan rate of R_{st}. Banks earn zero profits on SOE loans in equilibrium. However, the reserve requirements drive a wedge between the loan rate and the deposit rate such that

$$(R_{st}-1)(1-\tau_t) = (R_t - 1), \tag{28}$$

where R_{st} represents the interest rate on SOE loans.

The amount of off-balance sheet loans to POEs is equal to the amount of deposits not allocated to on-balance sheet activity $B_{pt} = (1-\zeta_t)D_t$. Banks are also assumed to be competitive in off-balance sheet lending, with funding costs given by $R_{pt} = R_t$ since this activity is not subject to reserve requirements.

Since lenders can only observe a borrower's realized returns at a cost, they charge a state-contingent gross interest rate Z_{jt} $(j = s, p)$ on all loans to cover monitoring and liquidation costs. Under this financial arrangement, firms with sufficiently low levels of realized productivity will not be able to make repayments. There is a cut-off level of productivity $\bar{\omega}_{jt}$ such that firms with $\omega_{jt} < \bar{\omega}_{jt}$ choose to default. The default decision is described by,

$$\omega_{jt} < \bar{\omega}_{jt} \equiv \frac{Z_{jt}B_{jt}}{\tilde{A}_{jt}(N_{j,t-1}+B_{jt})}. \tag{29}$$

If the firm fails to make the repayments, the lender pays a liquidation cost and obtains the revenue. In the process of liquidating, a fraction m_{jt} of output is lost. Furthermore, the government is assumed to cover a fraction l_j of the loan losses financed by lump-sum taxes collected from the households, where $l_s = 1$ and $l_p = 0$ such that the government covers the entire loss to banks for SOE defaults but nothing for POE defaults.

We now describe the optimal contract. Under the loan contract characterized by $\bar{\omega}_{jt}$ and B_{jt}, the expected nominal income for a firm in sector j is given by

$$\begin{aligned}
&\int_{\overline{\omega}_{jt}}^{\infty} \tilde{A}_{jt}\omega_{jt}(N_{j,t-1}+B_{jt})dF(\omega) - (1-F(\overline{\omega}_{jt}))Z_{jt}B_{jt} \\
&= \tilde{A}_{jt}(N_{j,t-1}+B_{jt})[\int_{\overline{\omega}_{jt}}^{\infty} \omega dF(\omega) - (1-F(\overline{\omega}_{jt}))\overline{\omega}_{jt}] \\
&\equiv \tilde{A}_{jt}(N_{j,t-1}+B_{jt})f(\overline{\omega}_{jt}),
\end{aligned}$$

where $f(\overline{\omega}_{jt})$ is the share of production revenue going to the firm under the loan contract.

The expected nominal income for the lender is given by,

$$\begin{aligned}
&(1-F(\overline{\omega}_{jt}))Z_{jt}B_{jt} + \int_0^{\overline{\omega}_{jt}} \{(1-m_{jt})\tilde{A}_{jt}\omega(N_{j,t-1}+B_{jt}) \\
&\qquad +l_j[Z_{jt}B_{jt} - (1-m_{jt})\tilde{A}_{jt}\omega(N_{j,t-1}+B_{jt})]\}dF(\omega) \\
&= \tilde{A}_{jt}(N_{j,t-1}+B_{jt})\{[1-(1-l_j)F(\overline{\omega}_{jt})]\bar{\omega}_{jt} + (1-m_{jt})(1-l_j)\int_0^{\overline{\omega}_t} \omega dF(\omega)\} \\
&\equiv \tilde{A}_{jt}(N_{j,t-1}+B_{jt})g_{jt}(\overline{\omega}_{jt}),
\end{aligned} \tag{30}$$

where $g_j(\overline{\omega}_{jt})$ is the share of production revenue going to the lender. Note that

$$f(\overline{\omega}_{jt}) + g_{jt}(\overline{\omega}_{jt}) = 1 - m_{jt}\int_0^{\overline{\omega}_{jt}} \omega dF(\omega) + l_j\int_0^{\overline{\omega}_{jt}} [\overline{\omega}_{jt} - (1-m_{jt})\omega]dF(\omega).$$

The optimal contract is a pair $(\bar{\omega}_{jt}, B_{jt})$ chosen at the beginning of period t to maximize the borrower's expected period t income,

$$\max \tilde{A}_{jt}(N_{j,t-1} + B_{jt}) f(\overline{\omega}_{jt}) \tag{31}$$

subject to the lender's participation constraint

$$\tilde{A}_{jt}(N_{j,t-1} + B_{jt}) g_j(\overline{\omega}_{jt}) \geq R_{jt} B_{jt}. \tag{32}$$

The optimizing conditions for the contract characterize the relation between the leverage ratio and the productivity cut-off

$$\frac{N_{j,t-1}}{B_{jt} + N_{j,t-1}} = -\frac{g_j'(\overline{\omega}_{jt})}{f'(\overline{\omega}_{jt})} \frac{\tilde{A}_{jt} f(\overline{\omega}_{jt})}{R_{jt}}. \tag{33}$$

Following Bernanke et al. (1999), we assume that a manager in sector $j \in \{s, p\}$ survives at the end of each period with probability ξ_j. Thus, the average lifespan for the firm is $\frac{1}{1-\xi_j}$. The $1 - \xi_j$ fraction of exiting managers is replaced by an equal mass of new managers, so that the population size of managers stays constant. New managers have start-up funds equal to their managerial labor income $w^e_{jt} H^e_{jt}$. For simplicity, we follow the literature and assume that each manager supplies one unit of labor inelastically and the managerial labor is sector specific (so that $H^e_{jt} = 1$ for $j \in \{s, p\}$).

The end-of-period aggregate net worth of all firms in sector j consists of profits earned by surviving firms and also managerial labor income. In particular, we have

$$N_{jt} = \xi_j \tilde{A}_{jt}(N_{j,t-1} + B_{jt}) f(\overline{\omega}_{jt}) + P_t w^e_{jt} H^e_{jt}. \tag{34}$$

III.6. **Government policy.** The government conducts monetary policy by following a Taylor-type rule, under which the nominal deposit rate responds to deviations of inflation from target and changes in output gap. The government's interest-rate rule is given by

$$R_t = \bar{R} \left(\frac{\pi_t}{\bar{\pi}}\right)^{\psi_{rp}} \left(\frac{G\tilde{D}P_t}{G\tilde{D}P}\right)^{\psi_{ry}}, \tag{35}$$

where $\bar{R}$ and $\bar{\pi}$ denote the steady-state interest rate and inflation rate, respectively, and the parameters ψ_{rp} and ψ_{ry} are the response coefficients. The term $G\tilde{D}P_t$ denotes the output gap, defined the deviation of real GDP from its trend.

In the benchmark economy, we assume that the government fixes the required reserve ratio at $\tau_t = \bar{\tau}$. We also consider an alternative reserve requirement policy under which the government varies τ_t in response to fluctuations in inflation and output gap (Section V.2).

Government spending consists of an exogenous component, G_t, which is a constant fraction of real GDP nand the SOE bailout costs.

III.7. **Market clearing and equilibrium.** The final good is used for consumption, investment, government spending, paying price adjustment costs, and covering bankruptcy costs. Final-good market clearing implies that

$$\begin{aligned} Y_t^f &= C_t + I_t + G_t + \frac{\Omega_p}{2}(\frac{\pi_t}{\pi} - 1)^2 C_t + \tilde{A}_{st}\frac{N_{s,t-1} + B_{st}}{P_t} m_t \int_0^{\overline{\omega}_{st}} \omega dF(\omega) \\ &+ \tilde{A}_{pt}\frac{N_{p,t-1} + B_{pt}}{P_t} m_t \int_0^{\overline{\omega}_{pt}} \omega dF(\omega). \end{aligned} \tag{36}$$

Intermediate goods market clearing implies that

$$M_t = \left(\phi Y_{st}^{\frac{\sigma_m - 1}{\sigma_m}} + (1-\phi) Y_{pt}^{\frac{\sigma_m - 1}{\sigma_m}}\right)^{\frac{\sigma_m}{\sigma_m - 1}}. \tag{37}$$

Capital market clearing implies that

$$K_{t-1} = K_{st} + K_{pt}. \tag{38}$$

Labor market clearing implies that

$$H_t = H_{st} + H_{pt}. \tag{39}$$

Bond market clearing implies that

$$B_{st} = (1-\tau_t)\zeta_t D_t, \quad B_{pt} = (1-\zeta_t) D_t. \tag{40}$$

For convenience of discussion, we define real GDP as the final output net of the costs of firm bankruptcies and price adjustments. In particular, real GDP is defined as

$$GDP_t = C_t + I_t + G_t. \tag{41}$$

We also define two measures of aggregate TFP, one based on gross output and the other based on value added (i.e., GDP). Output-based TFP is defined as

$$\tilde{A}_{Y,t} = \frac{Y_t^f}{(K_{st} + K_{pt})^{1-\alpha} H_t^{\alpha\theta}}, \tag{42}$$

while value-added based TFP is defined as

$$\tilde{A}_{GDP,t} = \frac{GDP_t}{(K_{st} + K_{pt})^{1-\alpha} H_t^{\alpha\theta}}. \tag{43}$$

IV. Calibration

We solve the model numerically based on calibrated parameters. Five sets of parameters need to be calibrated. The first set are those in the household decision problem. These include β, the subjective discount factor; η, the inverse Frisch elasticity of labor supply; Ψ, the utility weight on leisure; δ, the capital depreciation rate; and Ω_k, the investment adjustment cost parameter. The second set are those in the retailers' decision problem, including ϵ, the elasticity of substitution between differentiated retail products; and Ω_p, the price adjustment cost parameter. The third set includes parameters in the decisions for firms and financial intermediaries. These include g, the average trend growth rate; ω_m and k, the scale and the shape parameters for the idiosyncratic shock distribution; α, the capital share in the production function; θ, the share of labor supplied by the household; ψ, the share of SOE products in the intermediate good basket; σ_m, the elasticity of substitution between SOE products and POE products; $\bar{A}_s$ and $\bar{A}_p$, the average productivity of the SOE firms and POE firms, respectively; m_s and m_p, the monitoring costs for SOE firms and POE firms, respectively; and ξ_s and ξ_p, the survival rates of managers for SOE firms and POE firms, respectively. The fourth set of parameters are those in government policy, which include $\bar{\pi}$, steady-state inflation (as well as the inflation target); $\bar{\tau}$, the steady-state required reserve ratio; $\psi_{\tau p}$ and $\psi_{\tau y}$, the Taylor rule coefficients on inflation and output gap, respectively; and l_s and l_p, the fractions of debts guaranteed by the government for SOEs and POEs, respectively. The fifth set are parameters in the technology shock process, including ρ_a and σ_a, the persistence and standard deviation of the shock, respectively. Table 3 summarizes the calibrated parameter values.

A period in the model corresponds to one quarter. We set the subjective discount factor to $\beta = 0.995$. We set $\eta = 2$, implying a Frisch labor elasticity of 0.5, which lies in the range of empirical studies. We calibrate $\Psi = 18$ such that the steady state value of labor hour is about one-third of total time endowment (which itself is normalized to 1). For the parameters in the capital accumulation process, we calibrate $\delta = 0.035$, implying an annual depreciation rate of 14%, as in the Chinese data. We have less guidance for calibrating the investment adjustment cost parameter Ω_k. We use $\Omega_k = 1$ as a benchmark, which lies in the range of empirical estimates of DSGE models (Christiano et al., 2005; Smets and Wouters, 2007).

For the parameters in the retailers' decision problems, we calibrate the elasticity of substitution between differentiated retail goods ϵ at 10, implying an average gross markup of 11%. We set $\Omega_p = 22$, implying an average duration of price contracts of about three quarters.[12]

[12]Log-linearizing the optimal pricing decision equation (15) around the steady state leads to a linear form of Phillips curve relation with the slope of the Phillips curve given by $\kappa = \frac{\epsilon-1}{\Omega_p}\frac{C}{Y}$. Our calibration implies a

For the technology parameters, we set the steady-state balanced growth rate to $g = 1.0125$, implying an average annual growth rate of 5%. We assume that the idiosyncratic productivity shocks are drawn from a Pareto distribution with the cumulative density function $F(\omega) = 1 - (\frac{\omega_m}{\omega})^k$ over the range $[\omega_m, \infty)$. We calibrate the scale parameter ω_m and the shape parameter k to match empirical estimates of cross-firm dispersions of TFP in China's data. In particular, Hsieh and Klenow (2009) estimated that the standard deviation of the logarithm of TFP across firms is about 0.63 in 2005. Since ω is drawn from a Pareto distribution, the logarithm of ω (scaled by ω_m) follows an expential distribution with a standard deviation of $1/k$. To match the empirical dispersion of TFP estimated by Hsieh and Klenow (2009), we set $k = 1/0.63$. To keep the mean of ω at one then requires $\omega_m = \frac{k-1}{k}$. These results in $k = 1.587$ and $\omega_m = 0.37$. We normalize the scale of SOE TFP to $\bar{A}_s = 1$ and calibrate the scale of POE TFP parameter at $\bar{A}_p = 1.42$, consistent with the TFP gap estimated by Hsieh and Klenow (2009).

We calibrate the labor income share to $\alpha = 0.5$, consistent with empirical evidence in Chinese data (Brandt et al., 2008; Zhu, 2012). Out of the total labor income, we calibrate the share of household labor to $\theta = 0.9$; accordingly, the managerial labor share is 0.1. We calibrate $\psi = 0.45$, so that the steady-state share of SOE output in the industrial sector is 0.3, as in the data. We set the elasticity of substitution between SOE output and POE output to $\sigma_m = 3$, which lies in the range estimated by Chang et al. (2015a).[13]

For the parameters associated with financial frictions, we follow Bernanke et al. (1999) and set the liquidation cost parameters to $m_s = m_p = 0.15$. We set the SOE manager's survival rate to $\xi_s = 0.97$, implying an average term for the SOE manager of around eight years. We set the POE manager's survival rate to $\xi_p = 0.69$, implying an average term of about nine months. These survival rates are chosen to yield the steady state outcome that the annual bankruptcy ratio is 0.25 for SOEs and 0.10 for POEs. These numbers match the annual fraction of industrial firms that earns negative profits reported by China's National Bureau of Statistics's (NBS) Annual Industrial Survey.

steady state ratio of consumption to gross output of about 50%. The values of $\epsilon = 10$ and $\Omega_p = 22$ imply that $\kappa = 0.2$. In an economy with Calvo-type price contracts, the slope of the Phillips curve is given by $(1 - \beta\alpha_p)(1 - \alpha_p)/\alpha_p$ where α_p is the probability that a firm cannot re-optimize prices. To obtain a slope of 0.2 for the Phillips curve in the Calvo model, α_p must be set equal to 0.66, which corresponds to an average duration of price contracts of about three quarters.

[13] Chang et al. (2015a) estimate that the elasticity of substitution between SOE and POE outputs is about 4.53 if annual output data are used. The estimated elasticity is about 1.92 if monthly sales are used to measure output.

For the monetary policy parameters, we set the steady-state inflation target $\bar{\pi}$ to 2% per year. We calibrate the steady-state required reserve ratio to $\bar{\tau} = 0.15$. We set the Taylor rule parameters to $\psi_{rp} = 1.5$ and $\psi_{ry} = 0.2$.

For the fiscal policy parameters, we assume that the government provides complete guarantees for SOE debt, but no guarantees for POE debt ($l_s = 1, l_p = 0$). Furthermore, we set government consumption to GDP ratio at 0.14%, which corresponds to the sample average in the Chinese data from 2001 to 2015.

Finally, for the technology shock parameters, we follow the standard real business cycle literature and set the persistence parameter to $\rho_a = 0.95$ and the standard deviation parameter to $\sigma_a = 0.01$.

V. Quantitative results

We next investigate the implications of adjusting reserve requirements (τ) for the steady-state equilibrium and aggregate dynamics, and its impact on productivity and welfare.

V.1. **Optimal steady-state reserve requirements.** We begin by exploring how steady-state equilibrium allocations and welfare depend on the required reserve ratio. We focus on the deterministic steady-state equilibrium, in which all exogenous shocks are turned off. As we have discussed above, reserve requirements act like a tax on SOE activity since SOEs borrow from banks through on-balance sheeting channels and those banking loans are subject to reserve requirement regulations. An increase in the reserve requirements thus diverts resources from SOEs to POEs. Since POEs are on average more productive than SOEs, this resource reallocation raises allocative efficiency and aggregate TFP. However, an increase in reserve requirements also raises the incidence of SOE bankruptcies; while banks are protected from loan losses by the government guarantees, the bailouts are socially costly and imply a tradeoff.

This tradeoff is illustrated in Figure 3, which displays the relations between the steady-state required reserve ratio (τ) and the levels of several macroeconomic variables. The figure also shows the welfare gains associated with different values of τ relative to the steady-state level of $\tau = 0.15$. Consistent with the mechanism described above, an increase in τ reduces SOE output relative to POE output. As resources are reallocated from SOEs to POEs, aggregate TFP rises. However, with increased funding costs, the incidence of SOE bankruptcies rises, which leads to an increase in costly bailouts.

The tradeoff between efficiency gains and bankruptcy losses implies that there should be an interior optimum for the required reserve ratio that maximizes social welfare. Under our calibration, this is indeed the case. As shown in the lower-right panel of Figure 3, the representative household's steady-state welfare has a hump-shaped relation with τ and reaches the maximum at $\tau^* = 0.34$.

V.2. **Optimal simple policy rules.** We have shown that reserve requirement policy plays an important role in reallocating resources between SOEs and POEs in the steady state. We now examine the effectiveness of reserve requirement policy for macroeconomic stabilization over the business cycle.

We focus on an aggregate TFP shock. The central bank can adjust the nominal deposit rate or the required reserve (or both) to stabilize macroeconomic fluctuations. We assume that the central bank follows simple rules and adjust the relevant policy instrument(s) (R or τ) to respond to fluctuations in inflation and the output gap.

As a benchmark, we assume that the central bank follows the standard Taylor rule for the nominal deposit rate and keeps the required reserve ratio constant at its steady state level. Relative to this benchmark policy regime, we evaluate the performance of three counterfactual policy regimes for macroeconomic stability and social welfare: an optimal interest rate rule, an optimal reserve requirement rule, and jointly optimal rules for both instruments.

Specifically, the interest rate rule is given by Eq (35), which we rewrite here in logarithmic form:

$$\ln\left(\frac{R_t}{R}\right) = \psi_{rp}\ln\left(\frac{\pi_t}{\bar{\pi}}\right) + \psi_{ry}\ln\left(\frac{G\tilde{D}P_t}{G\tilde{D}P}\right). \tag{44}$$

The reserve requirement rule takes a similar form:

$$\ln\left(\frac{\tau_t}{\tau}\right) = \psi_{\tau p}\ln\left(\frac{\pi_t}{\bar{\pi}}\right) + \psi_{\tau y}\ln\left(\frac{G\tilde{D}P_t}{G\tilde{D}P}\right), \tag{45}$$

where the parameters $\psi_{\tau p}$ and $\psi_{\tau y}$ measure the responsiveness of the required reserve ratio to changes in inflation and output gap.

Under the optimal interest rate rule, the reaction coefficients ψ_{rp} and ψ_{ry} in (44) are set to maximize the representative household's welfare, while the required reserve ratio is kept at the benchmark value (i.e., $\tau_t = \tau$). Under the optimal reserve requirement rule, the reaction coefficients $\psi_{\tau p}$ and $\psi_{\tau y}$ are set to maximize welfare, while the interest rate follows the benchmark Taylor rule in (44), with $\psi_{rp} = 1.5$ and $\psi_{ry} = 0.2$ fixed. Under the jointly optimal rule, all four reaction coefficients ψ_{rp}, ψ_{ry}, $\psi_{\tau p}$, and $\psi_{\tau y}$ are optimally set to maximize welfare.

We measure welfare gains under each counterfactual policy relative to the benchmark model as the percentage change in permanent consumption such that the representative household is indifferent between living in an economy under a given optimal policy rule and in the benchmark economy. Denote by C_t^b and H_t^b the allocations of consumption and hours worked under the benchmark policy regime. Denote by V^a the value of the household's welfare obtained from the equilibrium allocations under an alternative policy regime. Then, the welfare gain under the alternative policy relative to the benchmark is measured by the constant χ, which is implicitly solved from

$$\sum_{t=0}^{\infty} \beta^t \left[\ln(C_t^b(1+\chi)) - \Psi \frac{(H_t^b)^{1+\eta}}{1+\eta} \right] = V^a. \tag{46}$$

V.2.1. *Macroeconomic stability and welfare under alternative policy rules.* Table 4 shows the macroeconomic volatilities under the four different policy regimes as well as the welfare gains under each rule relative to the benchmark regime.

Under the optimal reserve requirement rule (the second column), the required reserve ratio τ_t increases with the output gap but decreases with inflation. In our model, equilibrium dynamics are driven by aggregate TFP shocks. A positive shock to aggregate TFP raises real GDP and lowers inflation. To stabilize output, the central bank raises reserve requirements. The increase in τ reduces aggregate demand and thus, all else equal, reduces inflation. However, an increase in τ can also alleviate the decline in inflation through a cost channel. In particular, as the funding costs for SOE firms rise, the price of intermediate goods also rises. Retailers will respond to this increase in intermediate input prices by raising the final good price. While the positive TFP shock tends to lower inflation, the cost-channel tends to raise inflation. The net effects on inflation then depend on parameter calibration. Under our calibration, an increase in τ helps alleviate the decline in inflation. Table 4 shows that the volatilities of both real GDP and inflation are both smaller under the optimal reserve requirement rule than in the benchmark policy regime with the required reserve ratio held constant. Furthermore, the optimal reserve requirement rule also leads to a modest welfare gain relative to the benchmark policy (about 0.24% of consumption equivalent).

The optimal interest rate rule (column three) is more aggressive against inflation fluctuations than the benchmark policy, but assigns a smaller weight to output gap. In particular, when we hold τ constant as in the benchmark regime and choose the inflation and output coefficients in the Taylor rule to maximize social welfare, we find that the optimal coefficients become 7.42 for inflation and 0.07 for output gap. The optimal interest rate rule produces better macroeconomic stability and higher welfare than either the benchmark policy or the optimal reserve requirement rule. Indeed, the welfare gain by moving from the benchmark regime to that under the optimal interest rate rule is sizable, at 1.18% of consumption equivalent.

Under the jointly optimal policy rule, the coefficients in both the interest rate rule and the reserve requirement rule are choosen to maximize social welfare. Under the optimal joint rule, the central bank can use the nominal interest rate to stabilize macroeconomic fluctuations and adjust the required reserve ratio to reallocate resources between the two sectors. Under our calibration, it acts to mitigate the financial accelerator effects in the POE sector. The jointly optimal rule achieves better macroeconomic stability and higher social welfare than the benchmark policy. It also modestly outperforms each individual optimal rule in terms of welfare, although the gains relative to the optimal interest rate rule are small.

V.2.2. *The economic mechanism.* To help understand the economic mechanism underlying our quantitative results, we examine the impulse responses of several key macroeconomic variables and sector-level variables following a positive TFP shock.

Figure 4 displays the impulse responses of real GDP, inflation, the nominal deposit rate, and the required reserve ratio following the shock under the benchmark policy and the three alternative policy regimes. Figure 5 shows the impulse responses of output, leverage, the bankruptcy rate, and the credit spread in each sector.

We begin with discussing the impulse responses in the benchmark model (the black solid lines in the figures). Figure 4 shows that a positive TFP shock raises real GDP and lowers inflation. Under the benchmark policy regime, the nominal deposit rate declines to accommodate the fall of inflation while the required reserve ratio stays constant.

Figure 5 shows that the TFP shock raises output in both sectors. Since SOE debts are guaranteed by the government, bank loans are free from default risk. The bank loan rate to SOEs is a constant markup over the deposit rate, with the wedge determined by the constant required reserve ratio τ. Thus, neither the SOE credit spread nor the SOE leverage ratio respond to changes in macroeconomic conditions under our calibration (with the idiosyncratic productivity shocks drawn from a Pareto distribution). With constant credit spread and leverage, the financial accelerator mechanism of the BGG framework is muted for the SOE sector. However, the improvement in aggregate TFP lowers the bankruptcy rate in the SOE sector.

In the POE sector, however, there are no loan guarantees. Default risks are internalized through a credit spread. The TFP shock raises POE output, driving up demand for loans and POE leverage. The increase in loan demand by POE firms leads to an increase in loan interest rate and thus an increase in the credit spread; the increases in leverage and credit spread in turn raise the bankruptcy rate of POE firms despite the productivity improvement.

We then discuss the impulse responses under three counterfactual policy regimes. Consider first the optimal reserve requirement rule (the red dashed lines in the figures). In response to the positive TFP shock, the central bank optimally chooses to raise the required reserve ratio to stabilize aggregate fluctuations. Since the interest rate follows the benchmark Taylor rule, the central bank cannot optimize the adjustments of interest rates. As shown in Figure 4, the optimal reserve requirement rule modestly outperforms the benchmark policy in stabilizing real GDP and inflation responses to the shock.

At the sectoral level, the increase in τ leads to a greater expansion of POE output relative to SOE output than in the benchmark, as shown in Figure 5. This is because the increase in τ acts as a tax on formal banking activity and thus shifts credit and capital from SOEs to POEs. The policy responses under the optimal reserve requirement rule also lead to larger increases in POE leverage, credit spread, and bankruptcy rate relative to the benchmark regime, although the differences in these financial variables' responses from those under the benchmark regime are relatively small under our calibration.

Consider next the optimal interest rate rule (the blue dashed lines in Figures 4 and 5). In this case, the central bank adjusts the nominal deposit rate more aggressively in response to fluctuations in inflation than under the benchmark regime. As a consequence, the response of inflation to the TFP shock becomes much more subdued. The optimal interest rate rule also implies more stability in real GDP fluctuations. Under the optimal interest rate rule, the real interest rate declines more than that in the benchmark following a positive technology shock. The greater reduction in the real interest rate amplifies consumption responses, but dampens the increases in saving and investment. The net effects lead to a more muted increase in real GDP. Since equilibrium inflation does not fall much in response to a productivity improvement, the central bank does not need to cut the nominal interest rate much either.

At the sectoral level, the optimal interest rate rule dampens the increase in SOE output but amplifies the POE output increase in the short run. Since POE firms are more sensitive to changes in the real interest rate, the responses of leverage, credit spread, and bankruptcy rate in the POE sectors are also amplified modestly.

Finally, we consider the jointly optimal policy rule (the magenta dashed line). Under this policy regime, the central bank responds to the TFP shock by raising the required reserve ratio and lowering the nominal interest rate. The rise in τ dampens the expansion in aggregate demand and thus, all else equal, contributes to lowering inflation. However, an increase in τ also pushes up the funding costs for firms and thus contributes to raising inflation. The reduction in the interest rate unambiguously contributes to raising inflation. Under the jointly optimal policy, the technology improvement leads to a much more muted decline in inflation on impact; and over time, inflation rises above steady state, reflecting the joint effects of higher funding costs with a higher τ and greater aggregate demand with a lower R, as shown in Figure 4. The figure also shows that the jointly optimal rule is more effective than either individual optimal rule in stabilizing real GDP fluctuations.

As in the case with the optimal τ rule, the increase in τ under the jointly optimal policy reallocates capital from SOEs to POEs. At the same time, the greater reduction in the real interest rate helps raise POE output relative to SOE output even more since POEs are more sensitive to changes in the interest rate than the SOEs. As shown in Figure 5, by reducing the share of expansions in SOE output, the jointly optimal policy also saves the government's bailout costs by reducing the SOE bankruptcy rate. As a result, it increases welfare relative to both individual policy tool rules. However, as shown in Table 4, the gains relative to the optimal interest rate rule are quite modest.

Overall, our impulse responses suggest that the interest rate policy tool is relatively effective for stabilizing fluctuations in real GDP and inflation, while adjusting reserve requirements is more effective for stabilizing sectoral allocations at business cycle frequencies. By using the two policy instruments together, the central bank is able to achieve better macroeconomic stability and higher welfare relative to under each individually optimal policy rule. However, we find that the interest rate tool is a more important one of the two, as the jointly optimal rule only yields quite modest welfare gains relative to the optimal interest rate rule alone.

VI. Conclusion

We study the benefits from adjusting reserve requirements as a policy instrument in a two-sector DSGE model with Chinese characteristics. Our model generalizes the standard financial accelerator model of Bernanke et al. (1999) to include two key forms of frictions: First, the model features segmented credit markets, in which SOE firms are able to obtain on-balance sheet bank loans, while POE firms rely on off-balance sheet lending for financing. Second, and more importantly, the government provides guarantees for formal bank loans to SOE firms, but not to off-balance sheet activity. We show that government guarantees of SOE loans are an important source of distortions and that adjustments in reserve requirements can be an effective second-best policy.

Under this framework, adjusting reserve requirements can not only alleviate steady-state distortions but also help stabilize business cycle fluctuations. In our model, POEs are more sensitive to business cycle shocks than SOEs because the government guarantees SOE loans only. By adjusting reserve requirements, the central bank is able to influence the allocations of credit and capital between SOEs and POEs to achieve its stabilization goals. However, under our calibration, the nominal interest rate is a more effective policy instruments for macroeconomic stabilization. When interest rate policy is optimized, allowing the central bank to optimally set the required reserve ratio only provides modest welfare gains.

Of course, a more effective long-term reform would be to address the distortions in our framework explicitly, in particular to reduce or eliminate the distortion from the government guarantees on SOE loans only. More broadly, our results suggest potential gains from coordination between banking regulations and monetary policy.

Our model is a closed-economy environment, where private firms rely on domestic shadow banking loans to finance their operation. This is a reasonable approximation to China's current financial system because China has maintained tight controls over the capital account, so that it is difficult for domestic firms to obtain foreign funding. However, the Chinese government has set out plans to loosen its capital account. Similar to the shadow banking sector in our model, having improved access to foreign funds would help make financing for POEs more readily available. To the extent that private firms remain more productive than SOE firms, this may also improve overall allocative efficiency in China. While opening China's financial market to foreign lenders may crowd out some domestic off-balance sheet activity, risks may be better diversified with foreign lenders present. A full analysis of the consequences of opening the capital account in such an environment therefore requires an open-economy model with these features. Future research along this line should be promising.

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Table 1. Announcement Effects of RR policy on stock returns

Event window	1-day (H=0)	3-day (H=1)	5-day (H=2)
ΔRR_{t-1}	0.00206	0.00479	0.01057
	(7.20)	(9.21)	(15.74)
$\mathbf{SOE_{jt} \times \Delta RR_{t-1}}$	-0.0012	-0.00225	-0.00442
	(-3.21)	(-3.32)	(-5.05)
SOE_{jt}	-0.00007	-0.00026	-0.00041
	(-2.60)	(-5.29)	(-6.47)
Firm size	-0.00034	-0.00099	-0.00155
	(-27)	(-43)	(-53)
Book-to-market ratio	0.00009	0.00024	0.00047
	(2.22)	(3.29)	(4.96)
Industry fixed effects	Y	Y	Y
Year fixed effects	Y	Y	Y
Sample size	4,119,971	4,079,847	4,0003,53
R^2	0.00071	0.00182	0.00288

Note: For each coefficient, the upper row displays the estimated valued and the numbers shown in parantheses are the t-statistics. The critical values of t-statistics are 1.64. 1.96, and 2.58 for the 10%, 5%, and 1% significance levels, respectively.

TABLE 2. Announcement Effects of RR policy on stock returns: Before and after fiscal stimulus

	Pre-stimulus (2005-2008)		Post-stimulus (2009-2015)	
Event window	1-day (H=0)	3-day (H=1)	1-day (H=0)	3-day (H=1)
RR_{t-1}	0.0010	0.0003	0.0029	0.0081
	(2.00)	(0.31)	(8.08)	(12.57)
$\mathbf{SOE_{jt} \times RR_{t-1}}$	0.0001	0.0012	-0.0024	-0.0046
	(0.11)	(1.03)	(-4.78)	-5.03
SOE_{jt}	0.00002	0.0005	-0.0002	-0.0005
	(2.90)	(4.09)	(-4.85)	(-8.86)
Firm size	-0.0003	-0.0008	-0.0004	-0.0011
	(-9)	(-14)	(-26)	(-41)
Book-to-market ratio	0.0000	0.0001	0.0001	0.0004
	(-0.25)	(-0.56)	(2.91)	(4.50)
Industry fixed effects	Y	Y	Y	Y
Year fixed effects	Y	Y	Y	Y
Sample size	1,018,628	1,003,518	3,101,343	3,076,329
R^2	0.0005	0.0011	0.0008	0.0022

Note: For each coefficient, the upper row displays the estimated valued and the numbers shown in parantheses are the t-statistics. The critical values of t-statistics are 1.64. 1.96, and 2.58 for the 10%, 5%, and 1% significance levels, respectively.

Table 3. Calibrated values.

Variable	Description	Value
	A. Households	
β	Subjective discount factor	0.995
η	Inverse Frisch elasticity of labor supply	2
Ψ	Weight of disutility of working	18
δ	Capital depreciation rate	0.035
Ω_k	Capital adjustment cost	1
	B. Retailers	
ϵ	Elasticity of substitution between retail products	10
Ω_p	Price adjustment cost parameter	22
	C. Firms and financial intermediaries	
g	Steady state growth rate	1.0125
k	Shape parameter in Pareto distribution of idiosyncratic shocks	1.587
ω_m	Scale parameter in Pareto distribution of idiosyncratic shocks	0.37
A_s	SOE TFP scale (normalized)	1
A_p	POE TFP scale	1.42
α	Capital income share	0.5
θ	Share of household labor	0.94
ψ	Share parameter for SOE output in intermediate good	0.45
σ_m	Elasticity of substitution between SOE and POE products	3
m_s	SOE monitoring cost	0.15
m_p	POE monitoring cost	0.15
ξ_s	SOE manager's survival rate	0.97
ξ_p	POE manager's survival rate	0.69
	D. Government policy	
π	Steady state inflation rate	1.005
τ	Required reserve ratio	0.15
ψ_{rp}	Taylor rule coefficient for inflation	1.5
ψ_{ry}	Taylor rule coefficient for output	0.2
$\frac{G}{GDP}$	Share of government spending in GDP	0.14
l_s	Fraction of SOE debt guaranteed by the government	1
l_p	Fraction of SOE debt guaranteed by the government	0
	E. Shock process	
ρ_a	Persistence of TFP shock	0.95
σ_a	Standard deviation of TFP shock	0.01

TABLE 4. Volatilities and welfare under alternative policy rules

Variables	Benchmark	Optimal τ rule	Optimal R rule	Jointly optimal rule
		Policy rule coefficients		
ψ_{rp}	1.50	1.50	7.42	5.18
ψ_{ry}	0.20	0.20	0.07	-0.12
$\psi_{\tau p}$	0.00	-13.14	0.00	11.67
$\psi_{\tau y}$	0.00	4.81	0.00	15.96
		Volatility		
GDP	8.618%	8.155%	5.279%	4.952%
π	3.409%	3.231%	0.084%	0.136%
C	6.118%	5.950%	4.388%	4.306%
H	2.103%	1.835%	0.599%	0.416%
R	3.412%	3.236%	0.398%	0.349%
Y_s	9.091%	6.999%	5.362%	3.415%
Y_p	8.132%	8.455%	5.552%	5.982%
		Welfare		
Welfare gains	—	0.2423%	1.1799%	1.1801%

Note: The welfare gain under each optimal policy rule is the consumption equivalent relative to the benchmark economy (see the text in Section V.2 for details).

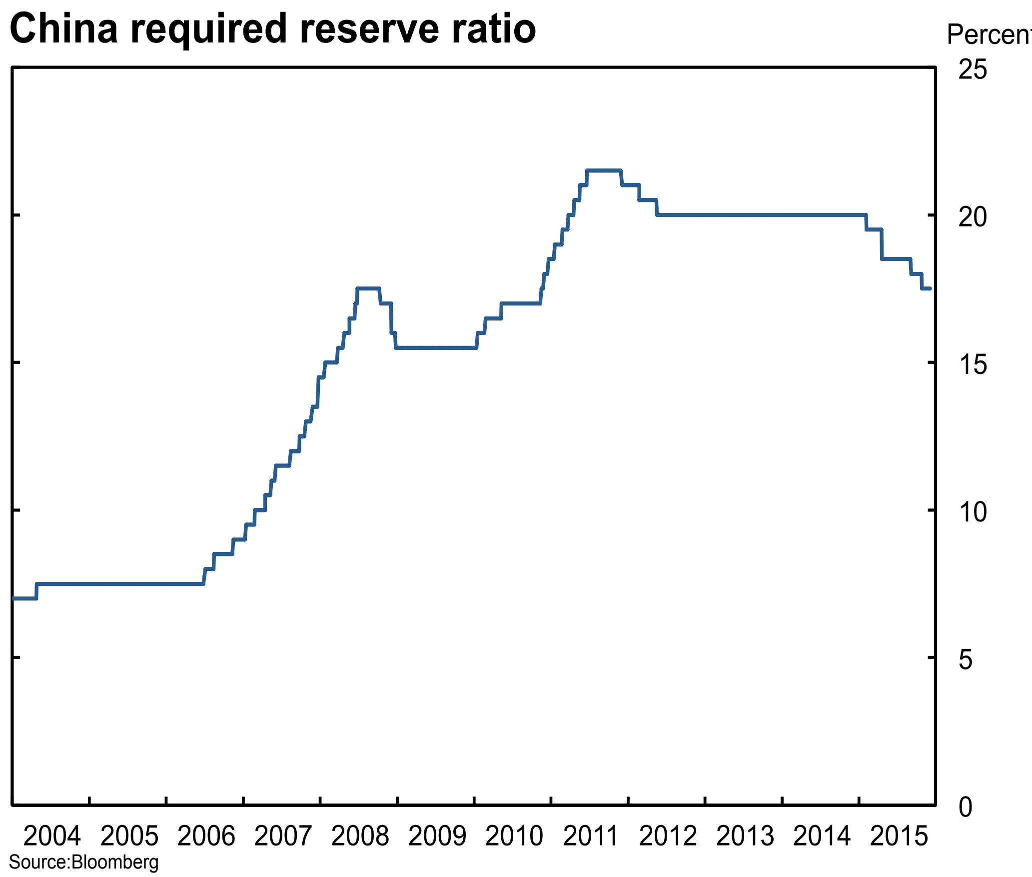

FIGURE 1. China's required reserve ratio (daily frequencies).

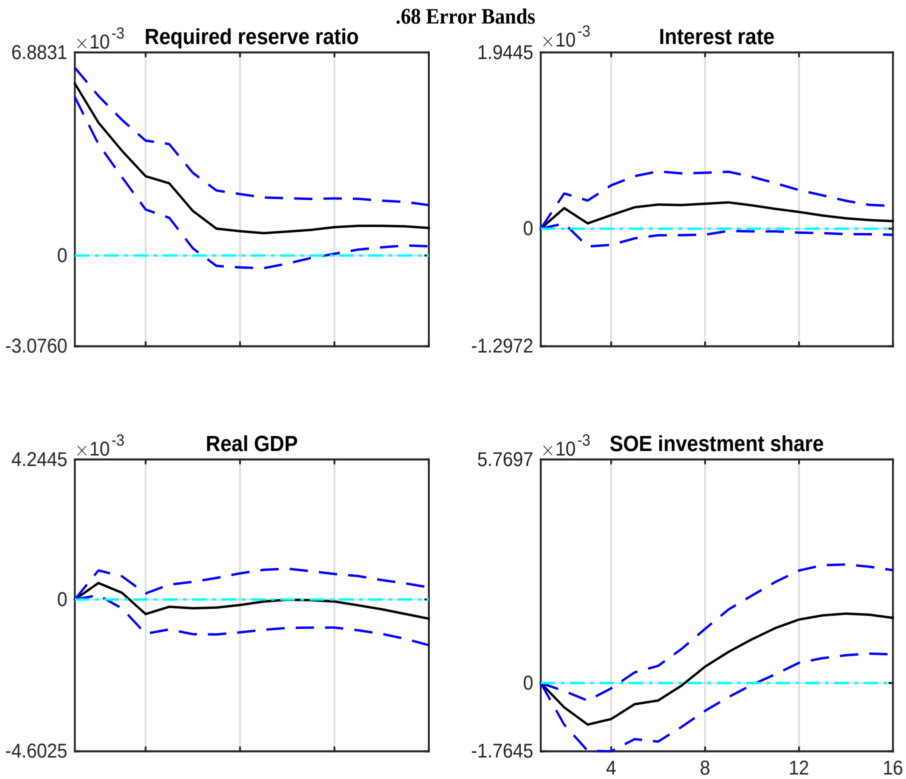

FIGURE 2. Impulse responses to a shock to the required reserve ratio estimated from the BVAR model.

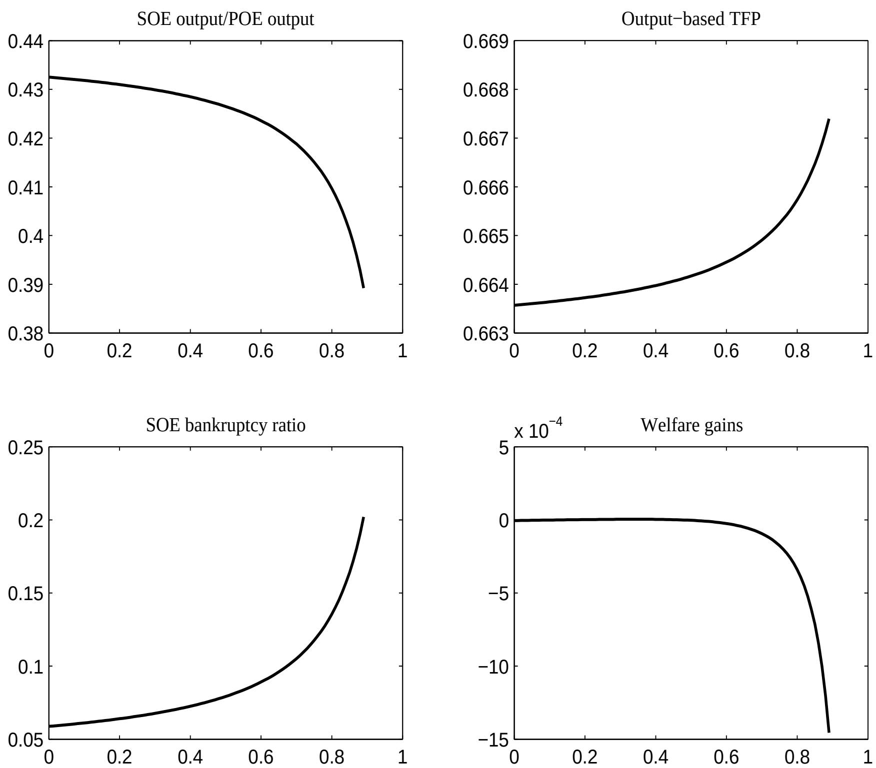

FIGURE 3. Steady-state implications of the required reseve ratio (τ) for macroeconomic variables and welfare. Welfare gains are measured as consumption equivalent relative to the steady state in the benchmark model with $\tau = 0.15$. The optimal required resreve ratio in the steady state is 0.34.

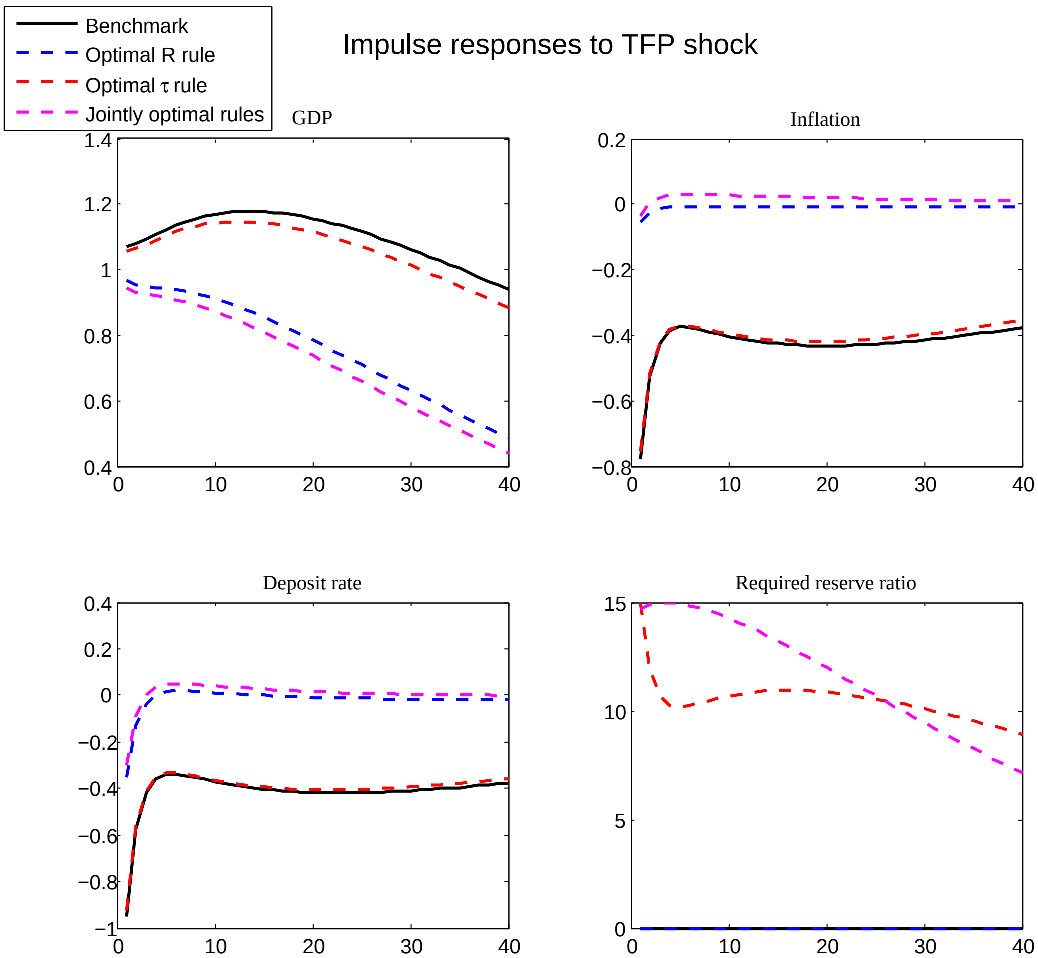

FIGURE 4. Impulse responses of aggregate variables to a positive TFP shock under alternative policy rules. Benchmark rule: black solid lines; optimal interest rate rule: blue dashed lines; optimal reserve requirement rule: red dashed lines; jointly optimal rule: magenta dashed-dotted lines. The vertical-axis unit of the required reserve ratio is the percentage-point deviations from the steady state level. The vertical-axis units for all other variables are percent deviations from the steady state levels. The variables displayed include real GDP (GDP_t), inflation (π_t), the nominal deposit rate (R_t), and the required reserve ratio (τ_t).

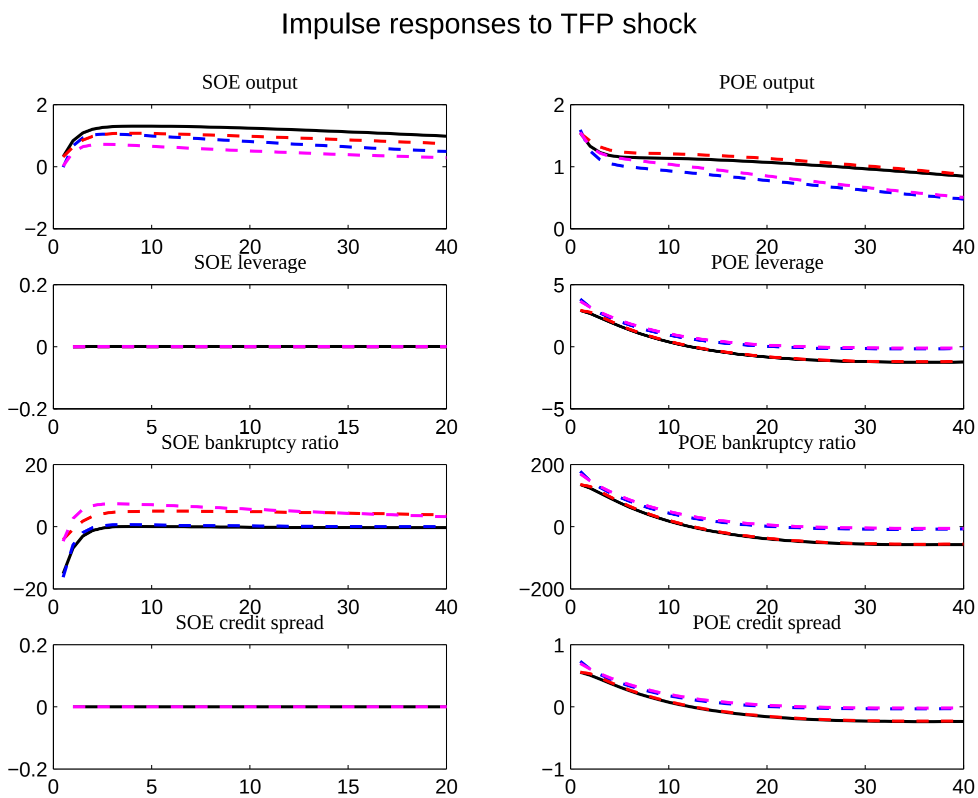

FIGURE 5. Impulse responses of sector-specific variables to a positive TFP shock under alternative policy rules. Benchmark rule: black solid lines; optimal interest rate rule: blue dashed lines; optimal reserve requirement rule: red dashed lines; jointly optimal rule: magenta dashed-dotted lines. The vertical-axis units are percent deviations from the steady state levels. The variables displayed include SOE output (Y_{st}), POE output (Y_{pt}), SOE leverage ratio (B_{st}/N_{st}), POE leverage ratio (B_{pt}/N_{pt}), SOE bankruptcy ratio ($F(\overline{\omega}_{st})$), POE bankruptcy ratio ($F(\overline{\omega}_{pt})$), SOE credit spread ($Z_{st}/R_t$), and POE credit spread (Z_{pt}/R_t).

Appendix A. Balanced-Growth Path Equilibrium Conditions

On a balanced growth path, output, consumption, investment, real bank loans and real wage rates all grow at a constant rate g. To obtain balanced growth, we make the stationary transformations

$$y_t^f = \frac{Y_t^f}{g^t}, m_t = \frac{M_t}{g^t}, c_t = \frac{C_t}{g^t}, i_t = \frac{I_t}{g^t}, k_t = \frac{K_t}{g^t}, gdp_t = \frac{GDP_t}{g^t}, \lambda_t = \Lambda_t g^t,$$
$$y_{st} = \frac{Y_{st}}{g^t}, y_{pt} = \frac{Y_{pt}}{g^t}, k_{st} = \frac{K_{st}}{g^t}, k_{pt} = \frac{K_{pt}}{g^t}, \tilde{w}_t = \frac{w_t}{g^t}, \tilde{w}_{s,e,t} = \frac{w_{s,e,t}}{g^t}, \tilde{w}_{p,e,t} = \frac{w_{p,e,t}}{g^t},$$
$$n_{st} = \frac{N_{st}}{P_t g^t}, n_{pt} = \frac{N_{pt}}{P_t g^t}, b_{st} = \frac{B_{st}}{P_t g^t}, b_{pt} = \frac{B_{pt}}{P_t g^t}.$$

On the balanced growth path, the transformed variables, the interest rate and the inflation rate are all constants.

The balanced growth equilibrium is summarized by the following equations:

1) Households.

$$k_t = \tfrac{1-\delta}{g} k_{t-1} + i_t[1 - \tfrac{\Omega_k}{2}(\tfrac{i_t g}{i_{t-1}} - g)^2], \tag{A1}$$

$$\lambda_t = \tfrac{1}{c_t}, \tag{A2}$$

$$\tilde{w}_t = \Psi \tfrac{H_t^\eta}{\lambda_t}, \tag{A3}$$

$$1 = \mathrm{E}_t \beta \tfrac{\lambda_{t+1}}{\lambda_t} \tfrac{R_t}{\pi_{t+1} g}, \tag{A4}$$

$$1 = q_t^k[1 - \tfrac{\Omega_k}{2}(\tfrac{i_t g}{i_{t-1}} - g)^2 - \Omega_k(\tfrac{g i_t}{i_{t-1}} - g)\tfrac{i_t g}{i_{t-1}}] + \beta \mathrm{E}_t q_{t+1}^k \tfrac{\lambda_{t+1}}{\lambda_t g} \Omega_k (\tfrac{i_{t+1} g}{i_t} - g)(\tfrac{i_{t+1} g}{i_t})^2, \tag{A5}$$

$$q_t^k = \beta \mathrm{E}_t \tfrac{\lambda_{t+1}}{\lambda_t g}[(1-\delta) q_{t+1}^k + r_{t+1}^k]. \tag{A6}$$

2) Firms and banks.

$$y_{st} = A_t^m \bar{A}_s k_{st}^{1-\alpha} (H_{st}^\theta)^\alpha, \tag{A7}$$

$$\tilde{w}_t H_{st} = \alpha\theta(\tfrac{n_{s,t-1}}{\pi_t g} + b_{st}), \tag{A8}$$

$$\tilde{w}_{s,e,t} = (\tfrac{n_{s,t-1}}{\pi_t g} + b_{st})\alpha(1-\theta), \tag{A9}$$

$$k_{st} r_t^k = (1-\alpha)(\tfrac{n_{s,t-1}}{\pi_t g} + b_{st}), \tag{A10}$$

$$\tilde{A}_{st} = \frac{p_{st} y_{st}}{\frac{n_{s,t-1}}{\pi_t g} + b_{st}}, \tag{A11}$$

$$\tilde{A}_{st}(\tfrac{n_{s,t-1}}{\pi_t g} + b_{st}) g_s(\overline{\omega}_{st}) = b_{st} R_{st}, \tag{A12}$$

$$\frac{\frac{n_{s,t-1}}{\pi_t g}}{\frac{n_{s,t-1}}{\pi_t g}+b_{st}} = -\frac{g_s'(\overline{\omega}_{st})f(\overline{\omega}_{jt})}{f'(\overline{\omega}_{st})}\frac{\tilde{A}_{st}}{R_{st}}, \tag{A13}$$

$$n_{st} = \tilde{w}_{s,e,t} + \xi_s \tilde{A}_{st}(\frac{n_{s,t-1}}{\pi_t g} + b_{st})f(\overline{\omega}_{st}), \tag{A14}$$

$$y_{pt} = A_t^m \bar{A}_p k_{pt}^{1-\alpha}(H_{pt}^{\theta})^{\alpha}, \tag{A15}$$

$$\tilde{w}_t H_{pt} = \alpha\theta(\frac{n_{p,t-1}}{\pi_t g} + b_{pt}), \tag{A16}$$

$$\tilde{w}_{p,e,t} = \alpha(1-\theta)(\frac{n_{p,t-1}}{\pi_t g} + b_{pt}), \tag{A17}$$

$$r_t^k k_{pt} = (1-\alpha)(\frac{n_{p,t-1}}{\pi_t g} + b_{pt}), \tag{A18}$$

$$\tilde{A}_{pt} = \frac{p_{pt}y_{pt}}{\frac{n_{p,t-1}}{\pi_t g}+b_{pt}}, \tag{A19}$$

$$\tilde{A}_{pt}(\frac{n_{p,t-1}}{\pi_t g} + b_{pt})g_p(\overline{\omega}_{pt}) = b_{pt}R_{pt}. \tag{A20}$$

$$\frac{\frac{n_{p,t-1}}{\pi_t g}}{\frac{n_{p,t-1}}{\pi_t g}+b_{pt}} = -\frac{g_p'(\overline{\omega}_{pt})f(\overline{\omega}_{pt})}{f'(\overline{\omega}_{pt})}\frac{\tilde{A}_{pt}}{R_{pt}}, \tag{A21}$$

$$n_{pt} = \tilde{w}_{p,e,t} + \xi_p \tilde{A}_{pt}(\frac{n_{p,t-1}}{\pi_t g} + b_{pt})f(\overline{\omega}_{pt}), \tag{A22}$$

$$(R_{st}-1)(1-\tau_t) = R_t - 1, \tag{A23}$$

$$R_{pt} = R_t. \tag{A24}$$

3) Pricing, market clearing and monetary policy.

$$p_{wt} = \frac{\epsilon-1}{\epsilon} + \frac{\Omega_p}{\epsilon}\frac{1}{y_t}[(\frac{\pi_t}{\pi}-1)\frac{\pi_t}{\pi}c_t - \beta \mathrm{E}_t\frac{\lambda_{t+1}}{\lambda_t}(\frac{\pi_{t+1}}{\pi}-1)\frac{\pi_{t+1}}{\pi}c_{t+1}], \tag{A25}$$

$$\ln(\frac{R_t}{\bar{R}}) = \psi_{ry}\ln(\frac{gdp_t}{\bar{gdp}}) + \psi_{rp}\ln(\frac{\pi_t}{\bar{\pi}}), \tag{A26}$$

$$\ln(\frac{\tau_t}{\bar{\tau}}) = \psi_{\tau y}\ln(\frac{gdp_t}{\bar{gdp}}) + \psi_{\tau p}\ln(\frac{\pi_t}{\bar{\pi}}), \tag{A27}$$

$$g_t = gdp_t g^c, \tag{A28}$$

$$\begin{aligned} y_t^f &= i_t + c_t + g_t + c_t\frac{\Omega_p}{2}(\frac{\pi_t}{\pi}-1)^2 + \tilde{A}_{st}(\frac{n_{s,t-1}}{\pi_t g}+b_{st})m_t\int_0^{\overline{\omega}_{st}}\omega dF(\omega) \\ &+\tilde{A}_{pt}(\frac{n_{p,t-1}}{\pi_t g}+b_{pt})m_t\int_0^{\overline{\omega}_{pt}}\omega dF(\omega), \end{aligned} \tag{A29}$$

$$y_t^f = m_t, \tag{A30}$$

$$m_t = \left(\phi y_{st}^{\frac{\sigma_m-1}{\sigma_m}} + (1-\phi)y_{pt}^{\frac{\sigma_m-1}{\sigma_m}}\right)^{\frac{\sigma_m}{\sigma_m-1}}, \tag{A31}$$

$$y_{st} = \phi^{\sigma_m} \left(\frac{p_{st}}{p_{wt}}\right)^{-\sigma_m} y_t, \tag{A32}$$

$$y_{pt} = (1-\phi)^{\sigma_m} \left(\frac{p_{pt}}{p_{wt}}\right)^{-\sigma_m} y_t, \tag{A33}$$

$$\frac{k_{t-1}}{g} = k_{st} + k_{pt}, \tag{A34}$$

$$H_t = H_{st} + H_{pt}, \tag{A35}$$

$$gdp_t = g_t + i_t + c_t. \tag{A36}$$

where

$$f(\overline{\omega}_{st}) = \frac{1}{k-1}\omega_m^k \overline{\omega}_{st}^{1-k}, \tag{A37}$$

$$f'(\overline{\omega}_{st}) = -\omega_m^k \overline{\omega}_{st}^{-k}, \tag{A38}$$

$$g_s(\overline{\omega}_{st}) = \omega_m \frac{k}{k-1}(1-l_s)(1-m) + l_s\overline{\omega}_{st} + (1-l_s)[1-\frac{(1-m)k}{k-1}]\omega_m^k \overline{\omega}_{st}^{1-k}, \tag{A39}$$

$$g_s'(\overline{\omega}_{st}) = l_s + (1-l_s)(1-mk)\omega_m^k \overline{\omega}_{st}^{-k}, \tag{A40}$$

$$f(\overline{\omega}_{pt}) = \frac{1}{k-1}\omega_m^k \overline{\omega}_{pt}^{1-k}, \tag{A41}$$

$$f'(\overline{\omega}_{pt}) = -\omega_m^k \overline{\omega}_{pt}^{-k}, \tag{A42}$$

$$g_p(\overline{\omega}_{pt}) = \omega_m \frac{k}{k-1}(1-l_p)(1-m) + l_p\overline{\omega}_{pt} + (1-l_p)[1-\frac{(1-m)k}{k-1}]\omega_m^k \overline{\omega}_{pt}^{1-k}, \tag{A43}$$

$$g_p'(\overline{\omega}_{pt}) = l_p + (1-l_p)(1-mk)\omega_m^k \overline{\omega}_{pt}^{-k}, \tag{A44}$$

$$\int_0^{\overline{\omega}_{st}} \omega dF(\omega) = \frac{k}{k-1}(\omega_m - \omega_m^k \overline{\omega}_{st}^{1-k}), \tag{A45}$$

$$\int_0^{\overline{\omega}_{pt}} \omega dF(\omega) = \frac{k}{k-1}(\omega_m - \omega_m^k \overline{\omega}_{pt}^{1-k}). \tag{A46}$$

The system of 36 equations from (A1) to (A36) determine the equilibrium solution for the 36 endogenous variables summarized in the vector,

$$[y_t^f, m_t, c_t, i_t, g_t, gdp_t, k_t, \lambda_t, \tilde{q}_t^k, H_t, H_{st}, H_{pt},$$
$$y_{st}, y_{pt}, k_{st}, k_{pt}, n_{st}, n_{pt}, b_{st}, b_{pt}, \tilde{A}_{st}, \tilde{A}_{pt}, \overline{\omega}_{st}, \overline{\omega}_{pt},$$
$$\tilde{w}_t, \tilde{w}_{s,e,t}, \tilde{w}_{p,e,t}, r_t^k, R_t, R_{st}, R_{pt}, \pi_t, p_{wt}, p_{st}, p_{pt}, \tau_t]$$