Bank Recapitalization in a DSGE framework[*†]

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Abstract

We build a DSGE model with state owned banks and financial frictions in the form of statutory liquidity requirements, to analyze the impact of bank recapitalization due to firm level defaults. We calibrate the model to India, which we view as a proto-typical emerging economy with state owned banks. We model recapitalization as a conditional transfer made by the government to banks. Our impulse response functions to a one-period negative productivity shock indicate that recapitalization and capital adequecy concerns, in the absence of moral hazard, have a positive effect on capital formation and growth. However, it could be welfare reducing especially when social expenditure by the government is depressed. We, hence, call for appropriate policy attention to address this long term possibility.

Keywords : Bank recapitalization, SLR requirements, Emerging Market Economies, Financial Frictions, state owned banks

JEL Codes : E32, E62

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1 Introduction

The global financial crisis (2008) clearly underlined the pivotal role of the banking sector in advanced and emerging market economics and also brought to fore some of the limitations of the existing international banking regulations. Considering the importance of banks as a shock absorber between financial and real sector academicians and policy makers initiated a series of measures focusing upon improving the quality and quantity of banking capital to provide the cushion against unexpected shocks. It followed large recapitalization drive in advanced economies during 2008-09 (BIS paper No. 48) and in emerging market economics.

The objective of recapitalization is to build up adequate cushion to reduce frequency of default and loss given default to make the financial system resilient, reduce cost of capital and to promote economic growth. Banking recapitalization, however, could take several forms that include capital infusion by promoters and /or market borrowing, which might result in crowding out of private investment. Another possible way to mechanically improve capital adequacy numbers is by reducing risky investment or risk weight in these investment and thereby inflate the capital. Both of these could adversely affect economic growth, especially so in bank loan dependent emerging market economies (EMEs). We therefore take a general equilibrium approach, with dominance of state owned banks and banking sector frictions to have a totalitarian view on the impact of bank recapitalization on the economy.

We parametrize our model for the Indian economy for several reasons, which include (a) overall dependence of economic activities on the bank finances (b) public sector ownership of banks (c) large non-performing assets, write-offs and capital requirements of these banks and (d) the statutory liquidity ratio (SLR) and cash reserve ratio (CRR) requirement of the banking sector. Moreover, there have been episodes of recapitalization in the Indian banking sector in 1994, through recap bonds, in 2015 through budgetary allocations and market borrowing (Indradhanush Plan) and in October 2017 through Recapitalization bonds. These diverse policy measures would help us to calibrate banking recapitalization experience from most of the EME and also to calibrate counterfactuals to analyze recent recapitalization.

The uniqueness of our model lies with the banking sector which is state owned and has a financial constraint in the form of SLR requirements.We build a five sector model including state owned banks that lend to firms for purchasing capital for production. In this model firms default on their repayments to these state owned banks with probability that is state contingent on total factor productivity. We assume two different scenarios-first, unconditional transfers made by the government to the state owned banks to cover up their losses due to firm defaults; second, conditional transfers, i.e., wherein government's equity holding in these banks are linked with additional transfers. The main findings of the model are government transfer helps the banking sector in both the scenarios in the short to medium term. However, increase in such transfer could impact public expenditure in social sector that may have an adverse impact on welfare. In general our research suggests that a calibrated approach to address banks' balance-sheet issues by fresh capital injection for immediate credit creation can be given priority. Equity transfers could provides for a good way of bringing discipline into a public recapitalization program compared to the unconditional budgetary transfer. We call for appropriate vigil on public expenditure in social sectors to prevent any welfare consequence over the long run, given that in most of the Emerging economies, capital expenditure is already getting squeezed due to large revenue expenditure and fiscal consolidation.

The paper is organized as follows. Section 2 presents the baseline model. Section 3 offers some concluding remarks and policy implications.

2 Baseline model

2.1 Model environment

In this model, there are five agents - Households, final good firms, intermediate capital good firms, banks and the Government. Households make deposits in banks, and derive utility from effective consumption and leisure. Effective consumption in this model a function of private consumption and utility enhancing government expenditure (see Ghate et al 2016). This gives a crucial labor market channel due to fiscal policy. Households supply labor to firms and own them. They also own a share of banks, which are largely state owned, i.e., a significant portion of the banks' ownership lies with the government. As a result their small holding of banks' ownership, households also receive a portion of banks' profits in the form of dividends payments. The final goods firms produce the final good using labor hired from households, and new capital purchased from the intermediate capital goods sector. The intermediate capital goods sector purchase undepreciated capital from firms producing the final good and refurbish them to produce new capital (see Basu et al. (2018), Gunn and Johri (2016), and Gerali et al. (2010) for a setup of the capital goods sector).

Banks receive deposits from households, of which a fixed portion is mandatorly held in the form of government bonds. The remainder is lent to firms to purchase new capital for producing the single final good in the economy. Finally, the government taxes household consumption and wage incomes, borrow by issuing bonds to banks, and undertakes two kinds of expenditures. The first enhances productivity of final goods firm, and the second enhances utility of households, as discussed above. The government in this model exists passively, and taxes are exogenous. In an extension, we assume that the tax rates endogenously adjust to balance the government's budget constraint.

2.2 Firms

The economy consists of two sectors on the production side - a final goods producing firm and a capital goods producing firm. The capital goods firm supplies new capital to the final goods firm at a market price in every time period. The final goods firm produces the final good which is consumed by the households, the government and as investment in physical asset.

2.2.1 Capital goods producing firm

Our description of the capital goods producing firms is as in Gerali et al. (2010) and Basu et al. (2018). Perfectly competitive firms buy last period's undepreciated capital, $(1-\delta_K)K_{t-1}$ at price Q_t from the final goods firms and I_t units of the final good. The transformation of the final good into new capital is subject to adjustment costs, S , such that

$$S\left(\frac{K_t}{K_{t-1}}\right) = \frac{\kappa}{2}\left(\frac{K_t}{K_{t-1}} - 1\right)^2 \tag{1}$$

The new capital is then sold to the final goods firm. The discounted lifetime profit function of the capital goods firm is given by

$$\max_{\{K_t\}} E_0 \sum_{t=0}^{\infty} \Omega_{t,t+s}[Q_t\left[K_t - (1-\delta_K)K_{t-1}\right] - I_t], \tag{2}$$

where,

$$\Omega_{t,t+s} = \frac{\beta^s U'\left(C_{t+s}\right)}{U'\left(C_t\right)}$$

is the stochastic discount factor, and subject to

$$I_t = K_t - (1-\delta_K)K_{t-1} + K_{t-1} S\left(\frac{K_t}{K_{t-1}}\right). \tag{3}$$

The first order condition w.r.t K_t and I_t are

$$\{K_t\} : Q_t + \Omega_{t,t+1}\lambda_{t+1}\left[\frac{K_{t+1}}{K_t}S'\left(\frac{K_{t+1}}{K_t}\right) - S\left(\frac{K_{t+1}}{K_t}\right) + (1-\delta_K)\right] = \lambda_t\left[1 + S'\left(\frac{K_t}{K_{t-1}}\right)\right] \tag{4}$$

$$+\,\Omega_{t+1,t+2}[(1-\delta_K)Q_{t+1}],$$

$$\{I_t\} : \lambda_t - 1 = 0. \tag{5}$$

Equations (4) and (5) together yield the following capital pricing equation,

$$Q_t + \Omega_{t,t+1}\left[\frac{K_{t+1}}{K_t}S'\left(\frac{K_{t+1}}{K_t}\right) - S\left(\frac{K_{t+1}}{K_t}\right) + (1-\delta_K)\right] = \left[1 + S'\left(\frac{K_t}{K_{t-1}}\right)\right] + \Omega_{t+1,t+2}[(1-\delta_K)Q_{t+1}]$$

In the Steady State

$$Q = 1.$$

2.2.2 Final goods producing firm

At any given time t, a representative firm hires labor (H_t) and uses capital (K_{t-1}) accumulated in time period $t-1$ to produce final output Y_t such that

$$Y_t = A_t K_{t-1}^{\alpha}(G_t^P H_t)^{1-\alpha} \tag{6}$$

The firm borrows $L_t = Q_t K_t$ from the bank in order to purchase new capital next period. In this framework, we assume that the firm defaults in its repayments to the bank with a probability p_t^*. In the baseline case, we assume that the firm's defaults are exogenous, i.e.,

$$p_t^* \sim U\left(0,1\right). \tag{7}$$

In other words, the defaults are contingent on the state of the economy. The stochastic probability of defaults is high if the state of the economy is 'more bad' versus 'less bad'.[1]

The firm maximizes it's profits given by,

$$\max_{\{K_t,H_t\}} E_0 \sum_{t=0}^{\infty} \Omega_{t,t+s}[Y_t - W_t H_t - Q_t K_t + \tag{8}$$
$$(1-\delta_K)Q_t K_{t-1} + L_t - (1-p_t^*)R_t^L L_{t-1}],$$

where

$$G_t^P \sim CSSP. \tag{9}$$

G_t^P is an exogenous government spending that is announced in every period t. This follows a covariance stationary stochastic process.[2] This yields the following first order conditions w.r.t. K_t and H_t

$$\{K_t\} : E_t\left[\alpha\frac{Y_{t+1}}{K_t} + (1-\delta_k)\,Q_{t+1} - \left(1-p_{t+1}^*\right)R_{t+1}^L Q_t\right] = 0 \tag{10}$$
$$\{H_t\} : E_t\left[(1-\alpha)\,\frac{Y_t}{H_t} - W_t\right] = 0 \tag{11}$$

[1] In an alternative framework, we are tying the default probability of firms to their productivity business cycles. In other words,

$$p_t^* = p^*\left(\overline{A} - A_t\right).$$

Therefore, if the exogenous TFP is lower than the steady state level of TFP, the probability of default is higher. While this alternative specification is important when we analyze impulse responses, in the current framework we only focus on steady state computations.

[2] This will be used when we run impulse responses to understand the general equilibrium effects due to a shock to G_t^P. This is ongoing.

In the steady state,

$$K = \left[\frac{A\alpha}{Q[(1-p)R^L - (1-\delta_k)]}\right]^{\frac{1}{1-\alpha}} G^P H$$
$$H = \left[\frac{(1-\alpha)A\left(G^P\right)^{1-\alpha}}{w}\right]^{\frac{1}{\alpha}} K$$

2.3 Households

The economy is populated by infinitely lived households with a mass normalized to 1. The representative household consumes and invests a homogenous good and supplies labor and capital to firms. Households derive utility from effective consumption (C_t^*) and leisure $(1-H)$. The representative household has the following expected discounted lifetime utility

$$E_0 \sum_{t=0}^{\infty} \beta^t U(C_t^*, H_t), \tag{12}$$

where $\beta \in (0,1)$ denotes the households subjective discount factor. We assume that

$$C_t^* = C_t + \mu G_t^C, \qquad \mu > 0 \tag{13}$$

where household consumption (C_t) is augmented by government consumption (G_t^C). The parameter μ captures the weight of public consumption in household utility, where $\mu > 0$. Given our specification in equation (13), C_t and G_t^C are assumed to be perfect substitutes.[3] The only source of consumption smoothing for the household is that they make bank deposits. Households make deposits d_t in state owned banks on which they receive gross interest income R_t^D. They supply labor to firms, and in return receive wages W_t.They also receive $(1-e)$ proportion of the bank's profit, Π_t^b. Therefore, the representative household maximizes the following discounted life-time utility function

$$\max_{\{C_t, H_t, d_t\}} E_0 \sum_{t=0}^{\infty} \beta^t [\ln(C_t + \mu G_t^C) + \ln(1-H_t)], \tag{14}$$

subject to,

[3] In an emerging markets context, an example of G_t^C can be public health or public transportation services whose quality is typically seen as being superior to private alternatives. See Barro (1981), Christiano and Eichenbaum (1992), Ambler and Paquet (1996), and Ghate et al. (2016).

$$(1+\tau_C)C_t + d_t \leq (1-\tau_W)W_tH_t + R_t^D d_{t-1} + (1-e)\Pi_t^b,$$

where τ_C is the tax on consumption, and τ_W is the tax on labor income. First order conditions yield

$$\frac{1}{C_t^*} = \beta E_t \left[\frac{R_t^D}{C_{t+1}^*} \right], \tag{15}$$

where (15) is the Euler equation, and (16) is the standard marginal rate of substitution between effective consumption and leisure.

$$\left(\frac{C_t^*}{W_t} \right) \left(\frac{1+\tau_C}{1-\tau_W} \right) = 1 - H_t \tag{16}$$

In the steady state,

$$R^D = \frac{1}{\beta},$$

that is, in the steady state, the deposit rate is the inverse of the discount factor. Finally,

$$\left(\frac{C^*}{W} \right) \left(\frac{1+\tau_C}{1-\tau_W} \right) = 1 - H.$$

2.4 Banks

Banks are state owned. A portion e of a representative bank's profits in every time period t, goes to the government, and the rest goes to households. The bank receives deposits d_t from the household, a fraction Φ of which is held as government bonds. On these government bonds, the bank earns a pre-announced gross interest rate of R_t^G at a given t. The remaining proportion $(1-\Phi)$ of total deposits is used for lending activity to the final good firms so that they can purchase new capital from the intermediate capital producing sector. The lending rate is R_t^L at a given time period t. The bank also incurs a monitoring cost $\gamma(L_t)$ to reduce the default risk, and receives a transfer $p_t^* R_t^L L_{t-1}$ from the government for the loss due to non-repayment by firms. The following is the optimization problem of a standard state owned bank.

$$\Pi_t^b = E_0 \sum_{t=0}^{\infty} \Omega_{t,t+s}[d_t - R_t^D d_{t-1} - L_t + (1-p_t^*)R_t^L L_{t-1} \tag{17}$$
$$- \Phi d_t + R_t^G \Phi d_{t-1} - \gamma(L_t) + p_t^* R_t^L L_{t-1}]$$

where,

$$L_t = (1-\Phi)d_t \tag{18}$$

$$\gamma(L_t) = \gamma L_t^{\sigma}, \qquad \sigma \geq 1. \tag{19}$$

This yields the first order condition

$$R_{t+1}^D = (1-\Phi)R_{t+1}^L + \Phi R_{t+1}^G - \frac{1}{\Omega}\gamma\sigma(1-\Phi)^{\sigma} d_t^{\sigma-1} \tag{20}$$

Assuming $\sigma = 1$ for analytical tractability, in the steady state,

$$R^L = \frac{1 - \beta\Phi R^G + \gamma(1-\Phi)}{(1-\Phi)\beta}. \tag{21}$$

From (21), is the No-Arbitrage condition which governs the relationship between the steady deposit rate, the gross return on government bonds, and the lending rate. We can show that as Φ increases, R^L, i.e., the steady state gross lending rate decreases. At the same time, as R^G increases, R^L decreases. This is because government bond in this economy is the most risk free asset.

2.5 Government

The government exists passively in this model. It collects taxes on consumption and wage income and receives a proportion e of bank's profits.[4] It give unconditional transfers to banks for the loss due to non-repayment by the firms. Apart from this, It undertakes an exogenous public expenditure G_t^P which enhances the productivity of the final goods sector. We assume the tax rates τ_C and τ_W are exogenous, and therefore the government expenditure G_t^C which

[4]In an extension, we will analyze the model under endogenous wage income tax adjustments for exogenous government spending. This is ongoing.

enhances household's utility endogenously adjusts to balance the government's budget. The following is therefore the budget constraint faced by the government,

$$G_t^P + G_t^C = \tau_C C_t + \tau_W W_t H_t - \Phi R_t^G d_{t-1} + \Phi d_t + e\Pi_t^b - pR_t^L L_{t-1} \tag{22}$$

2.6 The non-stochastic steady state system

The following summarizes the non-stochastic steady state of the system

$$\left(\frac{C^*}{W}\right)\left(\frac{1+\tau_C}{1-\tau_W}\right) = 1 - H \tag{23}$$

$$R^D = \frac{1}{\beta} \tag{24}$$

$$(1+\tau_C)C + d = (1-\tau_W)WH + R^D d + (1-e)\Pi^b \tag{25}$$

$$Q = 1 \tag{26}$$

$$K = \left[\frac{A\alpha}{Q[(1-p)R^L - (1-\delta_k)]}\right]^{\frac{1}{1-\alpha}} G^P H \tag{27}$$

$$H = \left[\frac{(1-\alpha)A\left(G^P\right)^{1-\alpha}}{w}\right]^{\frac{1}{\alpha}} K \tag{28}$$

$$L = QK \tag{29}$$

$$Y = AK^\alpha (G^P H)^{1-\alpha} \tag{30}$$

$$R^L = \frac{1 - \beta\Phi R^G + \gamma(1-\Phi)}{(1-\Phi)\beta} \tag{31}$$

$$\Pi^b = \gamma(1-\Phi)(\frac{1}{\beta} - 1)d \tag{32}$$

$$L = (1-\Phi)d \tag{33}$$

$$G^P + G^C = \tau_C C + \tau_W WH - \Phi R^G d + \Phi d + e\Pi^b - pR^L L \tag{34}$$

2.7 Numerical simulations

2.7.1 Parameter Values

We fix the tax rate on consumption $\tau_c = 0.12$ and $\alpha = 0.35$ from Ghate et al. (2016). We choose the productivity enhancing government expenditure G^P and A arbitrarily. Given that India has a very narrow income tax base and depends more on generating revenue from indirect taxation, we allow for a low income tax at $\tau_w = 0.01$ (see Poirson (2001)). The depreciation rate of capital $\delta_k = 0.1$, which matches approximately 10% of annual rate of depreciation (Gabriel et al. (2012)). The gross rate of return on government bonds R^G is equal to 1.02 which roughly matches the long run average gross real rate of return on 91-day treasury bill rates in India. The mandatory proportion of deposits that are to be held in the form of government bonds Φ, is equals to 0.2, which roughly matches the Statutory Liquidity Rates in India. The household's discount rate β is fixed at 0.98 (see Gabriel et al. (2012)). Monitoring cost parameters γ and σ are arbitrarily fixed at values > 1 and $\geqslant 1$ respectively. Table 1 below summarizes our choice of deep parameters in our model. In the next section, we will show numerical simulations by varying e, and p^* in the steady state, for given changes to the SLR rates Φ.

Parameters	Values	Source
α	0.35	Ghate et al. (2016)
β	0.98	Gabriel et al. (2012)
γ	> 1	Arbitrary
σ	$\geqslant 1$	Arbitrary
τ_c	0.12	Ghate et al. (2016)
τ_w	0.01	Poisron (2001)
μ	0.5	Arbitrary
δ_k	0.1	Data
R^G	1.02	Data
Φ	0.2	Data
G^P, A	Exogenous	Authors

2.8 Impulse Response Functions

In this section, we will analyze the impact of a one period shock to productivity that affects the probability of default, p_t^*. We will assume the following CSSP processes:

$$p_t^* = p^* \exp\left(A - \widehat{A}_t\right), \text{ where } \widehat{A}_t \sim N\left(0, \sigma_A^2\right)$$

2.8.1 Baseline case - Unconditional transfers

Suppose the government makes an unconditional transfer. In this case, the government compensates the banks for all the loss due to non-repayment by the borrowing firms. In other words, the transfers made by the government to the banks is

$$p_t^* R_t^L L_{t-1}.$$

At the same time, the government does not expect banks to take any austerity measures. This case effectively boils down to a simple compensatory transfers extended to banks, and lowering costs of firm borrowing. The default probabilities p^* are contingent on the state of the economy. They are tied to the firm's productivity business cycle such that,

$$p_t^* = p^*(A - A_t)$$

Now, suppose there is a one period productivity shock. Figure 1 shows the impulse response functions of various macroeconomic variables. A negative productivity shock leads to a fall in the probability of default. On the firm's side, this leads to a rise in their profits since they can now default in repaying their debts without affecting their chances of getting loans in future. This leads to an increase in capital formation and output, further leading to a rise in labour. This Indicates that a rise in the default probability outweighs a fall in the productivity resulting in a rise in firm's profits. Further, a rise in capital leads to a rise in firm's borrowing from the bank. This leads to a rise in gross interest rate on deposits by the bank to boost up their deposits in order to meet this increased demand for loans.

Increased deposits leads to an intertemporal substitution of today's consumption for tomorrow's consumption causing an initial fall in consumption. On the other hand, With higher transfers, on account of higher p^*, government will be left with less funds to spend leading to a fall in public utility spending. This implies that there is a fall in the effective consumption causing a welfare loss.

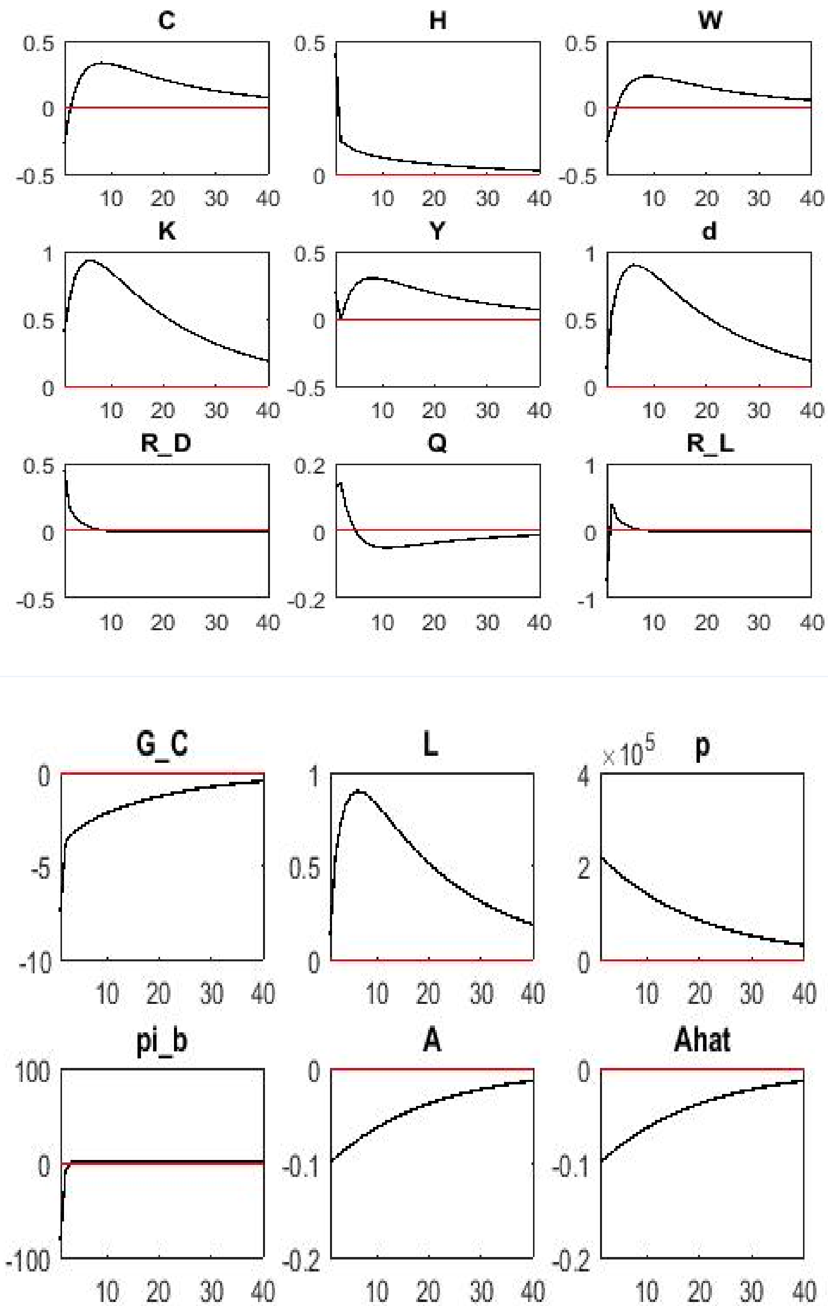

Figure 1: One period negative productivity shock

2.9 Conditional transfers

Now suppose, the government imposes a rule that it will transfer $p_t^* R_t^L L_{t-1}$ to banks in the instance of firms defaulting, but in return, insists on a higher equity holding of banks. One can think of this as analogous to the case where in a more risky environment, the government takes greater charge of the banking sector. In this case, we assume

$$e = \underline{e} + \varpi.p^{*}, \varpi > 0,$$

i.e., a higher p^{*} implies higher e, or in other words, a higher share of the representative bank's accrues to the government. As a consequence, the residual bank profits accruing to households is lower.

Figure 2 shows the impulse response functions of a one period productivity shock in the case where the governement demands higher equity holding in bank's profits in return of higher transfers being made, on account of higher p^{*}. As before, the default probability of the firm is tied to the productivity business cycle such that,

$$p_t^{*} = p^{*}(A - A_t)$$

It is observed that the impact of a negative productivity shock on the real economy remains unchanged. However, the public utility spending decreases by a lesser amount as compared to the unconditional transfer case. This is so because a negative productivity shock leads to a rise in probability of default and with it, government's equity in bank's profits. Hence, there is a rise in govenment's revenue. But since government transfers to bank also increases on account of a higher p^{*}, and hence, government's expenditure, there is a small fall in G^{C} than before . This indicates that there is a lesser welfare loss in this case as compared to the unconditional transfers.

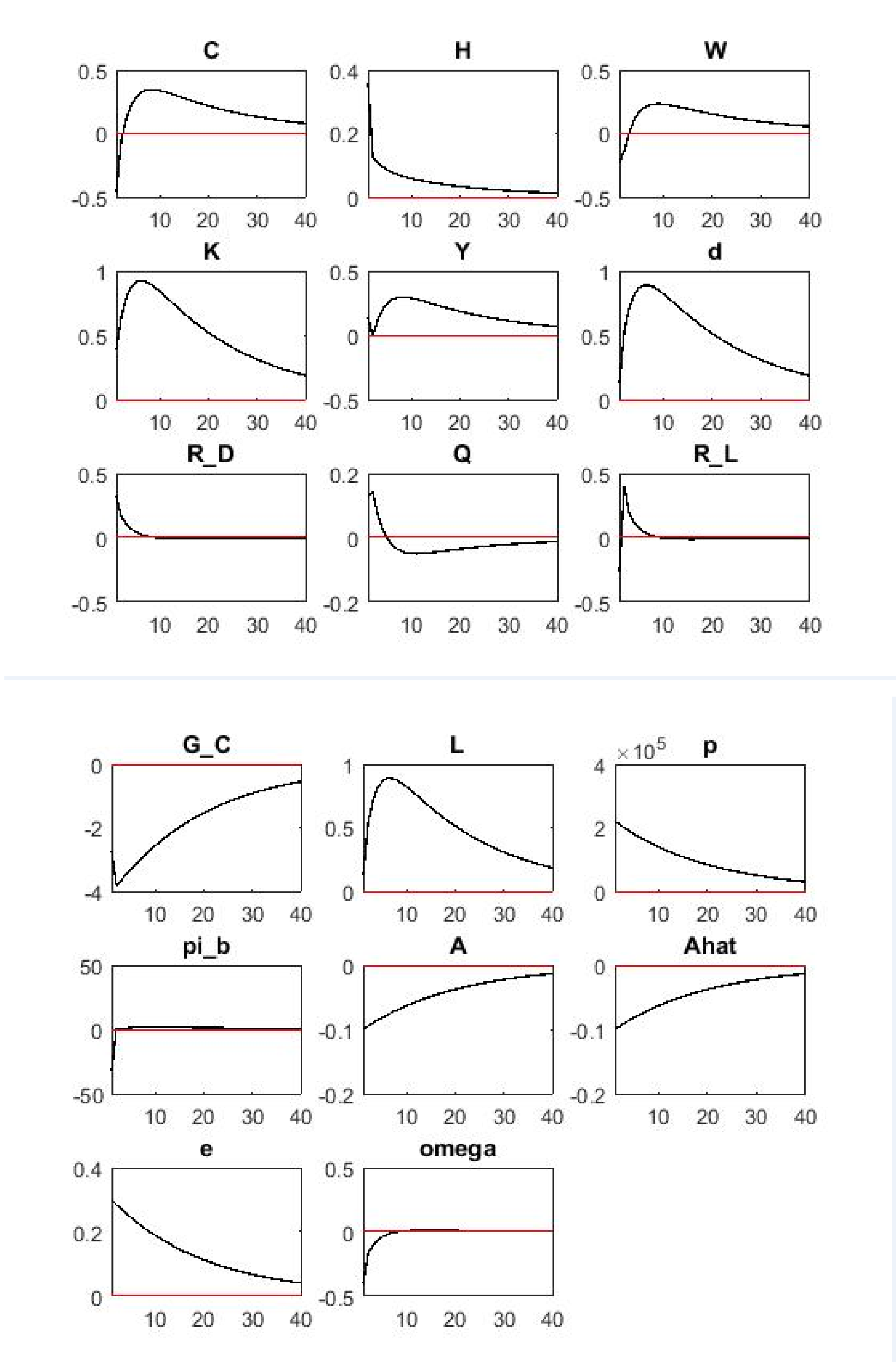

Figure 2: One period productivity shock: endogeneous equity

3 Conclusion and policy implications

The goal of this paper has been to understand the impact of government's attempt to recapitalize banks in the Indian context. To this end, we have used a Dynamic Stochastic General Equilibrium model in which we have five agents - Households, final good firms, capital good firms, banks and the Government. In the baseline case, the government makes an unconditional transfer to the banks for the loss due to non-repayment by the borrowing firms. Based on the impulse response functions of a single period negative productivity shock, in a framework where the default probabilities are state contingent on total factor productivity, our result indicates that in the absence of moral hazard, an unconditional transfer enhances capital formation and growth. However, it could shrink public utility spending and could be welfare reducing.

We then consider an alternative scenario of conditional transfers, where the government demands an increase in equity holding in bank's profits in return of the transfers made, on account of non-repayment by borrowing firms. Assuming equity to be one-to-one linked with the transfers, the impulse response functions of a negative productivity shock shows the same impact on the real economy as in the case of unconditional transfers but, with a relatively smaller fall in public utility spending, suggesting equity transfers to be a better way of bringing discipline into a public recapitalization program compared to the unconditional transfer. This indicates that recapitalization and capital adequacy concerns, in the absence of moral hazard, have a positive effect on capital formation and growth.

This project is ongoing. We also intend to analyze impulse responses due to single period shocks to the base gross real interest rate and productive government spending. Finally, we also intend to extend the baseline case to assume endogenous income tax adjustments in the government's problem. However, given our initial baseline model's results, our analysis suggests that in the present juncture, bank recapitalization is a welcome move to kick-start credit creation, capital formation and growth. In the long run we call for appropriate policy vigil to protect public expenditure in the social sector to maximize welfare.

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Technical Appendix

Derivation of the closed form solutions for the baseline model

From { 30} and { 27} respectively, we have

$$
\begin{aligned}
Y &= \left[A\left(\frac{K}{Y}\right)^{\alpha}\right]^{\frac{1}{1-\alpha}} G^P H \\
\frac{K}{Y} &= \frac{\alpha}{(1-p)R^L-(1-\delta_K)}
\end{aligned}
$$

Substituting for $\frac{K}{Y}$, we get

$$
\begin{aligned}
Y &= \left\{A\left[\frac{\alpha}{(1-p)R^L-(1-\delta_K)}\right]^{\alpha}\right\}^{\frac{1}{1-\alpha}} G^P H \\
\Longrightarrow Y &= \kappa_6 H \qquad (35)
\end{aligned}
$$

Now, Manipulating { 23}, we get:

$$
H = \frac{1}{1+\frac{(1+\tau_C)(\frac{C}{Y}+\mu\frac{G^C}{Y})}{(1-\tau_W)(1-\alpha)}} \qquad (36)
$$

Next, Dividing both sides of the consumer's budget constraint { 25}by Y and rearranging, we get

$$
\begin{aligned}
(1+\tau_C)\frac{C}{Y} &= (1-\tau_W)(1-\alpha)+\left[\left(\frac{1}{\beta}-1\right)+\left(\frac{1}{\beta}-1\right)(1-e)\gamma(1-\Phi)\right]\frac{d}{Y} \\
\Longrightarrow \frac{C}{Y} &= \frac{(1-\tau_W)(1-\alpha)+\left[\left(\frac{1}{\beta}-1\right)+\left(\frac{1}{\beta}-1\right)(1-e)\gamma(1-\Phi)\right]\frac{d}{Y}}{(1+\tau_C)} = \kappa_5 \qquad (37)
\end{aligned}
$$

Similarly, dividing both sides of the government's budget constraint { 34) by Y, we get

$$
\begin{aligned}
\frac{G^P}{Y}+\frac{G^C}{Y} &= \tau_C\frac{C}{Y}+\tau_W(1-\alpha)+\left[e\gamma(1-\Phi)\left(\frac{1}{\beta}-1\right)-(R^G-1)\Phi-pR^L(1-\Phi)\right]\frac{d}{Y} \\
\Longrightarrow \frac{G^C}{Y} &= \tau_C\kappa_5+\tau_W(1-\alpha)+\kappa_3-\frac{G^P}{Y} \qquad (38)
\end{aligned}
$$

where,

$$
\begin{aligned}
\frac{d}{Y} &= \frac{1}{1-\Phi}\left[\frac{\alpha}{(1-p)R^L-(1-\delta_K)}\right] = \kappa_2 \\
\kappa_3 &= \left[e\gamma(1-\Phi)\left(\frac{1}{\beta}-1\right)-(R^G-1)\Phi-pR^L(1-\Phi)\right]\kappa_2
\end{aligned}
$$

Substituting { 37} and { 38} into { 36)

$$
H = \frac{1}{1+\frac{(1+\tau_C)}{(1-\tau_W)(1-\alpha)}\left\{\kappa_5+\mu\left[\tau_C\kappa_5+\tau_W(1-\alpha)+\kappa_3-\frac{G^P}{Y}\right]\right\}} \tag{39}
$$

Solving { 35} and { 39} simultaneously

$$
H = \frac{(1-\tau_W)(1-\alpha)\kappa_6+(1+\tau_C)\mu G^P}{\kappa_6\{(1-\tau_W)(1-\alpha)+(1+\tau_C)[\kappa_5+\mu\tau_C\kappa_5+\mu\tau_W(1-\alpha)+\mu\kappa_3]\}} = \kappa_7 \tag{40}
$$

$$
Y = \kappa_6\kappa_7 \tag{41}
$$

$$
C = \kappa_5\kappa_6\kappa_7 \tag{42}
$$

$$
K = \left[\frac{\alpha}{(1-p)R^L-(1-\delta_K)}\right]\kappa_6\kappa_7 \tag{43}
$$

$$
W = (1-\alpha)\kappa_6 \tag{44}
$$

$$
d = \frac{1}{(1-\Phi)}\left[\frac{\alpha}{(1-p)R^L-(1-\delta_K)}\right]\kappa_6\kappa_7 \tag{45}
$$

$$
\Pi^b = \gamma\left(\frac{1}{\beta}-1\right)\left[\frac{\alpha}{(1-p)R^L-(1-\delta_K)}\right]\kappa_6\kappa_7 \tag{46}
$$

$$
G^C = \tau_C C+\tau_W(1-\alpha)\kappa_6\kappa_7+\kappa_3\kappa_6\kappa_7-G^P\kappa_6\kappa_7 \tag{47}
$$

Derivation of the closed form solutions for the model with endogenous taxation

Dividing both sides of the government's budget constraint { 34} by Y and rearranging, we get

$$
\tau_W(1-\alpha) = \frac{G^P}{Y}+\frac{G^C}{Y}-\tau_C\frac{C}{Y}-\kappa_3 \tag{48}
$$

Similarly, dividing both sides of the consumer's budget constraint { 25} by Y and rearranging, we get

$$(1+\tau_C)\frac{C}{Y} = (1-\tau_W)(1-\alpha) + \left[\left(\frac{1}{\beta}-1\right) + \left(\frac{1}{\beta}-1\right)(1-e)\gamma(1-\Phi)\right]\frac{d}{Y} \tag{49}$$

By solving { 48} and { 49} simultaneously, we get

$$\begin{aligned}\frac{C}{Y} &= (1-\alpha) - \frac{G^P}{Y} - \frac{G^C}{Y} + \kappa_3 + \left[\left(\frac{1}{\beta}-1\right) + \left(\frac{1}{\beta}-1\right)(1-e)\gamma(1-\Phi)\right]\frac{d}{Y}\\ \implies \frac{C}{Y} &= (1-\alpha) - \frac{G^P}{Y} - \frac{G^C}{Y} + \kappa_3 + Z\end{aligned} \tag{50}$$

and

$$\tau_W(1-\alpha) = (1+\tau_C)\left[\frac{G^P}{Y} + \frac{G^C}{Y} - \kappa_3\right] - \tau_C(1-\alpha) - \tau_C Z \tag{51}$$

Where,

$$Z = \left[\left(\frac{1}{\beta}-1\right) + \left(\frac{1}{\beta}-1\right)(1-e)\gamma(1-\Phi)\right]\kappa_2$$

Substituting { 50} and { 51} in { 36} and solving for H, we get

$$H = a \tag{52}$$

$$Y = \kappa_6 a \tag{53}$$

$$C = (1-\alpha)\kappa_6 a - G^P - G^C + \kappa_3\kappa_6 a + Z\kappa_6 a \tag{54}$$

$$W = (1-\alpha)\kappa_6 \tag{55}$$

$$K = \left[\frac{\alpha}{(1-p)R^L - (1-\delta_K)}\right]\kappa_6 a \tag{56}$$

$$d = \frac{1}{(1-\Phi)}\left[\frac{\alpha}{(1-p)R^L - (1-\delta_K)}\right]\kappa_6 a \tag{57}$$

$$\tau_W = \frac{(1+\tau_C)}{(1-\alpha)}\left[\frac{G^C}{\kappa_6 a} + \frac{G^P}{\kappa_6 a} - \kappa_3\right] - \tau_C - \frac{\tau_C}{(1-\alpha)}Z \tag{58}$$