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Modelling Monetary and Fiscal Policy to Achieve Climate Goals

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We present and estimate a Bernanke *et al*. (1999)-type dynamic general equilibrium model modified to allow the authorities to use monetary and fiscal policy to shape bank behavior in support of climate goals. In the model, central bank refinancing and reserve requirements are employed to support bank lending for environmentally friendly projects at lower rates of interest than for other projects. At the same time, fiscal policy supports green bank lending through loan guarantees, which also reduces the relative cost of borrowing by green firms. Under reasonable parameters of the model, rediscount lending is shown to be the most effective policy tool for directing bank lending to support climate goals.

Although the momentum for tackling CO_2 emissions has accelerated since the 2015 Paris Climate Accords, most countries are behind schedule on their commitments to achieve the goal of net-zero emissions in the second half of the twenty-first century (Jeudy-Hugo *et al*., 2021; International Energy Agency, 2022). As policymakers have sought to step up their endeavors in this regard, central banks are increasingly looking for ways in which monetary policy could actively support the transition to a low carbon economy. For example, following the 2015 Paris

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Agreement, eight countries—Mexico, the UK, France, Netherlands, Germany, Sweden, Singapore, and China—came together in 2017 to coordinate a response to climate change and formed the Network of Central Banks and Supervisors for Greening the Financial System (NGFS). By the end of 2022, the NGFS had over 120 members, while other key central banking forums, including the Basel Committee for Banking Supervision, have also taken up climate change as a relevant issue (e.g., BCBS 2022).

In practice, the climate-related policies of NGFS members have diverged broadly along two lines (DiLeo *et al*. 2023). One approach has been to consider the potential impact of climate change and how it affects central bank objectives, for example, through the identification of financial stability risks. A second approach, though still in its early stages, has been to look at how monetary policy might support of decarbonization more directly. Several proposal have been put forward that seek to lower the relative cost of capital for low-carbon sectors, by having the central bank provide indirect support to bank lending that supports low carbon outputs, such as preferential refinancing conditions and bank capital and reserve requirements for the banks involved, or more direct support, for example by issuing credit to non-financial firms directly or through a dedicated financial intermediary, or imposing binding rules on the growth of credit for low carbon projects as a criterion for banks accessing refinancing credit (Krogstrup and Oman, 2019; Monnet and van ’t Klooster, 2023). Other suggestions including implementing so-called “green” quantitative easing, whereby green assets would be actively purchased by the central bank; having the central bank eliminate assets with high carbon intensity from its portfolio (Ryan-Collins *et al*., 2013; Anderson 2015; van Lerven and Ryan-Collins, 2017), revising the collateral eligibility criteria for refinancing operations (Oustry et al., 2020), providing guarantees to banks to lending for low carbon economy projects, and using forward guidance policies to raise market expectations regarding green investments (Campiglio, 2016; Prasad *et al*., 2022).

In this paper, we incorporate some of the above monetary policy ideas into a Bernanke *et al*. (1999)-type dynamic general equilibrium model. Specifically, we develop and estimate a modified version of the model that incorporates the use of central bank refinancing and reserve requirements at preferential rates to support bank lending for low carbon projects, and a government sector that provides guarantees to banks for loans that support such lending. Our model has three important implications. First, central banks can use traditional monetary policy tools to support decarbonization. That is, central banks can design their refinancing facility and system of reserve requirements on bank deposits in ways that support can support bank lending for low carbon projects. Monetary policy does this by using these tools to reduce the costs of capital of so-called "green" firms relative to "brown" firm by providing banks that lend to them refinancing at preferential interest rates and subjecting their deposit liabilities to preferential reserve requirements. Second, our results suggest that of the three policy instruments that we consider in the model (central bank refinancing, reserves requirements on deposits and government loan guarantees), the monetary policy instruments are the most effective at promoting low carbon-related lending, with refinancing policy being the most effective of all. Finally, our model and estimated results are particularly relevant to middle- and lower income economies many of whom continue to make active use of refinancing policy and reserve requirements to influence the total and composition of bank lending.

The rest of the paper is organized as follows. Section 2 describes the model. Section 3 shows the model calibrations. Section 4 presents the results from estimated impulse-response functions discusses their implications for green monetary and fiscal policy. Section 5 concludes.

2 The Model

2.1 Overview

The Bernanke et al. (1999) (henceforth BGG) model contains an implicit financial intermediary that is conceptually equivalent to a perfectly competitive banking sector with no marginal costs for originating bank loans or accepting deposits, and that can borrow at the risk-free interest rate set by the central bank. We modify the BGG model to allow the authorities to use monetary and fiscal policy to shape bank behavior in support of climate goals. Central bank refinancing and reserve requirements on bank deposits are employed to support lending for environmentally friendly projects at lower rates of interest than for other projects. The banking sector in the model comprises banks that are either "green" or "brown", with the former lending only to firms engaged in the production of "green" outputs and the latter lending only to firms that produce brown outputs. Green banks have access to central bank rediscounting at preferential rates and are subject to lower reserve requirements on deposits, which enables them to deliver loans at preferential interest rates to "green" firms. The government sector in the model employs fiscal policy to support lending by green bank lending through loans guarantees that are not offered to brown banks making loans to brown firms, which further reduces the relative cost of borrowing by green firms.

With the implementation of the green monetary (fiscal policy) banks adjust their loan structure under the constraint of credit leverage to achieve profit maximization. There are six external shocks to the model: the preferential refinancing rate for green credit; the preferential reserve requirement ratio; the impact of government's guarantee for green loans; the impact of the ratio to total credit of the amount of assets that need to be pledged to obtain refinancing; and the impacts of technical shocks for green and brown entrepreneurs, respectively. We show the optimization problem of all agents in the model and list the calculation process in the Appendix. Under reasonable parameters of the model, all policy tools support lending for low carbon projects but rediscount lending is shown to be the most effective policy tool in this regard.

2.2 Household sector

The household sector comprises many homogeneous representative households, each of which seeks to maximise the expected present value of lifetime utility in period t. Households work, consume, save, and have leisure time. They hold real money balances and hold interest-bearing assets at financial intermediaries on which they earn a risk-free rate of return. Households choose between consumption, labor, capital, and money holdings to maximize their utility under the budget constraint of the representative household. In the model, we denote: β as a discount factor where $0 < \beta < 1$; c_t as household real consumption; M_t/P_t is real money balances acquired in period t and carried into $t + 1$; L_t is labor supply; and P_t is the final commodity price. σ_c and σ_m denote the relative risk aversion coefficient of consumption and currency holding, respectively, and σ_l is the reciprocal of Frisch elasticity of labor supply. W_t/P_t is the real wage for household labor; D_t is the real value of deposits in intermediaries; r_t is the deposit riskless real interest rate, and $r_t = i_t/\pi_t$, where i_t is the riskless nominal interest rate and π_t is the rate of inflation. Finally, T_t is lump sum real taxes paid by households, and PRO_t represents the real dividends from the ownership of retail companies.

Accordingly, the system of equations for the household sector is as follows:

$$\max_{C_t,M_t,L_t} E_t \sum_{k=0}^{\infty} \beta^k \left[\frac{C_{t+k}^{1-\sigma_c}}{1-\sigma_c} + \zeta \frac{\left(\frac{M_{t+k}}{P_{t+k}}\right)^{1-\sigma_m}}{1-\sigma_m} - \xi \frac{L_{t+k}^{1+\sigma_l}}{1+\sigma_l} \right] \quad (1)$$

$$s.t.\ C_t + \frac{(M_t - M_{t-1})}{P_t} + D_t = \frac{W_t}{P_t} L_t - T_t + r_{t-1} D_{t-1} + PRO_t \quad (2)$$

Labor supply equation:

$$\xi L_t^{\sigma_l} = \frac{W_t}{P_t} C_t^{-\sigma_c} \quad (3)$$

Euler equation of consumption decision:

$$\frac{1}{r_t} = \beta E_t \frac{\lambda_{t+1}}{\lambda_t} \quad (4)$$

Money demand equation:

$$\left(\frac{M_t}{P_t}\right)^{\sigma_m} = \zeta \left(\frac{r_t}{r_{t-1}}\right) C_t^{\sigma_c} \quad (5)$$

Lagrange multiplier λ_t:

$$\lambda_t = C_t^{-\sigma_c} \tag{6}$$

where the Lagrange multiplier, λ_t, represents the marginal utility of consumption and can also be thought of as the shadow price, meaning that when the budget constraint of a unit is relaxed the utility it can bring is just λ_t.

2.3 Retail sector

The retail sector is characterized by monopolistic competition with costs to adjusting nominal price making for a sticky price model. As in the Dixit and Stiglitz (1977), we assume that there is a representative final manufacturer in the economy that uses production technology to produce final output, $Y_{i,t}$, where i denotes green firms and brown firms respectively.

Let $Y_{i,t}^j$ be the output sold in units of wholesale goods by wholesaler j. Individual retail items are combined to provide the following total final usable goods, $Y_{i,t}$:

$$Y_{i,t} = \left[\int_0^1 {Y_{i,t}^j}^{(\epsilon_p - 1)/\epsilon_p} dj\right]^{\epsilon_p/(\epsilon_p - 1)} \tag{7}$$

ϵ_p is the elasticity of substitution of intermediate products, and $\epsilon_p > 1$ implies incomplete substitution between different intermediate products—that is, intermediate product manufacturers have some monopoly power that allows them to influence product prices. The corresponding price index is given by:

$$P_{i,t} = \left[\int_0^1 P_{i,t}^{j\ (1-\epsilon_p)} dj\right]^{1/(1-\epsilon_p)} \tag{8}$$

Under the given production technology, the final product manufacturer deems the final product price $P_{i,t}$ and the intermediate product price $P_{i,t}^{j}$ are givens. The intermediate product quantity, $Y_{i,t}$, that maximizes the profit of the retailer is given by:

$$\max_{Y_{i,t}^{j}} P_{i,t} Y_{i,t} - \int_0^1 P_{i,t}^{j}\, Y_{i,t}^{j}\, dj \tag{9}$$

$$s.t.\ Y_{i,t} = \left[\int_0^1 Y_{i,t}^{j\ (\epsilon_p-1)/\epsilon_p} dj\right]^{\epsilon_p/(\epsilon_p-1)} \tag{10}$$

and the optimal output of intermediate products is given by:

$$Y_{i,t}^{j} = \left(\frac{P_{i,t}^{j}}{P_{i,t}}\right)^{-\epsilon_p} Y_{i,t} \tag{11}$$

Equation (11) shows that the demand of intermediate products $Y_{i,t}^{j}$ depends on the relative price $P_{i,t}^{j}/P_{i,t}$ and the elastic parameters of price demand ϵ_p. It can be seen that when the price index is given, the demand for intermediate products is a downward sloping curve implying that retailers are faced with perfect competition. According to the classical assumption of perfect competition, the profit is zero and from Equation (9) the nominal total output (GDP) is represented by:

$$P_{i,t}Y_{i,t} = \int_0^1 P_{i,t}^j \, Y_{i,t}^j \, dj \tag{12}$$

Combining the demand function for intermediate products (10) and (11), the decision equation for the total price level (index) of the two types of entrepreneur can be given by:

$$P_{i,t} = \left(\int_0^1 {P_{i,t}^j}^{1-\epsilon_p} \, dj\right)^{\frac{1}{1-\epsilon_p}} \tag{13}$$

We now separate brown and green firms by replacing i with g (green firms) and b (brown firms). Y_t is the CES aggregator of production by green firms, $Y_{g,t}$, and by brown firms, $Y_{b,t}$, and P_t^m is the marginal cost for green and brown firms:

$$Y_t = \left[(\varphi)^{\frac{1}{\chi}}\left(Y_{g,t}\right)^{\frac{\chi-1}{\chi}} + (1-\varphi)^{\frac{1}{\chi}}\left(Y_{b,t}\right)^{\frac{\chi-1}{\chi}}\right]^{\frac{\chi}{\chi-1}} \tag{14}$$

$$P_t^m = \left[\varphi\left(P_{g,t}\right)^{1-\chi} + (1-\varphi)\left(P_{b,t}\right)^{1-\chi}\right]^{\frac{1}{1-\chi}} \tag{15}$$

where φ represents the weight of green goods, and χ is the elasticity of substitution of brown-green goods. In order to choose the optimal input, intermediate firms should solve the equations:

$$\max_{Y_{g,t},Y_{b,t}} \left[(\varphi)^{\frac{1}{\chi}}\left(Y_{g,t}\right)^{\frac{\chi-1}{\chi}} + (1-\varphi)^{\frac{1}{\chi}}\left(Y_{b,t}\right)^{\frac{\chi-1}{\chi}}\right]^{\frac{\chi}{\chi-1}} \tag{16}$$

$$s.t. P_{g,t}Y_{g,t} + P_{b,t}Y_{b,t} = P_t^m Y_t \tag{17}$$

where $P_t^m Y_t$ is a given level of production. Taking into account the output constraint, the demand function for green and brown outputs is given by:

$$Y_{g,t} = (\varphi)\left(\frac{P_{g,t}}{P_t^m}\right)^{-\chi} Y_t \quad (18)$$

$$Y_{b,t} = (1-\varphi)\left(\frac{P_{b,t}}{P_t^m}\right)^{-\chi} Y_t \quad (19)$$

Given price stickiness, we follow the Calvo (1983) hypothesis and assume that retailers can change prices in a given period only with a probability of θ_p, and can only change to the optimal price P_t^* freely with the probability of $1-\theta_p$. If we define $\pi_t^* = \frac{P_t^*}{P_t}$ as the price discrete kernel, d_t^P, leads to a decline in output as the direct result of price stickiness. As such, price stickiness leads to an efficiency loss:

$$d_t^P = (1-\theta_p)(\pi_t^*)^{-\epsilon_p} + \theta_p {\pi_t}^{\epsilon_p} d_{t-1}^P \quad (20)$$

$$Y_t = d_t^P Y_t^f \quad (21)$$

And the price of the final product is given by:

$$1 = (1-\theta_p)(\pi_t^*)^{(1-\epsilon_p)} + \theta_p(\pi_t)^{(\epsilon_p-1)} \quad (22)$$

Retailers buy products from intermediate firms and sell them to final firms. The optimization problem is as follows:

$$\max_{P_{i,t}} E_t\left[\sum_{s=0}^{\infty}(\beta\theta_p)^s \Lambda_{t,t+s}(P_t/P_{t+s})(P_{i,t}-P_{t+s}^m)\right]Y_{i,t+s} \tag{23}$$

The optimal price of intermediate products is defined as P_t^*, and the Lagrange equation is set to solve the optimal P_t^*:

$$1=\frac{\epsilon_p}{\epsilon_p-1}\frac{E_t\left[\sum_{s=0}^{\infty}(\beta\theta_p)^s\Lambda_{t,t+s}\left(\frac{P_t}{P_{t+s}}\right)Y_{t+s}\left(\frac{P_{t+s}^m}{P_t^*}\right)\left(\frac{P_t^*}{P_{t+s}}\right)^{-\epsilon_p}\right]}{E_t\left[\sum_{s=0}^{\infty}(\beta\theta_p)^s\Lambda_{t,t+s}\left(\frac{P_t}{P_{t+s}}\right)Y_{t+s}\left(\frac{P_t^*}{P_{t+s}}\right)^{-\epsilon_p}\right]} \tag{24}$$

We can substitute the relative price, $mc_t = P_t^m/P_t$, between the market price of intermediate products and the final price into the above equation and simplify $\Lambda_{t,t+s}$ to λ_{t+s}. By recursive solution, the final form of the model for this sector can be obtained.

$$\frac{P_t^*}{P_t}=\frac{\epsilon_p}{\epsilon_p-1}\frac{f_t^1}{f_t^2} \tag{25}$$

$$f_t^1=\lambda_t mc_t Y_t+\beta\theta_p E_t\pi_{t+1}^{\epsilon_p} f_{t+1}^1 \tag{26}$$

$$f_t^2=\lambda_t Y_t+\beta\theta_p E_t\pi_{t+1}^{\epsilon_p-1} f_{t+1}^2 \tag{27}$$

2.4 Wholesale sector

Intermediate firms aim to solve two problems: (i) cost minimization, to determine their marginal cost; and (ii) profit maximization, under the dynamic pricing strategy of intermediate firms and the introduction of sticky prices. We assume these firms are characterized by simple Cobb-Douglas production function with constant returns to scale to produce intermediate goods $Y_{i,t}^{j}$.

$$\max_{L_{g,t},K_{g,t}} \Pi_t = P_{g,t}Y_{g,t} - W_{g,t}L_{g,t} - R_{g,t}^{k}Q_{t-1}K_{g,t} + Q_t(1-\delta)K_{g,t} \tag{28}$$

$$s.t.\ Y_{g,t} = A_{g,t}K_{g,t}^{\alpha_g}L_{g,t}^{1-\alpha_g} \tag{29}$$

At the end of t period, the entrepreneur sells the depreciated capital to the capital producer at the price Q_t, buys new capital $K_{g,t}$ from the capital producer at the price Q_{t-1}, and sells the products to the intermediate producer firms at the price $P_{g,t}$.

The entrepreneur's labor supply equation is:

$$L_{g,t} = (1-\alpha_g)mc_{g,t}\frac{Y_{g,t}}{W_{g,t}} \tag{30}$$

The expected rate of return on capital goods is:

$$E_t\{R_{g,t+1}^{k}\} = E_t\left[\alpha_g mc_{g,t+1}\frac{Y_{g,t+1}}{K_{g,t}} + Q_{t+1}(1-\delta)\right]/Q_t \tag{31}$$

The marginal cost equation is:

$$P_{g,t} = mc_{g,t} \tag{32}$$

The model for the brown entrepreneur is similar and the related formulas are given as:

$$\max_{L_{b,t},K_{b,t}} \Pi_t = P_{b,t}Y_{b,t} - W_{b,t}L_{b,t} - R^k_{b,t}Q_{t-1}K_{b,t} + Q_t(1-\delta)K_{b,t} \tag{33}$$

$$s.t.\ Y_{b,t} = A_{b,t}K_{b,t}^{\alpha_b}L_{b,t}^{1-\alpha_b} \tag{34}$$

$$L_{b,t} = (1-\alpha_b)mc_{b,t}\frac{Y_{b,t}}{W_{b,t}} \tag{35}$$

$$E_t\{R^k_{b,t+1}\} = E_t\left[\alpha_b mc_{b,t+1}\frac{Y_{b,t+1}}{K_{b,t}} + Q_{t+1}(1-\delta)\right]/Q_t \tag{36}$$

$$P_{b,t} = mc_{b,t} \tag{37}$$

Assuming the homogeneity of the labor supply of wholesale firms, the total capital supply and total labor supply are given as:

$$K_t = K_{g,t} + K_{b,t} \tag{38}$$

$$L_t = L_{g,t} + L_{b,t} \tag{39}$$

$$W_t = W_{g,t} = W_{b,t} \tag{40}$$

2.5 Capital sector

To create physical capital, capital producers buy products from the retail sector and non-depreciable capital from intermediate product firms. Following that, green and brown firms buy capital. The following issues are solved by the capital producer:

$$\max_{I_t} E_t \sum_{s=0}^{\infty} \beta^s \Lambda_{t,t+s} \left\{ Q_{t+s} \left[1 - \Psi\left(\frac{I_{t+s}}{I_{t+s-1}} \right) - 1 \right] \right\} I_{t+s} \tag{41}$$

$$s.t.\ K_t = (1-\delta) K_{t-1} + \left[1 - \frac{\psi_1}{2} \left(\frac{I_t}{I_{t-1}} - 1 \right)^2 \right] I_t \tag{42}$$

$$\Psi\left(\frac{I_t}{I_{t-1}} \right) = \frac{\psi_1}{2} \left(\frac{I_t}{I_{t-1}} - 1 \right)^2 \tag{43}$$

Here $\Psi(\cdot)$ denotes the convex investment adjustment cost, I_t is the input-output of the final product as raw materials, δ is the depreciation rate of capital, and ψ_1 is the investment cost adjustment parameter. The first condition of I_t is given:

$$Q_t \left[1 - \frac{\psi_1}{2} \left(\frac{I_t}{I_{t-1}} - 1 \right)^2 - \psi_1 \left(\frac{I_t}{I_{t-1}} - 1 \right) \frac{I_t}{I_{t-1}} \right] + \beta E_t \frac{\lambda_{t+1}}{\lambda_t} \psi_1 \left(\frac{I_{t+1}}{I_t} - 1 \right) \left(\frac{I_{t+1}}{I_t} \right)^2 Q_{t+1} = 1 \tag{44}$$

2.6 Entrepreneurs with loan demand

From the standpoint of contract optimization between businesses and financial institutions, Bernanke *et al*. (1999) present a thorough analysis of the connection between frictions in the financial system and economic fluctuations and derive the quantitative relationship between the entrepreneur's cost of borrowing and the capital leverage ratio. We establish a financial accelerator with a soft budget constraint. The financing premium equation for entrepreneurs with a soft budget constraint is produced by optimizing the loan contract between entrepreneurs and banks. Entrepreneurial assets, $Q_t K_{i,t}$, consist of net wealth, $N_{i,t}$, and loans borrowed from banks, $B_{i,t}$. The leverage ratio of capital is given as $LEV_{i,t}$, then:

$$Q_t K_{i,t} = N_{i,t} + B_{i,t} \tag{45}$$

$$LEV_{i,t} = Q_t K_{i,t} / N_{i,t} \tag{46}$$

The return on capital of green entrepreneurs in the next period is $\omega_{i,t+1} R^k_{g,t+1}$, where $R^k_{g,t+1}$ represents the average return on capital and $\omega_{i,t+1}$ represents the default threshold separating entrepreneurs who cannot pay loan interest and principal from those that can pay. We assume that the Government guarantees a portion of the green entrepreneurs' capital income, denoted as G_{t+1}, which is exogenous, so that $g_{t+1} = G_{t+1} / \left(R^k_{g,t+1} Q_t K_{g,t}\right)$, which is the guaranteed proportion of green entrepreneurs' capital income.

The non-default loan rate of interest on debt is given as $R^l_{g,t+1}$ where:

$$G_{t+1} + \overline{\omega}_{g,t+1} R^k_{g,t+1} Q_t K_{g,t} = R^l_{g,t+1} B_{g,t} \tag{46}$$

If $\omega \geq \overline{\omega}_{g,t+1}$, at the end of $t+1$, then financial institutions will get $R^l_{g,t+1} B_{g,t}$, while green entrepreneurs will get $\omega R^k_{g,t+1} Q_t K_{g,t} - R^l_{g,t+1} B_{g,t}$. If $\omega R^k_{g,t+1} Q_t K_{g,t} < R^l_{g,t+1} B_{g,t}$, the Government will assist the green entrepreneur to pay its loan obligations and the green entrepreneur will assume a debt to the government. On the other hand, if $\omega < \overline{\omega}_{g,t+1}$, the green entrepreneurs' income and the amount of the Government guarantee will be insufficient to make the loan payment and the entrepreneur will be bankrupt. The government will lose G_{t+1}, financial institutions will make $G_{t+1} + \omega R^k_{g,t+1} Q_t K_{g,t} - \tau \omega R^k_{g,t+1} Q_t K_{g,t}$., and green firms will have zero revenue. Financial institutions compete freely for loans, and the supervision costs (e.g., auditing and liquidation) are assumed to be proportional to the capital gains of entrepreneurs, τ, when entrepreneurs default.

The financial market is competitive and financial institutions require that the expected return is equal to the opportunity cost of loans.

$$\left[1 - F\left(\overline{\omega}_{g,t+1}, \sigma_{\omega g}\right)\right] R^l_{g,t+1} B_{g,t} + \int_0^{\overline{\omega}_{g,t+1}} \left[G_{t+1} + (1-\tau)\omega_g R^k_{g,t+1} Q_t K_{g,t}\right] d\,F\left(\omega_g, \sigma_{\omega g}\right) = i_{t+1} B_{g,t} \tag{48}$$

The optimization of the debt contract between green entrepreneurs and financial institutions is:

$$\max_{LEV_g,\overline{\omega}_{g,t+1}} E_t\left[1-\Gamma\left(\overline{\omega}_{g,t+1},\sigma_{\omega g}\right)-g_{t+1}\right]R^k_{g,t+1}Q_tK_{g,t} \tag{49}$$

$$s.t.\left[\Gamma\left(\overline{\omega}_{g,t+1},\sigma_{\omega g}\right)-\tau G\left(\overline{\omega}_{g,t+1},\sigma_{\omega g}\right)+g_{t+1}\right]R^k_{g,t+1}Q_tK_{g,t}=i_{t+1}\left(Q_tK_{g,t}-N_{g,t}\right)$$

As $\Gamma\left(\overline{\omega}_{g,t+1},\sigma_{\omega g}\right)=\overline{\omega}_{g,t+1}\left(1-F\left(\overline{\omega}_{g,t+1},\sigma_{\omega g}\right)\right)+G_\omega\left(\overline{\omega}_{g,t+1},\sigma_{\omega g}\right)$, and $G_\omega\left(\overline{\omega}_{g,t+1},\sigma_{\omega g}\right)=$

$$\int_0^{\overline{\omega}_{g,t+1}}\omega_g\,d\,F\left(\omega_g,\sigma_{\omega g}\right) \tag{50}$$

From this optimization problem, we arrive at the relationship between the expected rate of return and the capital leverage ratio of green entrepreneurs with soft budget constraints. The larger the government guarantee, the lower the financing premium paid by green entrepreneurs. Under the same financing premium, entrepreneurs with soft budget constraints will take on more loans and the higher will be their leverage ratio. For a given leverage ratio, the financing premium of entrepreneurs with soft budget constraints is relatively low:

$$\left[1-\Gamma\left(\overline{\omega}_{g,t+1},\sigma_{\omega g}\right)-g_{t+1}\right]\frac{R^k_{g,t+1}}{i_{t+1}}=\frac{1}{LEV_{g,t}}\frac{1-F\left(\overline{\omega}_{g,t+1},\sigma_{\omega g}\right)}{1-F\left(\overline{\omega}_{g,t+1},\sigma_{\omega g}\right)-\tau\overline{\omega}_{g,t+1}F_\omega\left(\overline{\omega}_{g,t+1},\sigma_{\omega g}\right)} \tag{51}$$

If γ_g is the natural survival rate of secured entrepreneurs, then green entrepreneurs' net capital accumulation equation is given by:

$$N_{g,t} = \gamma_g\left[R^k_{g,t}Q_{t-1}K_{g,t-1}\left(1 - \tau G\left(\overline{\omega}_{g,t}, \sigma_{\omega g}\right) + g_t\right) - i_t B_{g,t-1}\right] \quad (52)$$

The impact of the government guarantee for green entrepreneurs is given by:

$$\log g_t = \left(1 - \rho_g\right)\log g_{ss} + \rho_g \log g_{t-1} + \varepsilon^g_t, \varepsilon^g_t \sim N\left(0, {\sigma_g}^2\right) \quad (53)$$

where the subscript ss represents the steady state. For the unsecured brown entrepreneurs, the expected return is equal to the opportunity cost of loans. The optimization of the debt contract, the relationship between expected their rate of return and their capital leverage ratio, and the net asset accumulation equations are as follows:

$$\overline{\omega}_{b,t+1}R^k_{b,t+1}Q_t K_{b,t} = R^l_{b,t+1}B_{b,t} \quad (54)$$

$$\left[1 - F(\overline{\omega}_{b,t+1}, \sigma_{\omega b})\right]R^l_{b,t+1}B_{b,t} + \int_0^{\overline{\omega}_{b,t+1}}\left[(1-\tau)\omega_b R^k_{b,t+1}Q_t K_{b,t}\right]d\,F(\omega_b, \sigma_{\omega b}) = i_{t+1}B_{b,t} \quad (55)$$

$$\max_{LEV_b, \overline{\omega}_{b,t+1}} E_t\left[1 - \Gamma\left(\overline{\omega}_{b,t+1}, \sigma_{\omega b}\right)\right]R^k_{b,t+1}Q_t K_{b,t} \quad (5\text{-}12)$$

$$s.t.\left[\Gamma(\overline{\omega}_{b,t+1}, \sigma_{\omega b}) - \tau G\left(\overline{\omega}_{b,t+1}, \sigma_{\omega b}\right)\right]R^k_{b,t+1}Q_t k_{b,t} = i_{t+1}(Q_t k_{b,t} - N_{b,t}) \quad (56)$$

$$\left[1-\Gamma\left(\bar{\omega}_{b,t+1},\sigma_{\omega b}\right)\right]\frac{R_{b,t+1}^{k}}{i_{t+1}}=\frac{1}{LEV_{b,t}}\frac{1-F\left(\bar{\omega}_{b,t+1},\sigma_{\omega b}\right)}{1-F\left(\bar{\omega}_{b,t+1},\sigma_{\omega b}\right)-\tau\bar{\omega}_{b,t+1}F_{\omega}\left(\bar{\omega}_{b,t+1},\sigma_{\omega b}\right)} \tag{57}$$

$$N_{b,t}=\gamma_{b}\left[R_{b,t}^{k}Q_{t-1}K_{b,t-1}\left(1-\tau G\left(\bar{\omega}_{b,t},\sigma_{\omega b}\right)\right)-i_{t}B_{b,t-1}\right] \tag{58}$$

2.7 Banking sector

Two different types of banks exist in the economy categorized as either g banks and b banks, of which the former lend only to green firms in the entrepreneur sector and the latter lend only to brown firms. We assume that the central bank has adopted a pro-green credit policy and uses monetary policy instruments to orientate liquidity to green firms in order to increase the amount of funding available to them and lower their financing costs. g banks can benefit from green credit policy from the central bank since they help green businesses with finance. As in Gerali et al. (2010), it is assumed that each type of bank has a continuum with a length of 1. In order to get loans of $B_{g,t}$ and $B_{b,t}$, entrepreneurs need to obtain loans from the corresponding green and brown banks as follows:

$$\left[\int_{0}^{1}\left(B_{i,t}^{j}\right)^{\frac{\kappa-1}{\kappa}}dj\right]^{\frac{\kappa}{\kappa-1}}\geq B_{i,t} \tag{59}$$

where $\frac{\kappa}{\kappa-1}>1$ represents the addition rate of entrepreneur loan interest rate and κ is the elasticity of substitution (intermediate substitution) of different bank loans. Defining the loan interest rate index as below and under the setting of symmetrical equilibrium, the loan demand of entrepreneurs is from minimizing the total repayment amount.

$$R_{i,t}^{l} = \left[\int_0^1 \left(R_{i,t}^{l,j}\right)^{1-\kappa} dj\right]^{\frac{1}{1-\kappa}} \tag{60}$$

$$B_{i,t}^{j} = \left(\frac{R_{i,t}^{l,j}}{R_{i,t}^{l}}\right)^{-\frac{\kappa}{\kappa-1}} B_{i,t} \tag{61}$$

Banks are constrained by their balance sheets. The assets of banks are composed of cash and loans from two industries, and the liabilities are deposits and green credit refinancing from the central bank. R_t^r is the reserve requirement ratio of the central bank. The balance of the statement of assets and liabilities is given:

$$\left(B_{g,t} + B_{b,t}\right) + R_t^r D_t = D_t + H_{g,t} \tag{62}$$

Banks takes deposits from the household sector and pay deposit reserves to the central bank and use capital and deposits to issue loans to two types of entrepreneurs respectively. Banks' revenue comes from the interest on entrepreneurs' loans, while their costs comprise the interest rate they pay on household sector deposits and on central bank refinancing, and the adjustment costs they incur. To maximize their profits, banks need to decisions with respect to the volume of loans they make to entrepreneurs, the amount of household deposits they take, and how much refinancing to seek from the central bank:

$$\max_{B_{g,t}} \Pi_{Bg} = E_t \sum_{t=0}^{\infty} \beta^t \left[(1-o_g) R_{g,t}^l B_{g,t} - i_t D_{g,t} - R_{g,t}^h H_{g,t} - Adcost_{g,t} \right] \quad (63)$$

$$s.t.\ Adcost_{g,t} = \frac{\psi_2}{2}\left(\frac{B_{g,t}}{B_{g,t-1}} - 1\right)^2 B_{g,t} + \frac{\psi_3}{2}\left(\frac{D_{g,t}}{D_{g,t-1}} - 1\right)^2 D_{g,t} + \frac{\psi_4}{2}\left(\frac{H_{g,t}}{H_{g,t-1}} - 1\right)^2 H_{g,t} \quad (64)$$

$$s.t.\ B_{g,t} = (1 - R_t^r) D_{g,t} + H_{g,t} \quad (65)$$

$$s.t.\ H_{g,t} = \varpi_t B_{g,t} \quad (66)$$

In equations (63) to (66), $B_{g,t}$ represents loans provided by banks to green entrepreneurs, $R_{g,t}^l$ is the corresponding loan interest rate, and o_g is the non-performing loan ratio. The risk-free deposit interest rate paid by banks is i_t. $D_{g,t}$ is the amount of household deposits taken by green banks. $R_{g,t}^h$ is the preferential refinancing rate for green entrepreneurs that is set by the central bank, and $H_{g,t}$ is the amount of refinancing from the central bank to support green credit. $Adcost_{g,t}$ represents the adjustment costs of green banks, where ψ_2 and ψ_5 are the adjustment coefficients of loans, ψ_3 and ψ_6 represent the adjustment coefficients of deposits, and ψ_4 represents green credit refinancing. Next, assume that there is an upper limit on the amount of refinancing that banks can access at the central bank, which is that it cannot exceed the ratio of bank assets to total credit that banks are required to pledge to obtain refinancing, that is, $H_{g,t} \leq \varpi_t B_{g,t}$, where ϖ_t is the upper limit to this "pledge ratio". Further assume that $R_{g,t}^h$, the cost for banks to obtain green credit from the central bank, is always lower than that for banks to obtain deposits from the household sector. This means that banks will first obtain lower-cost funds from the central bank until they reach the upper limit when they will take deposits from household sector such that the constraint $H_{g,t} = \varpi_t B_{g,t}$ will eventually be equal.

Compared with green lending banks, brown lending banks do not obtain green credit refinancing $H_{g,t}$ from the central bank, but the other parameters are as for green lending banks. The optimization of brown entrepreneurs is then:

$$\max_{B_{b,t}} \Pi_{Bb} = E_t \sum_{t=0}^{\infty} \beta^t \left[(1 - o_b) R_{b,t}^l B_{b,t} - i_t D_{b,t} - Adcost_{b,t}\right] \tag{67}$$

$$s.t.\ Adcost_{b,t} = \frac{\psi_5}{2}\left(\frac{B_{b,t}}{B_{b,t-1}} - 1\right)^2 B_{b,t} + \frac{\psi_6}{2}\left(\frac{D_{b,t}}{D_{b,t-1}} - 1\right)^2 D_{b,t} \tag{68}$$

$$s.t.\ B_{b,t} = (1 - R_t^r) D_{b,t} \tag{69}$$

2.8 *The central bank and government*

The central bank has two monetary policy tools: the ability to vary reserve requirements on bank deposits and a bank refinancing facility for which banks need to place collateral to gain access.

2.8.1 *Reserve requirements*

The central bank adjusts bank reserve requirements to meet a money supply rule set in the context of output and inflation developments:

$$\hat{R}_t^r = \rho_r \hat{R}_{t-1}^r + (1-\rho_r)\left(\phi_Y \hat{Y}_t + \phi_\pi \hat{\pi}_t\right) + \varepsilon_t^{R^r} \quad (70)$$

All variables are deviations from their steady-state values. The parameter ρ_r is the smoothing coefficient of the reserve requirement ratio and ϕ_Y and ϕ_π are the coefficients of reserve requirement ratios set in relation to output and inflation developments, respectively, and $\varepsilon_t^{R^r} \sim i.i.d.N(0, \sigma_{R^r}^2)$ is monetary policy shock.

2.8.2 *Green credit finance from the central bank*

In pursuing its pro-green monetary policy, the central bank provides credit to green entrepreneurs to encourage their production and development. Therefore, the central bank will determine banks' refinancing rate for loans to green firms, $R_{g,t}^h$, and thereby the interest rate charged on the total amount of green credit $H_{g,t}$. Assuming that the refinancing rate charged to banks involved in green lending is related to the central bank interest rate, and because the central bank provides a preferential refinancing rate to banks with high growth rate of green credit, the corresponding refinancing rate is $R_{g,t}^h = i_t(B_{g,t}/B_{g,t-1})^{-\mu_1}$.

According to the above rules, the higher the growth rate of a bank's green entrepreneur credit, the lower the refinancing rate charged by the central bank.

$$\hat{R}^h_{g,t} = \rho_h \hat{R}^h_{g,t-1} + (1-\rho_h)\left[\hat{\imath}_t - \mu_1\left(\hat{B}_{g,t} - \hat{B}_{g,t-1}\right)\right] + \varepsilon^h_t, , \varepsilon^h_t \sim N(0, {\sigma_h}^2) \quad (71)$$

Finally, the central bank has set a higher ϖ as an incentive measure for banks to provided credit to green entrepreneurs. The response parameters of the refinancing pledge rate $\varpi_t > 0$ to the credit growth rate of green entrepreneurs. represents the central bank reflects the credit growth rate of emerging industries.

According to the above rules, the higher the growth rate of a bank's green credit, the higher the corresponding loan pledge rate.

$$\hat{\varpi}_t = \rho_\varpi \hat{\varpi}_{t-1} + (1-\rho_\varpi)\left[\mu_2\left(\hat{B}_{g,t} - \hat{B}_{g,t-1}\right)\right] + \varepsilon^\varpi_t, \varepsilon^\varpi_t \sim N(0, {\sigma_\varpi}^2) \quad (72)$$

$\hat{R}^h_{g,t}$ and $\hat{\varpi}_t$ are, respectively, the refinancing rate and the loan pledge rate and ρ_h and ρ_ϖ are the respective smoothing parameters, $0 < \rho_h, \rho_\varpi < 1$.

The expenditure and income of the government are as follows:

$$Gov_t + G_{t+1} = \frac{M_t - M_{t-1}}{P_t} + T_t \quad (73)$$

$$Gov_t = \psi_7 Y^f_t \quad (74)$$

2.9 Market clearing

The economy must achieve general equilibrium with the labor, capital, product and credit markets clearing simultaneously:

$$Y_t^f = C_t + Gov_t + G_{t+1} + I_t + \tau G(\overline{\omega}_{g,t+1}, \sigma_{\omega g}) R_{g,t+1}^k Q_t K_{g,t} + \tau G(\overline{\omega}_{b,t+1}, \sigma_{\omega b}) R_{b,t+1}^k Q_t K_{b,t}$$

(75)

3 Model Calibration and the Steady State

We calibrate the parameters common in the New Keynesian literature to standard values. Each phase in the model corresponds to a quarter in time. The one-year average deposit interest rate is set at 2.75%, We calibrate the family discount factor β as fixed at 0.993 ($\beta = 1/(1 + 0.6875\%)$). The depreciation rate is set at δ=0.025 (Christiano *et al*. 2005; Foerster *et al*. 2011). The pledge rate for collateral to access the central bank's refinancing facility is capped at 70%. The ratio of government expenditure to GDP is set at ψ_7=0.1025. The response coefficient ϕ_Y of the deposit reserve ratio to the output gap and the response coefficient ϕ_π to the inflation gap are set to Gamma distribution, with the average values of 0.1798 and 1.3507, respectively.

In the literature, the setting of elasticity of substitution by firms between intermediate goods ϵ_p is usually between 5 and 11, so we select a median value 8 (Barsky et al. 2007). The investment adjustment cost elasticity is set at ψ_1=2.48 (Christiano et al. 2005). The reciprocal of intertemporal substitution elasticity of consumption is set at σ_c=2, and the reciprocal of the intertemporal substitution elasticity of cash balances is set at σ_m=1. The inverse of the Frisch elasticity of labor supply is σ_l=1 (Christiano et al. 2014), and the price stickiness parameter is set according to the general literature as θ_p=0.75. We calibrated the share of labor supply in household utility as ξ=1.5045, the weight of green goods as φ=0.5538, the natural survival rate of green firms as γ_g=0.9219, natural survival rate of brown firms as γ_b=0.9864, and bank supervision costs as τ=0.21 (Christiano et al. 2014). The leverage ratio of brown firms is set at $LEV_{b,t}$=1.54 and through calibration, we find that the leverage ratio of green firms is $LEV_{g,t}$=1.39. The response parameters of the refinancing rate to the proportion of green credit μ_1 and pledge rate to green industry credit ratio μ_2 are 0.4412 and 2.1309, respectively. The adjustment cost of green and brown firms' loans, bank deposits and refinancing are 2.47, 2.53, 2.48 and 2.5, respectively. Finally, the smoothing coefficient of the reserve ratio on deposits, the refinancing rate, the pledge rate, and the persistence of technological development of green firms and brown firms are 0.743, 0.33, 0.0536, 0.9583 and 0.7348, respectively The calibration values of the above parameters and of steady state variables are shown in Table 1.

4 Impulse response analysis

In this section we examine the economic impact of the two green monetary policy tools and the government guarantee of green lending in response to one unit of policy shock. The yield of the money and credit markets will vary when the central adjusts the reserve requirement ratio or its refinancing rate and in response to changes in the amount of government loan guarantees. In turn, these will result in changes in the behavior and decisions of households, entrepreneurs, and banks.

4.1 Reserve requirement policy shock

Figure 1 illustrates the impulse of 1% reduction in the reserve requirement ratio on output, credit growth, the financing premium, the loan interest rate, inflation, the riskless interest rate, and net assets. The impact of reserve requirement ratio directly affects the scale of bank loans through bank budget constraints and capital constraints.

In the short term, reducing the reserve requirement ratio leads to credit expansion: the measure adds liquidity to the market and the riskless interest rate falls in the short term. Due to the existence of investment adjustment costs and loan adjustment costs, the additional liquidity is nut fully released. At the same time, entrepreneurs have expanded the investment of capital factors, resulting in input-output friction, which leads to a decline in output and labor demand and the nominal wage level. Inflation increases and because of price stickiness, the real wage level and the purchasing power of the household sector declines and households net wealth falls, which reduces total bank deposits. As can be seen from Figure 1, for every 1% reduction in the deposit reserve ratio, the labor demand of green entrepreneurs and brown entrepreneurs will decrease, and the demand for capital and loans by green entrepreneurs increases. Comparatively speaking, brown entrepreneurs will suffer less short-term impact. Green entrepreneurs have a low return on capital and high risks, so the credit risk premium also rises, while brown entrepreneurs have high return on capital and face low risks, that is, the loss of bank net assets is reduced, which slows down the increase of market risk premium and has a negative impact on risk premium. Due to the short-term decline in deposits and the fluctuation of the risk premium, banks readjusted the use of funds, and then adjusted the supply of investment funds and loan pricing.

In the long term, the banking system adjusts its loans to the green and brown sectors and reduces the supply of green credit when the risk premium of green entrepreneurs is high. When the return on assets corresponding to the loan decreases, the bank's net assets suffer corresponding losses, and the bank's net assets decline. Because the bank's net assets are an important guarantee for the bank to absorb deposits and issue loans, the total amount of loans that the bank can provide will decrease in the next period, and the bank will adjust the supply of investment funds and loan pricing, which will cause the market risk premium to rise, meaning that entrepreneurs pay higher loan costs. At the same time, because of the reduction of entrepreneur investment, asset prices also decline, finally returning to a steady state.

4.1.2 Refinancing policy shock

We simulate the impact of reducing the refinancing rate by 1 percentage point, the results of which are illustrated in Figure 2. In the short term, when the refinancing rate for green entrepreneurs drops, the amount of loans provided by banks to green entrepreneurs increases and the financing cost decreases, which increases sharply the output of green entrepreneurs. Due to the crowding-out effect, the output of brown entrepreneurs falls. As green entrepreneurs expand production, the demand for labor and capital factors of production increases, and the nominal wages paid by green entrepreneurs rise. Because of price stickiness, the actual wage level rises. As the labor market is competitive, the labor force of brown entrepreneurs flows to green entrepreneurs so that the labor force of brown entrepreneurs' declines. Overall, the consumption level rises, and the inflation level rises slightly. Banks that provide loans to green entrepreneurs can first obtain funds through the refinancing rate lower than the deposit rate, then obtain funds at low cost and lend to green entrepreneurs. The amount of loans for green entrepreneurs increases, while reducing the financing cost of green entrepreneurs. As the interest rate on loans falls, the financing premium decreases and the net assets decreases, that is the leverage increases. Obviously, there is a negative correlation between the amount of refinancing obtained from the central bank which increases, and the deposits of green entrepreneurs decrease. The interest rate of bank deposits on loans to green entrepreneurs decreases accordingly. Due to the decreasing proportion of adjustment costs and the crowding-out effect between green and brown entrepreneurs, green entrepreneurs have obtained a large amount of green credit in a short period of time, resulting in a smaller amount of bank loans to brown entrepreneurs and the increase in risk premium.

In the long term, the amount of loans to green entrepreneur surges resulting in a sharp decline in banks' net assets and an increase in their leverage. The borrower's net asset decreases, the amount of external financing decreases and the financing cost increases. As a result, banks increase the interest rate on loans made to green business owners in response to an increase in risk in order to pay for the expense of monitoring. Green business owners respond by taking on less debt, which lowers total credit. Entrepreneurs buy less capital when they have less money available, which results in less investment and a fall in output and consumption. Capital prices also fall because of the decrease in investment prices results from a decrease in investment. Costs drop as a result of the economic production loss, which lowers inflation.

4.2 Government loan guarantees

We simulate the impact of the government increasing its guarantees on bank loans to green entrepreneurs increasing by 1 percentage point, the results of which are illustrated in Figure 3. In the short term, the net assets of green entrepreneurs increase. When the leverage ratio remains unchanged, the net assets of green entrepreneurs increase, the risks decrease and bank credit increases. The government guarantee reduces the default risk of entrepreneurs so that the loan interest rate charged to them declines. The net assets of banks increase allowing them to obtain deposits at a lower risk-free interest rate. Due to the decline in the overall loan interest rate, entrepreneurs pay lower loan costs and improve the investment level. In this process, the government guarantee results in a mismatch of resources causing price distortions, which leads in turn to the inefficient use of resources and the negative impact on overall output level. As a result, the demand labor drops, and the nominal wages also fall. Inflation rises and because of price stickiness, the real wage and purchasing power fall. At this time, family net wealth falls leading to a decline in bank deposits.

In the long run, because the loan guarantee to green entrepreneurs leads to a resource mismatch and price distortion. The return on assets corresponding to the loans decreases and the net assets of decline. Moreover, because the net assets of banks are an important guarantee for banks to absorb deposits and issue loans, the total amount of loans that banks can provide to the will decrease, especially for green entrepreneurs. Banks adjust the supply of investment funds and loan prices, which leads to an increase in the market risk premium. At the same time, because of the reduction of entrepreneur investment, output and asset prices declines to a steady level.

4.4 Comparing shocks

To facilitate comparison, we repeat the impulse responses to the three policies and illustrate the results in Figure 4. The reserve requirement shock results in large fluctuations in the key variables, including output, investment, and consumption. Through the implementation of the reserve requirement policy, the capital structure of financial institutions has been optimized, the liquidity demand of the banking system at a special time has been met, the support for entrepreneurs has been increased as a whole, the social financing cost has been reduced, and the positive role of supporting the real economy has been played. In supporting green entrepreneurs and brown entrepreneurs, the amount of loans for green entrepreneurs can be increased in the short term, but it will be reduced in the long term, and the effect of supporting green entrepreneurs is not lasting, which cannot play an obvious role in the sustainable development of green entrepreneurs.

The effects of central bank refinancing and government loan guarantees are more stable. However, due to soft budget constraints, there are price distortions, unreasonable resource allocation and high credit risk premium, which bring unnecessary risks to banks. Refinancing loans to green banks is the most effective policy, although there is friction in adjustment costs in the transmission mechanism of banks. It can be seen that the soft budget constraint counteracts the financial accelerator. The financial accelerator reveals the specific relationship between corporate financing premium and leverage ratio, and financial institutions allocate funds reasonably through market-oriented financing prices according to the principle of risk-return matching. Soft budget constraints cover up the real risks of entrepreneurs, distort the financing price, and cannot fully reflect the resource cost and risk premium, and the degree of price distortion is positively related to the degree of government guarantee. As a result, some inefficient entrepreneurs occupy a large number of production factors at low cost, resulting in resource mismatch, which in turn leads to problems such as overcapacity and excessive leverage.

Based on the above analysis results, we can see that the reserve requirement policy has the weakest economic stability effect under the condition of using a single policy tool, and the refinancing policy can stabilize economic fluctuations more quickly. Similarly, refinancing policy reduces the long-term negative impact on the economy and reduces the volatility of the macro-economy. From the perspective of policy effect, refinancing policy is the most conducive to economic stability, and can better balance the goals of economic stability and promoting low carbon output.

5. Conclusions

We presented and estimated a Bernanke *et al*. (1999)-type dynamic general equilibrium model modified to allow the authorities to use monetary and fiscal policy to shape bank behavior in support of climate goals. In the model, central bank refinancing and reserve requirements were employed to support lending for lower carbon projects at lower rates of interest than for other projects. Fiscal policy supported these projects by providing guarantees for banks loans to firms engaged in the production of low carbon outputs. Under reasonable parameters of the model, central bank refinancing is shown two be the most effective tool to influence bank lending that supports environment goals. By focusing on reserve requirements and rediscount policy as the monetary policy tools to support these oals our model may be particularly relevant to policymaking in middle- and low-income, where these tools have long played an important role in policymaking.

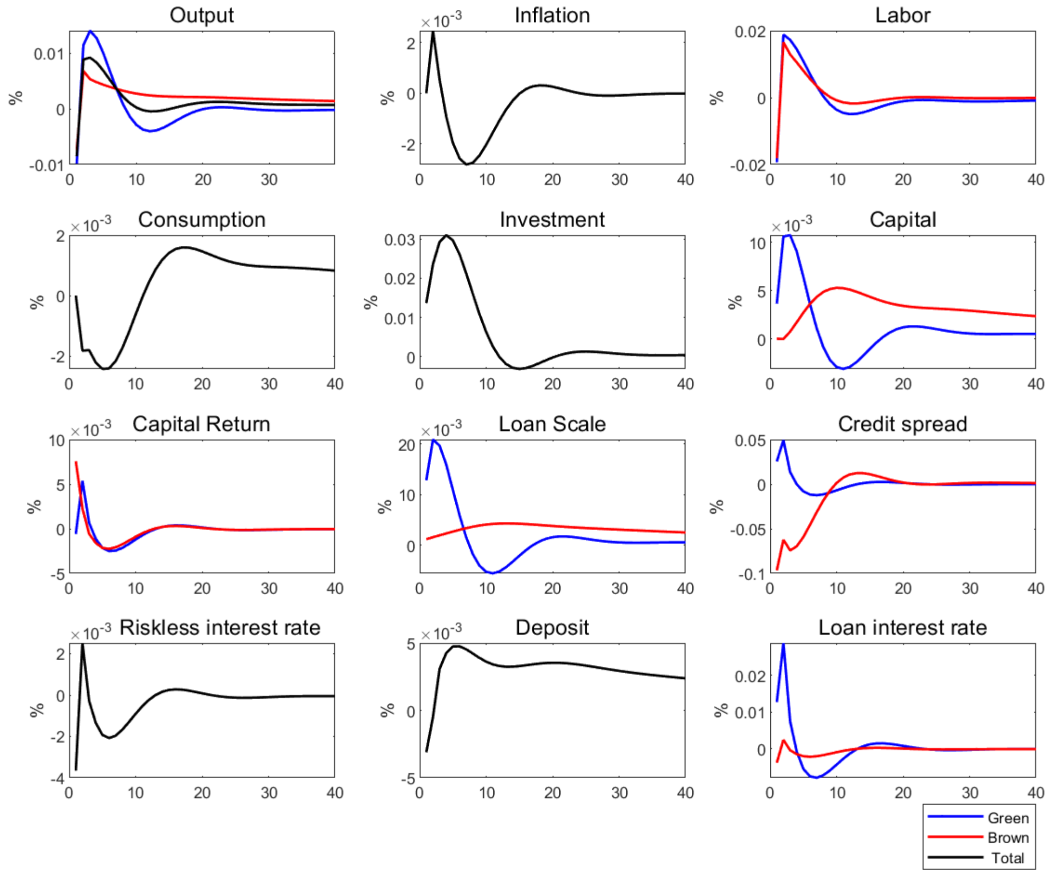

Fig. 1. Reserve Requirement Policy Shock

Note: The figure shows the impulse-response functions from a one-unit shock to the level of reserve requirements on banks' household deposits

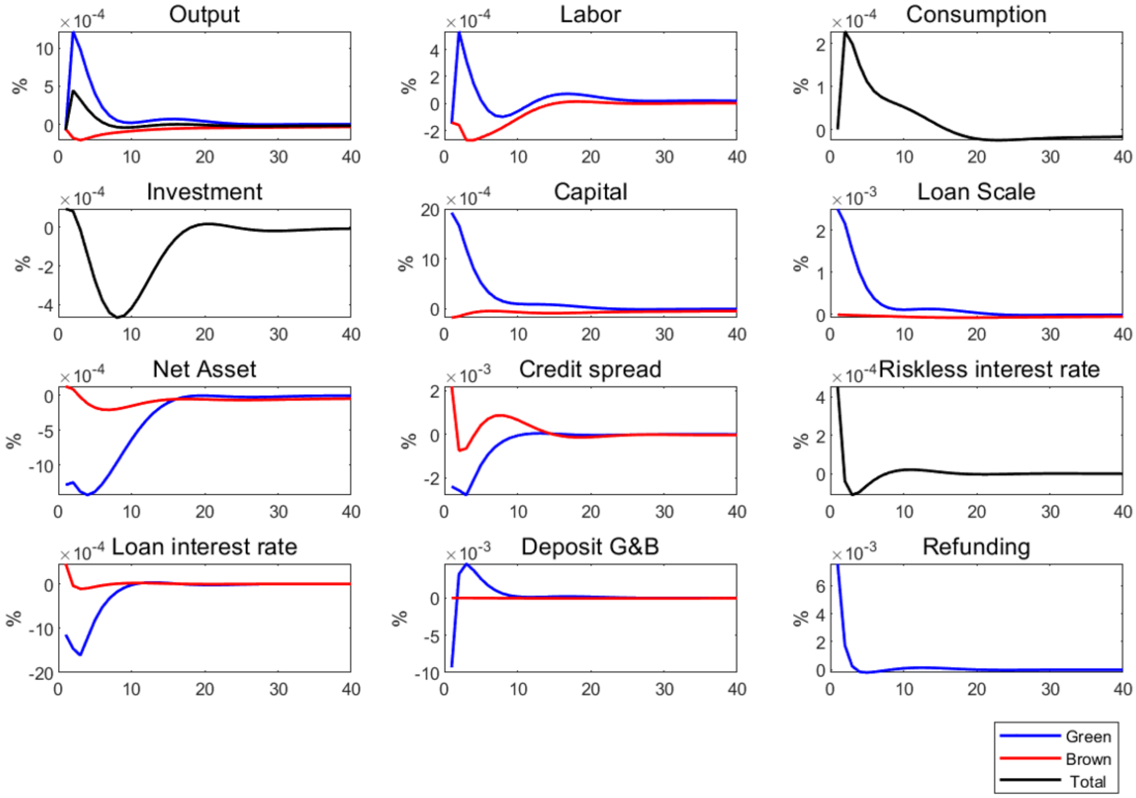

Fig. 2. Refinancing Policy Shock

Note: The figure shows the impulse-response functions from a one-unit shock to the level of central bank refinancing available to banks that lend to green firms

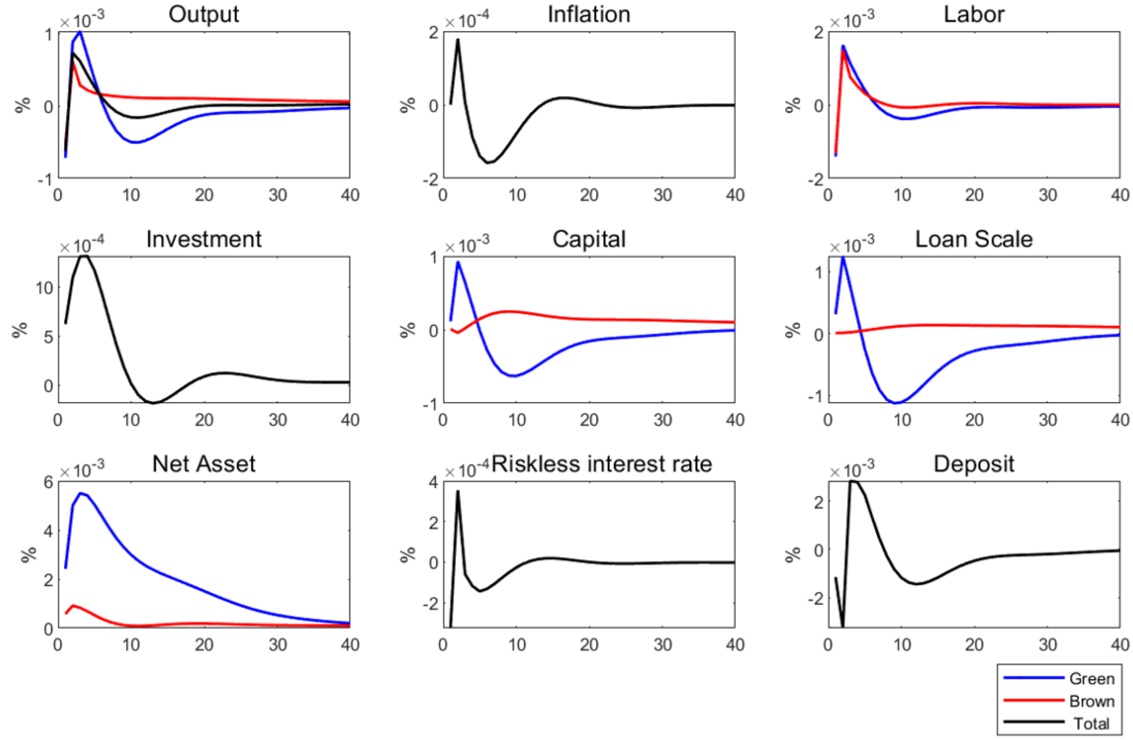

Fig.3. Loan Guarantee Policy Shock

Note: The figure shows the impulse-response functions from a one-unit shock to the number of guarantees made by the government for bank loans to green firms

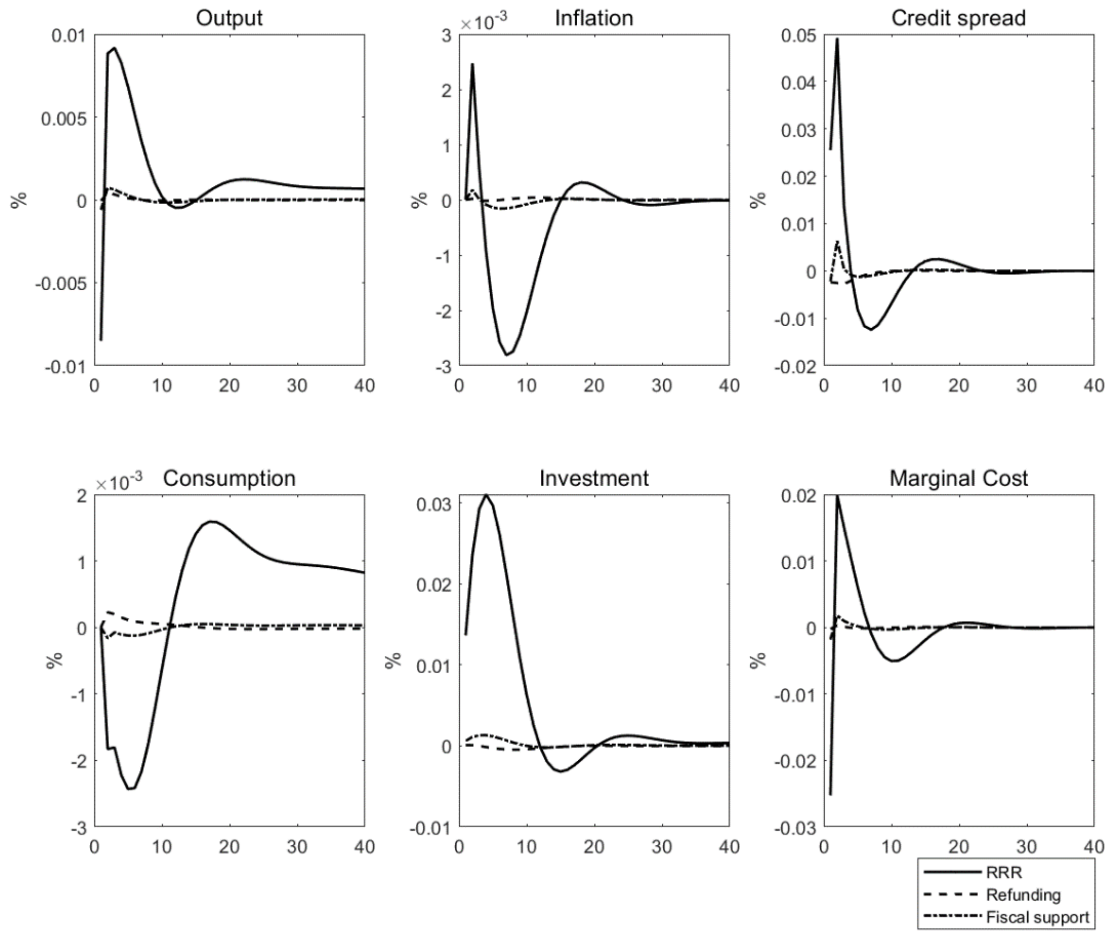

Fig.4. Comparing Policy Shocks

Note: The figure compares the impulse-response functions from a one-unit shock to the level of reserve requirements on bank deposits, the level of central bank re-financing available to banks that lend to green firms, and number of guarantees made by the government for bank loans to green firms.

Table 1
Calibrated Parameters

Parameter	Description	Value
β	Discount factor	0.993
σ_c	Inverse of elasticity intertemporal substitution of consumption	2
σ_m	Inverse of elasticity intertemporal substitution of cash balance	1
σ_l	The inverse of the Frisch elasticity of labor supply	1
ζ	The share of real money balance in household utility	1
ξ	The share of labor supply in household utility	1.5045
α_g	Share of capital in production in green firms	0.37
α_b	Share of capital in production in brown firms	0.35
δ	Depreciation rate	0.025
θ_p	Price stickiness parameter	0.75
χ	Elasticity of substitution brown-green goods	2
ϵ_p	Elasticity of firms' substitution between intermediate goods	8
φ	Weight of green goods	0.5538
γ_g	Natural survival rate of green firms	0.9219
γ_b	Natural survival rate of brown firms	0.9864
τ	Supervision costs	0.21
$LEV_{g,t}$	The leverage ratio of non-financial green firms	1.39
$LEV_{b,t}$	The leverage ratio of non-financial brown firms	1.54
ϖ_t	The pledge rate	0.7
ψ_1	Investment adjustment cost	2.48
ψ_2	Adjustment cost of green firms' loan	2.47
ψ_3	Adjustment cost of green credit bank deposits	2.48
ψ_4	Adjustment cost of refinancing (green credit)	2.5
ψ_5	Adjustment cost of brown firms' loan	2.53
ψ_6	Adjustment cost of brown credit bank deposits	2.48
ψ_7	Ratio of government expenditure to GDP	0.1025
μ_1	Response parameters of refinancing rate to the proportion of green credit	0.4412
μ_2	Response parameters of pledge rate to green industry credit ratio	2.1309
ϕ_Y	Response coefficient of deposit rate to output gap	0.1798
ϕ_π	Response coefficient of RRR to inflation gap	1.3507
ρ_r	Smoothing coefficient of deposit reserve ratio	0.743
ρ_h	Smoothing coefficient of refinancing rate	0.33
ρ_ϖ	Smoothing coefficient of refinancing pledge rate	0.0536
ρ_{ga}	Persistence of technical impact of green firms	0.9583
ρ_{ba}	Persistence of technical impact of brown firms	0.7348

The underlying equations for the model are as follows:

Labor supply equation:

$$\xi L_t^{\sigma_l} = \frac{W_t}{P_t} C_t^{-\sigma_c} \tag{A.1}$$

Euler equation of consumption decision:

$$\frac{1}{r_t} = \beta E_t \frac{\lambda_{t+1}}{\lambda_t} \tag{A.2}$$

Money demand equation:

$$\left(\frac{M_t}{P_t}\right)^{\sigma_m} = \zeta(\frac{r_t}{r_t - 1}) C_t^{\sigma_c} \tag{A.3}$$

Marginal utility of consumption:

$$\lambda_t = C_t^{-\sigma_c} \tag{A.4}$$

Price of the final commodity:

$$1 = \theta_p (\pi_t)^{(\epsilon_p - 1)} + \left(1 - \theta_p\right) \left(\frac{P_t^*}{P_t}\right)^{(1 - \epsilon_p)} \tag{A.5}$$

Output of green products:

$$Y_{g,t} = (\varphi) \left(\frac{P_{g,t}}{P_t^m}\right)^{-\chi} Y_t \tag{A.6}$$

Output of brown products:

$$Y_{b,t} = (1 - \varphi) \left(\frac{P_{b,t}}{P_t^m}\right)^{-\chi} Y_t \tag{A.7}$$

Aggregation price:

$$P_t^m = \left[\varphi \left(P_{g,t}\right)^{1-\chi} + (1 - \varphi)\left(P_{b,t}\right)^{1-\chi}\right]^{\frac{1}{1-\chi}} \tag{A.8}$$

Total marginal cost:

$$mc_t = P_t^m / P_t \tag{A.9}$$

NKPC:

$$\frac{P_t^*}{P_t} = \frac{\epsilon_p}{\epsilon_p - 1}\frac{f_t^1}{f_t^2} \quad \text{(A.10)}$$

$$f_t^1 = \lambda_t mc_t Y_t + \beta\theta_p E_t \pi_{t+1}^{\epsilon_p} f_{t+1}^1 \quad \text{(A.11)}$$

$$f_t^2 = \lambda_t Y_t + \beta\theta_p E_t \pi_{t+1}^{\epsilon_p - 1} f_{t+1}^2 \quad \text{(A.12)}$$

Price discrete kernel:

$$d_t^P = (1-\theta_p)(\pi_t^*)^{-\epsilon_p} + \theta_p \pi_t{}^{\epsilon_p} d_{t-1}^P \quad \text{(A.13)}$$

$$Y_t = d_t^P Y_t^f \quad \text{(A.14)}$$

Production function of green firms:

$$Y_{g,t} = A_{g,t} K_{g,t-1}^{\alpha_g} L_{g,t}^{1-\alpha_g} \quad \text{(A.15)}$$

Production function of brown firms:

$$Y_{b,t} = A_{b,t} K_{b,t-1}^{\alpha_b} L_{b,t}^{1-\alpha_b} \quad \text{(A.16)}$$

Labor demand equation of green firms:

$$L_{g,t} = (1-\alpha_g) mc_{g,t} \frac{Y_{g,t}}{W_{g,t}} \quad \text{(A.17)}$$

Labor demand equation of brown firms:

$$L_{b,t} = (1-\alpha_b) mc_{b,t} \frac{Y_{b,t}}{W_{b,t}} \quad \text{(A.18)}$$

Marginal cost of green firms:

$$mc_{g,t} = P_{g,t} \quad \text{(A.19)}$$

Marginal cost of brown firms:

$$mc_{b,t} = P_{b,t} \quad \text{(A.20)}$$

Capital return rate of green firms:

$$E_t\{R_{g,t+1}^k\} = E_t\left[\alpha_g mc_{g,t+1}\frac{Y_{g,t+1}}{K_{g,t}} + Q_{t+1}(1-\delta)\right]/Q_t \quad \text{(A.21)}$$

Capital return rate of brown firms:

$$E_t\{R^k_{b,t+1}\} = E_t\left[\alpha_b mc_{b,t+1}\frac{Y_{b,t+1}}{K_{b,t}} + Q_{t+1}(1-\delta)\right]/Q_t \quad \text{(A.22)}$$

Real interest rate:

$$r_t \equiv \frac{i_t}{\pi_t} \quad \text{(A.23)}$$

Sum of capital of green and brown firms:

$$K_t = K_{g,t} + K_{b,t} \quad \text{(A.24)}$$

Sum of capital of green and brown firms:

$$L_t = L_{g,t} + L_{b,t} \quad \text{(A.25)}$$

Wage of green and brown firms:

$$W_t = W_{g,t} \quad \text{(A.26)}$$

$$W_t = W_{b,t} \quad \text{(A.27)}$$

Capital accumulation:

$$K_t = (1-\delta)K_{t-1} + \left[1 - \frac{\psi_1}{2}\left(\frac{I_t}{I_{t-1}} - 1\right)^2\right] I_t \quad \text{(A.28)}$$

Tobin Q:

$$Q_t\left[1 - \frac{\psi_1}{2}\left(\frac{I_t}{I_{t-1}} - 1\right)^2 - \psi_1\left(\frac{I_t}{I_{t-1}} - 1\right)\frac{I_t}{I_{t-1}}\right] + \beta E_t\frac{\lambda_{t+1}}{\lambda_t}\psi_1\left(\frac{I_{t+1}}{I_t} - 1\right)\left(\frac{I_{t+1}}{I_t}\right)^2 Q_{t+1} = 1 \quad \text{(A.29)}$$

Balance sheet of green firms:

$$Q_t K_{g,t} = N_{g,t} + B_{g,t} \quad \text{(A.30)}$$

Balance sheet of brown firms:

$$Q_t K_{b,t} = N_{b,t} + B_{b,t} \quad \text{(A.31)}$$

Capital leverage of green firms:

$$LEV_{g,t} = Q_t K_{g,t}/N_{g,t} \quad \text{(A.32)}$$

Capital leverage of brown firms:

$$LEV_{b,t} = Q_t K_{b,t}/N_{b,t} \tag{A.33}$$

Expected rate of return of green firms:

$$[g_{t+1} + \Gamma(\overline{\omega}_{g,t+1}, \sigma_{\omega g}) - \tau G(\overline{\omega}_{g,t+1}, \sigma_{\omega g})]R^k_{g,t+1} Q_t K_{g,t} = i_{t+1}(Q_t K_{g,t} - N_{g,t}) \tag{A.34}$$

The degree of government guarantee:

$$g_{t+1} = \frac{G_{t+1}}{R^k_{g,t+1} Q_t K_{g,t}} \tag{A.35}$$

Expected rate of return of brown firms:

$$[\Gamma(\overline{\omega}_{b,t+1}, \sigma_{\omega b}) - \tau G(\overline{\omega}_{b,t+1}, \sigma_{\omega b})]R^k_{b,t+1} Q_t K_{b,t} = i_{t+1}(Q_t K_{b,t} - N_{b,t}) \tag{A.36}$$

Profit maximization of green firms:

$$[1 - \Gamma(\overline{\omega}_{g,t+1}, \sigma_{\omega g}) - g_{t+1}] \frac{R^k_{g,t+1}}{i_{t+1}} = \frac{1}{LEV_{g,t}} \eta_{g,t} \tag{A.37}$$

$$\eta_{g,t} = \frac{1 - F(\overline{\omega}_{g,t+1}, \sigma_{\omega g})}{1 - F(\overline{\omega}_{g,t+1}, \sigma_{\omega g}) - \tau \overline{\omega}_{g,t+1} F_\omega(\overline{\omega}_{g,t+1}, \sigma_{\omega g})} \tag{A.38}$$

Profit maximization of brown firms:

$$[1 - \Gamma(\overline{\omega}_{b,t+1}, \sigma_{\omega b})] \frac{R^k_{b,t+1}}{i_{t+1}} = \frac{1}{LEV_{b,t}} \eta_{b,t} \tag{A.39}$$

$$\eta_{b,t} = \frac{1 - F(\overline{\omega}_{b,t+1}, \sigma_{\omega b})}{1 - F(\overline{\omega}_{b,t+1}, \sigma_{\omega b}) - \tau \overline{\omega}_{b,t+1} F_\omega(\overline{\omega}_{b,t+1}, \sigma_{\omega b})} \tag{A.40}$$

Financing premium of green firms:

$$G_{t+1} + \overline{\omega}_{g,t+1} R^k_{g,t+1} Q_t K_{g,t} = R^l_{g,t+1} B_{g,t} \tag{A.41}$$

Financing premium of brown firms:

$$\overline{\omega}_{b,t+1} R^k_{b,t+1} Q_t K_{b,t} = R^l_{b,t+1} B_{b,t} \tag{A.42}$$

Net assets accumulation of green firms:

$$N_{g,t} = \gamma_g [R^k_{g,t} Q_{t-1} K_{g,t-1} (1 - \tau G(\overline{\omega}_{g,t}, \sigma_{\omega g}) + g_t) - i_t B_{g,t-1}] \tag{A.43}$$

Net assets accumulation of brown firms:

$$N_{b,t} = \gamma_b \left[R^k_{b,t} Q_{t-1} K_{b,t-1} \left(1 - \tau G\left(\overline{\omega}_{b,t}, \sigma_{\omega b}\right)\right) - i_t B_{b,t-1} \right] \tag{A.44}$$

Profit maximization of banks that provide loans to green firms:

$$\frac{\partial \Pi_{Bg}}{\partial B_{g,t}} = \left(1 - o_g\right) R^l_{g,t} - i_t \frac{(1-\varpi_t)}{(1-R^r_t)} - R^h_{g,t} \varpi_t -$$

$$\left\{ \begin{array}{c} \frac{\psi_2}{2}\left(\frac{B_{g,t}}{B_{g,t-1}} - 1\right)^2 + \psi_2 \frac{B_{g,t}}{B_{g,t-1}}\left(\frac{B_{g,t}}{B_{g,t-1}} - 1\right) + \frac{\psi_3}{2}\left(\frac{\frac{(1-\varpi_t)B_{g,t}}{(1-R^r_t)}}{\frac{(1-\varpi_{t-1})B_{g,t-1}}{(1-R^r_{t-1})}} - 1\right)^2 \frac{(1-\varpi_t)}{(1-R^r_t)} \\ +\psi_3\left(\frac{\frac{(1-\varpi_t)B_{g,t}}{(1-R^r_t)}}{\frac{(1-\varpi_{t-1})B_{g,t-1}}{(1-R^r_{t-1})}} - 1\right)\frac{(1-\varpi_t)}{(1-R^r_t)} \frac{\frac{(1-\varpi_t)B_{g,t}}{(1-R^r_t)}}{\frac{(1-\varpi_{t-1})B_{g,t-1}}{(1-R^r_{t-1})}} + \frac{\psi_4}{2}\left(\frac{\varpi_t B_{g,t}}{\varpi_{t-1} B_{g,t-1}} - 1\right)^2 \varpi_t + \psi_4 \left(\frac{\varpi_t B_{g,t}}{\varpi_{t-1} B_{g,t-1}} - 1\right) \varpi_t \frac{\varpi_t B_{g,t}}{\varpi_{t-1} B_{g,t-1}} \end{array} \right\} +$$

$$\beta E_t \left\{ \begin{array}{c} \psi_2 \left(\frac{B_{g,t+1}}{B_{g,t}} - 1\right)\left(\frac{B_{g,t+1}}{B_{g,t}}\right)^2 + \psi_3 \frac{(1-\varpi_t)}{(1-R^r_t)}\left(\frac{\frac{(1-\varpi_{t+1})B_{g,t+1}}{(1-R^r_{t+1})}}{\frac{(1-\varpi_t)B_{g,t}}{(1-R^r_t)}} - 1\right)\left(\frac{\frac{(1-\varpi_{t+1})B_{g,t+1}}{(1-R^r_{t+1})}}{\frac{(1-\varpi_t)B_{g,t}}{(1-R^r_t)}}\right)^2 \\ +\psi_4 \varpi_t \left(\frac{\varpi_{t+1} B_{g,t+1}}{\varpi_t B_{g,t}} - 1\right)\left(\frac{\varpi_{t+1} B_{g,t+1}}{\varpi_t B_{g,t}}\right)^2 \end{array} \right\} = 0$$

(A.45)

Profit maximization of banks that provide loans to brown firms:

$$\frac{\partial \Pi_{Bb}}{\partial B_{b,t}} = (1 - o_b) R^l_{b,t} - \frac{i_t}{(1-R^r_t)} - \left\{ \begin{array}{c} \frac{\psi_5}{2}\left(\frac{B_{b,t}}{B_{b,t-1}} - 1\right)^2 + \frac{\psi_6}{2}\frac{1}{(1-R^r_t)}\left(\frac{B_{b,t}}{B_{b,t-1}} - 1\right)^2 + \\ \psi_5 \left(\frac{B_{b,t}}{B_{b,t-1}} - 1\right)\frac{B_{b,t}}{B_{b,t-1}} + \psi_6 \left(\frac{\frac{B_{b,t}}{(1-R^r_t)}}{\frac{B_{b,t-1}}{(1-R^r_{t-1})}} - 1\right)\frac{\frac{B_{b,t}}{(1-R^r_t)}}{\frac{B_{b,t-1}}{(1-R^r_{t-1})}} \frac{1}{(1-R^r_t)} \end{array} \right\} +$$

$$\beta E_t \left\{ \psi_5 \left(\frac{B_{b,t+1}}{B_{b,t}} - 1\right)\left(\frac{B_{b,t+1}}{B_{b,t}}\right)^2 + \psi_6 \frac{1}{(1-R^r_t)}\left(\frac{\frac{B_{b,t+1}}{(1-R^r_{t+1})}}{\frac{B_{b,t}}{(1-R^r_t)}} - 1\right)\left(\frac{\frac{B_{b,t+1}}{(1-R^r_{t+1})}}{\frac{B_{b,t}}{(1-R^r_t)}}\right)^2 \right\} = 0$$

(A.46)

Demand for deposits:

$$D_t = \frac{B_{b,t} + (1-\varpi_t) B_{g,t}}{1 - R^r_t} \tag{A. 47}$$

$$B_{b,t} = (1 - R_t^r)D_{b,t} \tag{A.48}$$

$$D_t = D_{g,t} + D_{b,t} \tag{A.49}$$

$$B_{g,t} = (1 - R_t^r)D_{g,t} + H_{g,t} \tag{A.50}$$

Government budget constraint:

$$Gov_t + G_{t+1} = \frac{M_t - M_{t-1}}{P_t} + T_t \tag{A.51}$$

$$Gov_t = \psi_7 Y_t^f \tag{A.52}$$

Market clearing:

$$Y_t^f = C_t + Gov_t + G_{t+1} + I_t + \tau G(\overline{\omega}_{g,t+1}, \sigma_{\omega g})R_{g,t+1}^k Q_t K_{g,t} + \tau G(\overline{\omega}_{b,t+1}, \sigma_{\omega b})R_{b,t+1}^k Q_t K_{b,t} \tag{A.53}$$

Shock of reserve requirement ratio:

$$logR_t^r - logR_{ss}^r = \rho_r(logR_{t-1}^r - logR_{ss}^r) + (1 - \rho_r)\begin{bmatrix} \phi_Y(logY_t - logY_{ss}) \\ +\phi_\pi(log\pi_t - log\pi_{ss}) \end{bmatrix} + \varepsilon_t^{R^r} \tag{A.54}$$

Shock of refinancing rate for green firms:

$$logR_{g,t}^h - logR_{g,ss}^h = \rho_h\left(logR_{g,t-1}^h - logR_{g,ss}^h\right) + (1 - \rho_h)\left[(logi_t - logi_{ss}) - \mu_1\left[\left(logB_{g,t} - logB_{g,ss}\right) - \left(logB_{g,t-1} - logB_{g,ss}\right)\right]\right] + \varepsilon_t^{R_g^h} \tag{A.55}$$

Shock of refinancing pledge rate of green firms:

$$log\varpi_t - log\varpi_{ss} = \rho_\varpi(log\varpi_{t-1} - log\varpi_{ss}) + (1 - \rho_\varpi)\mu_2\left[\left(logB_{g,t} - logB_{g,ss}\right) - \left(logB_{g,t-1} - logB_{g,ss}\right)\right] + \varepsilon_t^{\varpi} \tag{A.56}$$

Shock of government guarantee rate for green firms:

$$log\, g_t = \left(1 - \rho_g\right) log\, g_{ss} + \rho_g\, log\, g_{t-1} + \varepsilon_t^g \tag{A.57}$$

Productivity shock of green firms:

$$log\, A_{g,t} = \rho_{ga}\, log\, A_{g,t-1} + \varepsilon_t^{A_g} \tag{A.58}$$

Productivity shock of brown firms:

$$log\, A_{b,t} = (1 - \rho_{ba})\, log\, A_{b,ss} + \rho_{ba}\, log\, A_{b,t-1} + \varepsilon_t^{A_b} \tag{A.59}$$

Appendix B

The steady state values of the exogenous variables are determined by the following equations.

$$L_{g,ss} = \frac{1}{3} \tag{A.60}$$

$$L_{b,ss} = \frac{1}{3} \tag{A.61}$$

$$L_{ss} = L_{g,ss} + L_{b,ss} \tag{A.62}$$

$$P_{g,ss} = 1 \tag{A.63}$$

$$P_{ss} = 1 \tag{A.64}$$

$$A_{g,ss} = 1 \tag{A.65}$$

$$r_{ss} = \frac{1}{\beta} \tag{A.66}$$

$$\pi_{ss} = 1 \tag{A.67}$$

$$Q_{ss} = 1 \tag{A.68}$$

$$Y_{b,ss} = 1 \tag{A.69}$$

$$i_{ss} = r_{ss}\pi_{ss} \tag{A.70}$$

$$P_{ss}^{*} = \left[\frac{1-\theta_p(\pi_{ss})^{(\epsilon_p-1)}}{(1-\theta_p)}\right]^{\frac{1}{(1-\epsilon_p)}} \tag{A.71}$$

$$d_{ss}^{P} = \frac{(1-\theta_p)(P_{ss}^{*})^{-\epsilon_p}}{(1-\theta_p{\pi_{ss}}^{\epsilon_p})} \tag{A.72}$$

$$mc_{ss} = \frac{\epsilon_p-1}{\epsilon_p}\frac{\left(1-\beta\theta_p\pi_{ss}^{\epsilon_p}\right)}{\left(1-\beta\theta_p\pi_{ss}^{\epsilon_p-1}\right)}P_{ss}^{*} \tag{A.73}$$

$$P_{ss}^{m} = mc_{ss} \tag{A.74}$$

$$mc_{g,ss} = P_{g,ss} \tag{A.75}$$

$$\varphi = \frac{P_{ss}^{m\,1-\chi}}{\frac{(1-\alpha_g) mc_{g,ss} L_{b,ss}}{(1-\alpha_b) L_{g,ss} P_{g,ss}{}^{\chi}} + \left(P_{g,ss}\right)^{1-\chi}} \tag{A.76}$$

$$P_{b,ss} = \left[\frac{(1-\varphi)}{P_{ss}^{m\,1-\chi} - \varphi\left(P_{g,ss}\right)^{1-\chi}}\right]^{\frac{1}{\chi-1}} \tag{A.77}$$

$$mc_{b,ss} = P_{b,ss} \tag{A.78}$$

$$W_{b,ss} = (1-\alpha_b) mc_{b,ss} \frac{Y_{b,ss}}{L_{b,ss}} \tag{A.79}$$

$$W_{ss} = W_{b,ss} \tag{A.80}$$

$$W_{g,ss} = W_{ss} \tag{A.81}$$

$$Y_{g,ss} = \frac{L_{g,ss} W_{g,ss}}{(1-\alpha_g) mc_{g,ss}} \tag{A.82}$$

$$Y_{ss} = \frac{Y_{g,ss}}{\varphi}\left(\frac{P_{g,ss}}{P_{ss}^m}\right)^{\chi} \tag{A.83}$$

$$Y_{ss}^f = \frac{Y_{ss}}{d_{ss}^P} \tag{A.84}$$

$$K_{g,ss} = \left(\frac{Y_{g,ss}}{A_{g,ss} L_{g,ss}^{1-\alpha_g}}\right)^{\frac{1}{\alpha_g}} \tag{A.85}$$

$$R_{g,ss}^k = \left[\alpha_g mc_{g,ss} \frac{Y_{g,ss}}{K_{g,ss}} + Q_{ss}(1-\delta)\right] / Q_{ss} \tag{A.86}$$

$$LEV_{b,ss} = 2 \tag{A.87}$$

$$\frac{LEV_{b,ss}-1}{\left[\Gamma(\bar{\omega}_{b,ss},\sigma_{\omega b}) - \tau G(\bar{\omega}_{b,ss},\sigma_{\omega b})\right]} = \frac{1-F(\bar{\omega}_{b,ss},\sigma_{\omega b})}{\left[1-F(\bar{\omega}_{b,ss},\sigma_{\omega b}) - \tau\bar{\omega}_{b,ss} F_{\omega}(\bar{\omega}_{b,ss},\sigma_{\omega b})\right]\left[1-\Gamma(\bar{\omega}_{b,ss},\sigma_{\omega b})\right]} \tag{A.88}$$

$$R_{b,ss}^k = \frac{i_{ss}\left[LEV_{b,ss}-1\right]}{LEV_{b,ss}\left[\Gamma(\bar{\omega}_{b,ss},\sigma_{\omega b}) - \tau G(\bar{\omega}_{b,ss},\sigma_{\omega b})\right]} \tag{A.89}$$

$$\eta_{b,ss} = \frac{1-F(\bar{\omega}_{b,ss},\sigma_{\omega b})}{1-F(\bar{\omega}_{b,ss},\sigma_{\omega b}) - \tau\bar{\omega}_{b,ss} F_{\omega}(\bar{\omega}_{b,ss},\sigma_{\omega b})} \tag{A.90}$$

$$K_{b,ss} = \frac{\alpha_b mc_{b,ss} Y_{b,ss}}{R_{b,ss}^k Q_{ss} - Q_{ss}(1-\delta)} \tag{A.91}$$

$$A_{b,ss} = \frac{Y_{b,ss}}{K_{b,ss}^{\alpha_b} L_{b,ss}^{1-\alpha_b}} \tag{A.92}$$

$$N_{b,ss} = Q_{ss}K_{b,ss}/LEV_{b,ss} \tag{A.93}$$

$$B_{b,ss} = Q_{ss}K_{b,ss} - N_{b,ss} \tag{A.94}$$

$$R^l_{b,ss} = \frac{\overline{\omega}_{b,ss}R^k_{b,ss}Q_{ss}K_{b,ss}}{B_{b,ss}} \tag{A.95}$$

$$K_{ss} = K_{g,ss} + K_{b,ss} \tag{A.96}$$

$$I_{ss} = \delta K_{ss} \tag{A.97}$$

$$\gamma_b = \frac{1/LEV_{b,ss}}{\left[R^k_{b,ss}\left(1-\tau G\left(\overline{\omega}_{b,ss},\sigma_{\omega b}\right)\right)-i_{ss}(1-1/LEV_{b,ss})\right]} \tag{A.98}$$

$$g_{ss} = 0.3 \tag{A.99}$$

$$1 - \left[g_{ss} + \Gamma\left(\overline{\omega}_{g,ss},\sigma_{\omega g}\right) - \tau G\left(\overline{\omega}_{g,ss},\sigma_{\omega g}\right)\right]\frac{R^k_{g,ss}}{i_{ss}} = \frac{\left[1-\Gamma\left(\overline{\omega}_{g,ss},\sigma_{\omega g}\right)-g_{ss}\right]\left[1-F\left(\overline{\omega}_{g,ss},\sigma_{\omega g}\right)-\tau\overline{\omega}_{g,ss}F_{\omega}\left(\overline{\omega}_{g,ss},\sigma_{\omega g}\right)\right]}{1-F\left(\overline{\omega}_{g,ss},\sigma_{\omega g}\right)}\frac{R^k_{g,ss}}{i_{ss}} \tag{A.100}$$

$$\eta_{g,ss} = \frac{1-F\left(\overline{\omega}_{g,ss},\sigma_{\omega g}\right)}{1-F\left(\overline{\omega}_{g,ss},\sigma_{\omega g}\right)-\tau\overline{\omega}_{g,ss}F_{\omega}\left(\overline{\omega}_{g,ss},\sigma_{\omega g}\right)} \tag{A.101}$$

$$G_{ss} = R^k_{g,ss}Q_{ss}K_{g,ss}g_{ss} \tag{A.102}$$

$$LEV_{g,ss} = \frac{i_{ss}\eta_{g,ss}}{\left[1-\Gamma\left(\overline{\omega}_{g,ss},\sigma_{\omega g}\right)-g_{ss}\right]R^k_{g,ss}} \tag{A.103}$$

$$N_{g,ss} = \frac{Q_{ss}K_{g,ss}}{LEV_{g,ss}} \tag{A.104}$$

$$B_{g,ss} = Q_{ss}K_{g,ss} - N_{g,ss} \tag{A.105}$$

$$R^l_{g,ss} = \frac{G_{ss}+\overline{\omega}_{g,ss}R^k_{g,ss}Q_{ss}K_{g,ss}}{B_{g,ss}} \tag{A.106}$$

$$\gamma_g = \frac{N_{g,ss}}{\left[R^k_{g,ss}Q_{ss}K_{g,ss}\left(1-\tau G\left(\overline{\omega}_{g,ss},\sigma_{\omega g}\right)+g_{ss}\right)-i_{ss}B_{g,ss}\right]} \tag{A.107}$$

$$Gov_{ss} = \psi_7 Y^f_{ss} \tag{A.108}$$

$$C_{ss} = (1-\psi_7)Y^f_{ss} - \left[G_{ss} + I_{ss} + \tau G\left(\overline{\omega}_{g,ss},\sigma_{\omega g}\right)R^k_{g,ss}Q_{ss}K_{g,ss} + \tau G\left(\overline{\omega}_{b,ss},\sigma_{\omega b}\right)R^k_{b,ss}Q_{ss}K_{b,ss}\right] \tag{A.109}$$

$$\xi = \frac{W_{ss}}{L_{ss}^{\sigma_l} P_{ss}} C_{ss}^{-\sigma_c} \quad \text{(A.110)}$$

$$M_{ss} = \left[\zeta(\frac{r_{ss}}{r_{ss}-1}) C_{ss}^{\sigma_c}\right]^{\frac{1}{\sigma_m}} \quad \text{(A.111)}$$

$$\lambda_{ss} = C_{ss}^{-\sigma_c} \quad \text{(A.112)}$$

$$f_{ss}^1 = \frac{\lambda_{ss} mc_{ss} Y_{ss}}{(1-\beta\theta_p \pi_{ss}^{\chi})} \quad \text{(A.113)}$$

$$f_{ss}^2 = \frac{\lambda_{ss} Y_{ss}}{\left(1-\beta\theta_p \pi_{ss}^{\chi-1}\right)} \quad \text{(A.114)}$$

$$T_{ss} = Gov_{ss} + G_{ss} \quad \text{(A.115)}$$

$$\varpi_{ss} = 0.7 \quad \text{(A.116)}$$

$$R_{ss}^r = 0.16 \quad \text{(A.117)}$$

$$o_b = 1 - \frac{i_{ss}}{(1-R_{ss}^r) R_{bss}^l} \quad \text{(A.118)}$$

$$R_{g,ss}^h = \frac{(1-o_g) R_{g,ss}^l - i_{ss} \frac{(1-\varpi_{ss})}{(1-R_{ss}^r)}}{\varpi_{ss}} \quad \text{(A.119)}$$

$$D_{ss} = \frac{B_{b,ss} + (1-\varpi_{ss}) B_{g,ss}}{1-R_{ss}^r} \quad \text{(A.120)}$$

$$D_{b,ss} = \frac{B_{b,ss}}{1-R_{ss}^r} \quad \text{(A.121)}$$

$$D_{g,ss} = D_{ss} - D_{b,ss} \quad \text{(A.122)}$$

$$H_{g,ss} = B_{g,ss} - (1-R_{ss}^r) D_{g,ss} \quad \text{(A.123)}$$

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