Appendix to Should Unconventional Monetary Policies Become Conventional?

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Abstract

This appendix provides a full description of the model and additional details on the estimation and policy simulations.

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A The Model

The model combines a standard DSGE model as in Justiniano *et al.* (2013), with a banking sector that can invest in corporate loans and government debt as in Gertler and Karadi (2013), extended with long-term private and public debt as in Andreasen *et al.* (2013). In this section, we present the problems of households, financial intermediaries and firms. In the subsequent sections, we define the equilibrium conditions, compute the steady state of the model, define the measurement equation used in the estimation and provide additional results on the welfare analysis.

A.1 Households

As in Gertler and Karadi (2011), there is a continuum of households in the economy. At any point in time, a fraction f of household members are bankers and a fraction $1-f$ are workers. Workers supply labor and bring wage income to the household. Bankers manage financial intermediaries and bring profits to the household. The household can save in deposits, but at financial intermediaries not owned by the household. Hence, financial intermediaries always manage other people's money.[1] In a given period, a banker stays in her job with probability θ_B. Thus, the expected professional life of a banker is $(1-\theta_B)^{-1}$, and every period a mass $(1-\theta_B)f$ of bankers become workers (and a similar mass of workers become bankers so this keeps proportions stable).

Each household j maximizes the following utility function:

$$E_0 \sum_{t=0}^{\infty} \beta^t \xi_t^{\mathscr{U}} \left\{ \log\left(C_{jt} - hC_{jt-1}\right) - \psi_t \frac{L_{jt}^{1+\varphi}}{1+\varphi} \right\}$$

where $\xi_t^{\mathscr{U}}$ is an intertemporal preference shock with law of motion:

$$\log\left(\xi_t^{\mathscr{U}}\right) = \rho_{\mathscr{U}} \log\left(\xi_{t-1}^{\mathscr{U}}\right) + \varepsilon_{\mathscr{U},t} \text{ where } \varepsilon_{\mathscr{U},t} \sim \mathscr{N}(0, \sigma_{\mathscr{U}}),$$

and ψ_t is a labor supply shock with law of motion:

$$\log\left(\psi_t\right) = \left(1-\rho_\psi\right)\psi + \rho_\psi \log\left(\psi_{t-1}\right) + \varepsilon_{\psi,t} \text{ where } \varepsilon_{\psi,t} \sim \mathscr{N}(0, \sigma_\psi).$$

[1]This assumption is needed to motivate the moral hazard problem that will be introduced in subsection A.4.

C_{jt} denotes consumption, L_{jt} stands for hours of type j worked, and $\beta \in (0,1)$ corresponds to the discount factor. ψ is a parameter that helps pin down the amount of hours worked in the steady state.

The budget constraint of the household (in real terms) is:

$$C_{jt} + \frac{D_{jt}}{P_t} + T_t = W_{jt}L_{jt} - AC_t^w + R_{t-1}\frac{D_{jt-1}}{P_t} + \Pi_t.$$

W_{jt} is the real wage of type j, D_{jt} are deposit holdings with nominal return R_t, T_t are lump-sum taxes to finance government expenditures, Π_t are real transfers from financial and non-financial firms, and P_t is the price of the final good. There are complete markets in the economy, however, since Arrow-Debreu securities are in zero net supply we omit them from the problem to save on notation. Moreover, given the complete market assumption we will drop the index j in households' consumption and deposit holdings to save on notation. Households set their wages following a Rotemberg (1982) setting with AC_t^w being the adjustment costs, which we will define below. The Lagrangian function of the household is:

$$E_0 \sum_{t=0}^{\infty} \beta^t \left[\begin{array}{c} \xi_t^{\mathscr{U}} \left\{ \log\left(C_t - hC_{t-1}\right) - \psi_t \frac{L_{jt}^{1+\varphi}}{1+\varphi} \right\} \\ -\Xi_t \left\{ C_t + \frac{D_t}{P_t} - W_{jt}L_{jt} + AC_t^w - R_{t-1}\frac{D_{t-1}}{P_t} - \Pi_t \right\} \end{array} \right],$$

with Ξ_t being the Lagrange multiplier of the budget constraint. Maximizing over C_t and D_t we obtain:

$$\frac{\xi_t^{\mathscr{U}}}{C_t - hC_{t-1}} - E_t \beta \xi_{t+1}^{\mathscr{U}} \frac{h}{C_{t+1} - hC_t} = \Xi_t, \tag{A.1}$$

$$\frac{\Xi_t}{P_t} = \mathbb{E}_t \left(\beta \frac{\Xi_{t+1}}{P_{t+1}} R_t \right) \Longrightarrow \Xi_t = \mathbb{E}_t \left(\beta \frac{\Xi_{t+1}}{\pi_{t+1}} R_t \right), \tag{A.2}$$

with $\pi_t \equiv {}^{P_t}\!/_{P_{t-1}}$ being the the CPI inflation rate. Equation (A.1) defines marginal utility of consumption while equation (A.2) describes the standard Euler equation for consumption.

A.2 The Labor Packer

The labor used by intermediate good producers (described in subsection A.3.1) is supplied by a representative, competitive firm that hires the labor supplied by workers in each household j. The labor supplier aggregates the differentiated labor of households with the following production function:

$$L_t^{\mathscr{D}} = \left(\int_0^1 L_{jt}^{\frac{\varepsilon_{L,t}-1}{\varepsilon_{L,t}}} dj \right)^{\frac{\varepsilon_{L,t}}{\varepsilon_{L,t}-1}}, \tag{A.3}$$

where $\varepsilon_{L,t}$ controls the elasticity of substitution among different types of labor and $L_t^{\mathscr{D}}$ is the aggregate labor demand. The elasticity is time-varying:

$$\log(\varepsilon_{L,t}) = (1-\rho_{\varepsilon L})\log(\varepsilon_L) + \rho_{\varepsilon L}\log(\varepsilon_{L,t-1}) + \varepsilon_{L,t},$$

where $\varepsilon_{L,t} \sim \mathscr{N}(0, \sigma_L)$. The labor packer maximizes profits subject to the production function (A.3), taking as given all differentiated labor wages W_{jt} and the aggregated wage W_t. Consequently, its maximization problem is:

$$\max_{L_{jt}} W_t L_t^{\mathscr{D}} - \int_0^1 W_{jt} L_{jt} dj,$$

whose first order conditions are:

$$W_t \frac{\varepsilon_{L,t}}{\varepsilon_{L,t}-1} \left(\int_0^1 L_{jt}^{\frac{\varepsilon_{L,t}-1}{\varepsilon_{L,t}}} dj \right)^{\frac{\varepsilon_{L,t}}{\varepsilon_{L,t}-1}-1} \frac{\varepsilon_{L,t}-1}{\varepsilon_{L,t}} L_{jt}^{\frac{\varepsilon_{L,t}-1}{\varepsilon_{L,t}}-1} - W_{jt} = 0.$$

Dividing the first order conditions for two types of labor i and j, we get:

$$W_{jt} = \left(\frac{L_{it}}{L_{jt}} \right)^{\frac{1}{\varepsilon_{L,t}}} W_{it}.$$

Hence:

$$W_{jt} L_{jt} = W_{it} L_{it}^{\frac{1}{\varepsilon_{L,t}}} L_{jt}^{\frac{\varepsilon_{L,t}-1}{\varepsilon_{L,t}}}$$

and integrating out:

$$\int_0^1 W_{jt} L_{jt} dj = W_{it} L_{it}^{\frac{1}{\varepsilon_{L,t}}} \int_0^1 L_{jt}^{\frac{\varepsilon_{L,t}-1}{\varepsilon_{L,t}}} dj = W_{it} L_{it}^{\frac{1}{\varepsilon_{L,t}}} \left(L_t^{\mathscr{D}} \right)^{\frac{\varepsilon_{L,t}-1}{\varepsilon_{L,t}}}.$$

Since by the zero profits condition implied by perfect competition $W_t L_t^{\mathscr{D}} = \int_0^1 W_{jt} L_{jt} dj$, we get:

$$W_t = W_{it} L_{it}^{\frac{1}{\varepsilon_{L,t}}} \left(L_t^{\mathscr{D}} \right)^{-\frac{1}{\varepsilon_{L,t}}}$$

and, consequently, the input demand functions associated with this problem are:

$$L_{jt} = \left(\frac{W_{jt}}{W_t}\right)^{-\varepsilon_{L,t}} L_t^{\mathscr{D}}. \tag{A.4}$$

To find the aggregate wage, we use again the zero profit condition $W_t L_t^{\mathscr{D}} = \int_0^1 W_{jt} L_{jt} dj$ and plug-in the input demand functions (A.4) to get:

$$W_t L_t^{\mathscr{D}} = \int_0^1 W_{jt} \left(\frac{W_{jt}}{W_t}\right)^{-\varepsilon_{L,t}} L_t^{\mathscr{D}} dj \Rightarrow W_t^{1-\varepsilon_{L,t}} = \int_0^1 W_{jt}^{1-\varepsilon_{L,t}} dj$$

This can be rearranged to get an expression for the aggregated wage:

$$W_t = \left(\int_0^1 W_{jt}^{1-\varepsilon_{L,t}} dj\right)^{\frac{1}{1-\varepsilon_{L,t}}}.$$

Households set their wages following a Rotemberg setting. They adjust wages each period but they have to pay the following adjustment cost as a fraction of final output (see e.g. Fernández-Villaverde *et al.* (2015)):

$$AC_t^w = \frac{\theta_w}{2}\left(\frac{W_{jt}}{W_{jt-1}}\frac{P_t}{P_{t-1}} - \exp(\Lambda_{t-1})^{\chi_w}\exp(\Lambda)^{1-\chi_w}\pi_{t-1}^{\chi_w}\pi^{1-\chi_w}\right)^2 Y_t \tag{A.5}$$

Households find it costly if their nominal wage growth deviates from a combination of productivity growth $\exp(\Lambda_t)$ and inflation π_t. If $\chi_w = 0$, households find it costly to deviate from steady-state inflation and growth. If $\chi_w = 1$, households find it costly to deviate from last period's inflation and productivity growth. The other cases when $\chi_w \in [0,1]$ are intermediate. Therefore, when setting wages, households maximize:

$$\max_{W_{jt}} E_t \sum_{\tau=0}^{\infty} (\beta)^\tau \left\{ -\xi_{t+\tau}^{\mathscr{U}} \psi_{t+\tau} \frac{L_{jt+\tau}^{1+\varphi}}{1+\varphi} + \Xi_{jt+\tau}(W_{jt+\tau}L_{jt+\tau} - AC_{t+\tau}^w) \right\}$$

subject to

$$L_{jt+\tau} = \left(\frac{W_{jt+\tau}}{W_{t+\tau}}\right)^{-\varepsilon_{L,t+\tau}} L_{t+\tau}^{\mathscr{D}} \tag{A.6}$$

or, substituting the demand function (A.4) and adjustment costs, we get:

$$\max_{W_{jt}} E_t \sum_{\tau=0}^{\infty} (\beta)^{\tau} \left\{ \begin{array}{c} -\xi_{t+\tau}^{\mathscr{U}} \psi_{t+\tau} \frac{\left(\frac{W_{jt+\tau}}{W_{t+\tau}}\right)^{-(1+\varphi)\varepsilon_{L,t+\tau}}}{1+\varphi} \left(L_{t+\tau}^{\mathscr{D}}\right)^{1+\varphi} + \Xi_{jt+\tau}\left[W_{jt+\tau}\left(\frac{W_{jt+\tau}}{W_{t+\tau}}\right)^{-\varepsilon_{L,t+\tau}} L_{t+\tau}^{\mathscr{D}}\right] \\ -\Xi_{jt+\tau}\left[\frac{\theta_w}{2}\left(\frac{W_{jt+\tau}}{W_{jt+\tau-1}}\frac{P_{t+\tau}}{P_{t+\tau-1}} - \exp\left(\Lambda_{t+\tau-1}\right)^{\chi_w}\exp\left(\Lambda\right)^{1-\chi_w}\pi_{t+\tau-1}^{\chi_w}\pi^{1-\chi_w}\right)^2 Y_{t+\tau}\right] \end{array} \right\}$$

The first order condition of this problem is:

$$\left\{ \begin{array}{c} \varepsilon_{L,t}\xi_t^{\mathscr{U}}\psi_t\left(\frac{W_{jt}}{W_t}\right)^{-[1+(1+\varphi)\varepsilon_{L,t}]}\frac{\left(L_t^{\mathscr{D}}\right)^{1+\varphi}}{W_t} + (1-\varepsilon_{L,t})\Xi_{jt}\left[\left(\frac{W_{jt}}{W_t}\right)^{-\varepsilon_{L,t}} L_t^{\mathscr{D}}\right] \\ -\Xi_{jt}\left[\theta_w\left(\frac{W_{jt}}{W_{jt-1}}\frac{P_t}{P_{t-1}} - \exp\left(\Lambda_{t-1}\right)^{\chi_w}\exp\left(\Lambda\right)^{1-\chi_w}\pi_{t-1}^{\chi_w}\pi^{1-\chi_w}\right)\frac{Y_t}{W_{jt-1}}\pi_t\right] + \\ +\beta E_t\left\{\Xi_{jt+1}\left[\theta_w\left(\frac{W_{jt+1}}{W_{jt}} - \exp\left(\Lambda_t\right)^{\chi_w}\exp\left(\Lambda\right)^{1-\chi_w}\pi_t^{\chi_w}\pi^{1-\chi_w}\right)\frac{Y_{t+1}W_{t+1}}{\left(W_t\right)^2}\pi_{t+1}\right]\right\} \end{array} \right\} = 0$$

In a symmetric equilibrium, all workers set the same wage, $W_{jt} = W_t$. Hence, we can drop the j from the choice of wages:

$$\left\{ \begin{array}{c} \varepsilon_{L,t}\xi_t^{\mathscr{U}}\psi_t\left(L_t^{\mathscr{D}}\right)^{1+\varphi} + (1-\varepsilon_{L,t})\Xi_t W_t L_t^{\mathscr{D}} \\ -\Xi_t\left[\theta_w\left(\frac{W_t}{W_{t-1}} - \exp\left(\Lambda_{t-1}\right)^{\chi_w}\exp\left(\Lambda\right)^{1-\chi_w}\pi_{t-1}^{\chi_w}\pi^{1-\chi_w}\right) Y_t\frac{W_t}{W_{t-1}}\pi_t\right] + \\ +\beta E_t\left\{\Xi_{t+1}\left[\theta_w\left(\frac{W_{t+1}}{W_t} - \exp\left(\Lambda_t\right)^{\chi_w}\exp\left(\Lambda\right)^{1-\chi_w}\pi_t^{\chi_w}\pi^{1-\chi_w}\right) Y_{t+1}\frac{W_{t+1}}{W_t}\pi_{t+1}\right]\right\} \end{array} \right\} = 0 \quad \text{(A.7)}$$

A.3 Firms, Technology, and Nominal Rigidities

There are three types of goods-producing firms and one type of capital-producing firms. First, intermediate goods producers hire labor and purchase capital to produce a homogeneous good. These firms face a Calvo-type restriction when they need to upgrade the capital stock, which captures the idea that investment expenditures are lumpy (see Reiter *et al.* 2013). Second, retailers purchase these homogeneous goods and turn them into differentiated goods. These firms operate under monopolistic competition and charge a time-varying mark-up over their marginal costs. Third, final good producers purchase differentiated goods and turn them into final goods that are used for consumption, investment and government spending. Finally, capital-producing firms purchase final goods to invest in capital goods that are sold to intermediate goods producers.

A.3.1 Intermediate Goods Producers

Intermediate goods producers produce an intermediate good Y_t^M, which will be the sole input for producing the final good Y_t. Intermediate goods producers differ in the possibility to adjust the capital stock. An intermediate goods producer combines capital K_t and labor $L_t^{\mathscr{D}}$ according to the following production function:

$$Y_t^M = A_t^{(1-\alpha)} Z_t (K_{t-1})^{\alpha} (L_t^{\mathscr{D}})^{(1-\alpha)}.$$

The production is affected by two productivity shocks: a stationary shock (Z_t) and a non-stationary shock (A_t). The two shocks evolve as follows:

$$\begin{aligned} d\log(A_t) &= (1-\rho_A)\Lambda + \rho_A d\log(A_{t-1}) + \varepsilon_{A,t} \\ \log(Z_t) &= \rho_Z \log(Z_{t-1}) + \varepsilon_{Z,t}, \end{aligned}$$

where $\varepsilon_{A,t} \sim \mathscr{N}(0,\sigma_A)$and $\varepsilon_{Z,t} \sim \mathscr{N}(0,\sigma_Z)$, and $d\log()$ is the first difference and log operator.

Every period, a fraction $1-\theta_k$ of intermediate goods producers adjust their capital stock, which will become productive the following period. We denote the capital stock adjusted in the current period with $\bar{K}_t$. When adjusting to the new capital stock, intermediate goods producers purchase capital from capital good producers financed by a credit obtained from financial intermediaries. When intermediate goods producers purchase capital, they pay a constant lending rate $\bar{r}_t^L$ over the contract period. In addition, intermediate goods producers pay a fee to capital goods producers that is a constant fraction of the value of the installed capital stock, $\omega P_t^K \bar{K}_t$. As in Andreasen *et al.* (2013), one can think of these expenditures as compensation to capital producers for providing support and maintenance on the rented capital. This setup implies that physical capital exchanged between intermediate goods producers and capital producing firms is valued based on the price of capital P_t^K when a contract is signed. This way, good-producing firms do not face uncertainty about the price of capital, and the interaction between intermediate good- and capital-producing firms resembles a leasing relationship. The price at which intermediate goods are sold to retailers is P_t^M.

Intermediate goods producers are indexed by $h \in [0,1]$. While capital cannot be adjusted every period, intermediate goods producers can change their labor input $L_t^{\mathscr{D}}(h)$ every period. Hence, they solve the following maximization problem:

$$\max_{\bar{K}_t(h), L^{\mathscr{D}}_{t+j|t}(h)} E_t \sum_{j=1}^{\infty} \left\{ (\theta_k)^{j-1} \beta^j \frac{\Xi_{t+j}}{\Xi_t} \left[\frac{P^M_{t+j}}{P_{t+j}} Y^M_{t+j|t}(h) - \bar{r}^L_t \left(\prod_{i=1}^{j} \frac{P_{t+i}}{P_{t+i-1}} \right)^{-1} \frac{P^K_t}{P_t} \bar{K}_t(h) \right.\right.$$
$$\left.\left. - \quad \omega \left(\prod_{i=1}^{j} \frac{P_{t+i}}{P_{t+i-1}} \right)^{-1} \frac{P^K_t}{P_t} \bar{K}_t(h) - W_{t+j} L^{\mathscr{D}}_{t+j}(h) \right] \right\}$$

with

$$Y^M_{t+j|t}(h) = A^{(1-\alpha)}_{t+j} Z_{t+j} \left[\bar{K}_t(h)\right]^{\alpha} \left[L^{\mathscr{D}}_{t+j|t}(h)\right]^{(1-\alpha)}. \tag{A.8}$$

The time notation $t+j \mid t$ indicates production and labor demand at time $t+j$ given that the capital stock was adjusted at time t. The FOCs are given by:

$$E_t \sum_{j=1}^{\infty} \left\{ (\theta_k)^{j-1} \beta^j \frac{\Xi_{t+j}}{\Xi_t} \left[\mathscr{P}^M_{t+j} \alpha \frac{Y^M_{t+j|t}(h)}{\bar{K}_t(h)} - \frac{\left(\bar{r}^L_t + \omega\right) \mathscr{P}^K_t}{\left(\prod_{i=1}^{j} \pi_{t+i}\right)} \right] \right\} = 0, \tag{A.9}$$

$$\mathscr{P}^M_t (1-\alpha) \frac{Y^M_t(h)}{L^{\mathscr{D}}_t(h)} = W_t. \tag{A.10}$$

with $\mathscr{P}^M_t$ and $\mathscr{P}^K_t$ being the real prices of intermediate goods and capital, respectively. We can use the production function (A.8) to rewrite the labor demand (A.10):

$$\frac{K_{t-1}}{L^{\mathscr{D}}_t} = \left[\frac{1}{A^{(1-\alpha)}_t Z_t} \frac{W_t}{(1-\alpha)\mathscr{P}^M_t} \right]^{\frac{1}{\alpha}}$$

All firms can adjust their labor demand every period and they take wages as given. Therefore, firms equalize real wages with the marginal product of labor. As a result, firms' capital-labor ratios are the same, and the aggregate level of production and labor demand depend on the aggregate level of capital. Also, because the capital stock and the cost of capital are fixed until the next reoptimization takes place, it is possible that, ex-post, firms can make profits or losses (even though, ex-ante, they make zero profits). In this case, we assume that households collect profits or cover losses. Given that all intermediate goods producers which are allowed to adjust their capital stock in the current period face the same marginal product of capital, we can use the capital-labor ratio to express the demand for capital as:

$$E_t \sum_{j=1}^{\infty} \left\{ (\theta_k)^{j-1} \beta^j \frac{\Xi_{t+j}}{\Xi_t} \left\{ \alpha \mathscr{P}^M_{t+j} \left(Z_{t+j}\right)^{\frac{1}{\alpha}} \left[\frac{W_{t+j}}{(1-\alpha) A_{t+j} \mathscr{P}^M_{t+j}} \right]^{-\frac{1-\alpha}{\alpha}} - \frac{\left(\bar{r}^L_t + \omega\right) \mathscr{P}^K_t}{\left(\prod_{i=1}^{j} \pi_{t+i}\right)} \right\} \right\} = 0. \tag{A.11}$$

We can rewrite the capital demand recursively as follows:

$$\begin{aligned}
z_{1,t} &= \left(\bar{r}^L_t + \omega\right) \mathscr{P}^K_t z_{2,t} \\
z_{1,t} &= \beta E_t \left\{ \frac{\Xi_{t+1}}{\Xi_t} \alpha \mathscr{P}^M_{t+1} (Z_{t+1})^{\frac{1}{\alpha}} \left[\frac{W_{t+1}}{(1-\alpha) A_{t+1} \mathscr{P}^M_{t+1}} \right]^{-\frac{1-\alpha}{\alpha}} \right\} + \theta_k \beta E_t \left(\frac{\Xi_{t+1}}{\Xi_t} z_{1,t+1} \right) \\
z_{2,t} &= \beta E_t \left[\frac{\Xi_{t+1}}{\Xi_t} \frac{1}{\pi_{t+1}} \right] + \theta_k \beta E_t \left[\frac{\Xi_{t+1}}{\Xi_t} \frac{1}{\pi_{t+1}} z_{2,t+1} \right]
\end{aligned}$$

A.3.2 Final Good Producers

Final good producers aggregate the differentiated retail goods $Y^R_t(h)$ they buy from retailers according to the following CES function:

$$Y_t = \left[\int_0^1 Y^R_t(h)^{\frac{\varepsilon_{Y,t}-1}{\varepsilon_{Y,t}}} dh \right]^{\frac{\varepsilon_{Y,t}}{\varepsilon_{Y,t}-1}},$$

with $\varepsilon_{Y,t}$ being the price elasticity of retail goods:

$$\log(\varepsilon_{Y,t}) = (1-\rho_{\varepsilon Y}) \log(\varepsilon_Y) + \rho_{\varepsilon Y} \log(\varepsilon_{Y,t-1}) + \varepsilon_{Y,t},$$

where $\varepsilon_{Y,t} \sim \mathscr{N}(0, \sigma_Y)$. The cost minimization of final good producers leads to the demand function for retail goods:

$$Y^R_t(h) = \left[\frac{P_t(h)}{P_t} \right]^{-\varepsilon_{Y,t}} Y_t,$$

where P_t is the price index for final goods:

$$P_t = \left\{ \int_0^1 [P_t(h)]^{1-\varepsilon_{Y,t}} dh \right\}^{\frac{1}{1-\varepsilon_{Y,t}}}.$$

A.3.3 Retailers

Retailers repackage intermediate goods and create differentiated brands, at no additional cost. One unit of intermediate goods can be transferred into one unit of retail goods. Since retailers operate under monopolistic competition, each retailer indexed by $h \in [0,1]$ adds a mark-up to the marginal cost (which is given by the price of intermediate goods P_t^M) and sells its type of good $Y_t^R(h)$ at a price $P_t(h)$. Retail prices are assumed to be sticky under a Rotemberg (1982) formulation. Firms can change prices but they pay an adjustment cost (as a fraction of final output) given by:

$$AC_t^p = \frac{\theta_p}{2}\left(\frac{P_t(h)}{P_{t-1}(h)} - \pi_{t-1}^{\chi_p}\pi^{1-\chi_p}\right)^2 Y_t. \tag{A.12}$$

It is costly for firms to deviate from a combination of steady-state and last period inflation. Indexation to past inflation is controlled by the parameter $\chi_p \in [0,1]$. The retailers problem is:

$$\max_{P_t(h)} E_t \sum_{\tau=0}^{\infty} (\beta)^\tau \frac{\Xi_{t+\tau}}{\Xi_t}\left\{\left[\frac{P_{t+\tau}(h)}{P_{t+\tau}} - \mathscr{P}_{t+\tau}^M\right] Y_{t+\tau}^R(h) - AC_{t+\tau}^p\right\}$$

subject to

$$Y_{t+\tau}^R(h) = \left[\frac{P_{t+\tau}(h)}{P_{t+\tau}}\right]^{-\varepsilon_{Y,t+\tau}} Y_{t+\tau},$$

where the marginal value of a dollar to the household Ξ_t, is treated as exogenous by the firm. Since we have complete markets in securities, this marginal value is constant across households and, consequently, $\beta^\tau \Xi_{t+\tau}/\Xi_t$ is the correct valuation on future profits. Substituting the demand curve in the objective function and the previous expression, we get:

$$\max_{P_t(h)} E_t \sum_{\tau=0}^{\infty} (\beta)^\tau \frac{\Xi_{t+\tau}}{\Xi_t}\left\{\left[\frac{P_{t+\tau}(h)}{P_{t+\tau}}\right]^{1-\varepsilon_{Y,t+\tau}} - \left[\frac{P_{t+\tau}(h)}{P_{t+\tau}}\right]^{-\varepsilon_{Y,t+\tau}} \mathscr{P}_{t+\tau}^M - \frac{\theta_p}{2}\left[\frac{P_{t+\tau}(h)}{P_{t+\tau-1}(h)} - \pi_{t+\tau-1}^{\chi_p}\pi^{1-\chi_p}\right]^2\right\} Y_{t+\tau}$$

The solution $P_t(h)$ is given by the first order condition:

$$\begin{aligned}\left\{(1-\varepsilon_{Y,t})\left[\frac{P_t(h)}{P_t}\right]^{-\varepsilon_{Y,t}}\frac{1}{P_t} + \varepsilon_{Y,t}\left[\frac{P_t(h)}{P_t}\right]^{-(\varepsilon_{Y,t}+1)}\frac{\mathscr{P}_t^M}{P_t} - \left[\frac{P_t(h)}{P_{t-1}(h)} - \pi_{t-1}^{\chi_p}\pi^{1-\chi_p}\right]\frac{\theta_p}{P_{t-1}(h)}\right\} Y_t + \\ + E_t \beta \theta_p \frac{\Xi_{t+1}}{\Xi_t}\left[\frac{P_{t+1}(h)}{P_t(h)} - \pi_t^{\chi_p}\pi^{1-\chi_p}\right]\frac{P_{t+1}(h)}{[P_t(h)]^2} Y_{t+1} = 0\end{aligned}$$

In a symmetric equilibrium, $P_t(h) = P_t$:

$$\left\{ (1-\varepsilon_{Y,t}) \frac{1}{P_t} + \varepsilon_{Y,t} \frac{\mathscr{P}_t^M}{P_t} - \left(\pi_t - \pi_{t-1}^{\chi_p} \pi^{1-\chi_p} \right) \frac{\theta_p}{P_{t-1}} \right\} Y_t$$
$$+ E_t \beta \frac{\Xi_{t+1}}{\Xi_t} \left(\pi_{t+1} - \pi_t^{\chi_p} \pi^{1-\chi_p} \right) \pi_{t+1} \frac{\theta_p}{P_t} Y_{t+1} = 0$$

or

$$\left\{ (1-\varepsilon_{Y,t}) + \varepsilon_{Y,t} \mathscr{P}_t^M - \pi_t \left(\pi_t - \pi_{t-1}^{\chi_p} \pi^{1-\chi_p} \right) \theta_p \right\}$$
$$+ \theta_p E_t \beta \frac{\Xi_{t+1}}{\Xi_t} \left(\pi_{t+1} - \pi_t^{\chi_p} \pi^{1-\chi_p} \right) \pi_{t+1} \frac{Y_{t+1}}{Y_t} = 0 \tag{A.13}$$

A.3.4 Capital Goods Producers

Capital goods producers sell capital to intermediate goods producers, with an agreement to re-purchase at the original price. In addition, they provide a service for maintenance of the capital stock for which they charge a fee that is proportional to the price of capital. Let ωP_t^K denote the fee charged for a contract signed in period t. The duration of the contract is determined in the intermediate good sector. Whenever intermediate good producers adjust their capital stock, they also renegotiate the fee with capital good producers. Capital good producers solve the following maximization problem:

$$\max E_t \sum_{j=0}^{\infty} \beta^j \frac{\Xi_{t+j}}{\Xi_t} \left(\omega \frac{V_{t+j}}{P_{t+j}} - I_{t+j} \right). \tag{A.14}$$

The firm value depends on capital sold in previous periods:

$$\begin{aligned}
\frac{V_t}{P_t} &= (1-\theta_K) \sum_{j=0}^{\infty} (\theta_K)^j \frac{P_{t-j}^K}{P_t} \bar{K}_{t-j} \\
&= (1-\theta_k) \sum_{j=0}^{\infty} (\theta_k)^j \left(\prod_{i=0}^{j-1} \pi_{t-i} \right)^{-1} \mathscr{P}_{t-j}^K \bar{K}_{t-j} \\
&= (1-\theta_K) \mathscr{P}_t^K \bar{K}_t + \theta_K \frac{1}{\pi_t} \frac{V_{t-1}}{P_{t-1}}.
\end{aligned} \tag{A.15}$$

The demand for capital is given by demand for new capital and the capital stock from last period:

$$K_t = (1-\theta_K) \bar{K}_t + \theta_K K_{t-1}. \tag{A.16}$$

While the law of motion for the overall capital stock takes into account the adjustment costs for investment:

$$K_t = (1-\delta) K_{t-1} + \xi_t^I \left[1 - F\left(\frac{I_t}{I_{t-1}}\right)\right] I_t, \tag{A.17}$$

where ξ_t^I is an investment shock which follows an AR(1) process:

$$\log\left(\xi_t^I\right) = \rho_I \log\left(\xi_{t-1}^I\right) + \varepsilon_{I,t},$$

with $\varepsilon_{I,t} \sim \mathscr{N}(0, \sigma_I)$.

The maximization problem is therefore:

$$\begin{aligned}
\mathscr{L}_t \;=\; & E_t \sum_{j=0}^{\infty} \beta^j \frac{\Xi_{t+j}}{\Xi_t}\left[\omega \frac{V_{t+j}}{P_{t+j}} - I_{t+j}\right] \\
& + E_t \sum_{j=0}^{\infty} \beta^j \frac{\Xi_{t+j}}{\Xi_t} u_{1,t+j}\left[(1-\theta_K)\mathscr{P}_{t+j}^K \bar{K}_{t+j} + \theta_K \frac{1}{\pi_{t+j}} \frac{V_{t-1+j}}{P_{t-1+j}} - \frac{V_{t+j}}{P_{t+j}}\right] \\
& + E_t \sum_{j=0}^{\infty} \beta^j \frac{\Xi_{t+j}}{\Xi_t} Q_{t+j}\left[(1-\delta) K_{t-1+j} + \xi_t^I \left[1 - F\left(\frac{I_{t+j}}{I_{t-1+j}}\right)\right] I_{t+j} - K_{t+j}\right] \\
& - E_t \sum_{j=0}^{\infty} \beta^j \frac{\Xi_{t+j}}{\Xi_t} u_{2,t+j}\left[(1-\theta_K)\bar{K}_{t+j} + \theta_K K_{t-1+j} - K_{t+j}\right].
\end{aligned}$$

The FOCs for capital goods producers is given by (solving for $\frac{V_t}{P_t}, I_t, K_t, \bar{K}_t$):

$$u_{1,t} = \omega + \theta_K E_t\left[\beta \frac{\Xi_{t+1}}{\Xi_t} \frac{1}{\pi_{t+1}} u_{1,t+1}\right] \tag{A.18}$$

$$\begin{aligned}
1 = \; & Q_t \xi_t^I \left[1 - F\left(\frac{I_t}{I_{t-1}}\right) - F'\left(\frac{I_t}{I_{t-1}}\right)\frac{I_t}{I_{t-1}}\right] \\
& + \beta E_t\left[\frac{\Xi_{t+1}}{\Xi_t} Q_{t+1} \xi_{t+1}^I F'\left(\frac{I_{t+1}}{I_t}\right)\left(\frac{I_{t+1}}{I_t}\right)^2\right]
\end{aligned} \tag{A.19}$$

$$Q_t = u_{2,t} + E_t\left\{\beta \frac{\Xi_{t+1}}{\Xi_t}\left[(1-\delta) Q_{t+1} - \theta_K u_{2,t+1}\right]\right\} \tag{A.20}$$

$$u_{1,t} \mathscr{P}_t^K = u_{2,t} \tag{A.21}$$

where $u_{1,t}$ is the Lagrangian for equation (A.15), $u_{2,t}$ the Lagrangian for the demand equation (A.16), and Q_t the Lagrangian for the law of motion (A.17). The Lagrangian Q_t can also be interpreted as Tobin's Q.

A.4 Financial Intermediaries

Banks use their net worth N_t and household deposits D_t to provide credit to intermediate good producers and to purchase government bonds. We extend Gertler and Karadi (2013) by introducing long-term private and public debt. In Gertler and Karadi (2011), bankers who exit the market transfer their final period assets to the household, which in turns transfer a fraction of that amount to new bankers as "startup funds". This simple mechanism can be implement because Gertler and Karadi (2011, 2013) have one-period loans only. With long-term debt, banks hold a loan portfolio of different maturities and hence exiting bankers need to sell this portfolio when they retire. As in Andreasen *et al.* (2013), we introduce an insurance agency financed by a proportional tax on banks' profit (τ_B). When a banker retires, the role of this agency is to create a new bank with an identical asset and liability structure and effectively guarantee the outstanding contracts of the old bank. This agency therefore ensures the existence of a representative bank and that the wealth of this bank is bounded with an appropriately calibrated tax rate.

A.4.1 Corporate Long-Term Loans

The bank manages the portfolio of loans given to the private sector, which includes all loans given at a nominal amount $P^K_{t-j}\bar{K}_{t-j}$ and which pay a gross interest rate of $\bar{R}^L_{t-j}$ for each period $j = 0, 1, \ldots$. We will define the gross interest rate as $\bar{R}^L_t \equiv 1 + \bar{r}^L_t$. Aggregate real lending to the private sector len_t, which takes into account that loans mature with probability θ_k, can be recursively written as:[2]

$$
\begin{aligned}
len_t &= (1-\theta_k)\sum_{j=0}^{\infty}(\theta_k)^j\left(\prod_{i=0}^{j-1}\pi_{t-i}\right)^{-1}\mathscr{P}^K_{t-j}\bar{K}_{t-j} \\
&= (1-\theta_k)\mathscr{P}^K_t\bar{K}_t + \theta_k\frac{1}{\pi_t}len_{t-1}, \qquad \text{(A.22)}
\end{aligned}
$$

[2]Given the probability θ_k, the average maturity of loans is $(1-\theta_k)^{-1}$.

and the total real revenues rev_t earned on the portfolio are given by:

$$\begin{aligned} rev_t &= (1-\theta_k)\sum_{j=0}^{\infty}(\theta_k)^j\left(\prod_{i=0}^{j-1}\pi_{t-i}\right)^{-1} R^L_{t-j}\mathscr{P}^K_{t-1}\bar{K}_{t-j} \\ &= (1-\theta_k)\bar{R}^L_t\mathscr{P}^K_t\bar{K}_t+\theta_k\frac{1}{\pi_t}rev_{t-1}. \end{aligned} \tag{A.23}$$

We define the average return on the private sector loan portfolio by:

$$R^L_t=\frac{rev_t}{len_t}, \tag{A.24}$$

which is a weighted average of past long-term loan interest rates.

A.4.2 Long-Term Government Bonds

We introduce long-term government debt in a similar way than private sector debt. Each period, the government issues new debt B^N_t with a gross interest rate $\bar{R}^G_t$. Once the security is issued, it pays the net interest rate $\bar{r}^G_t=\bar{R}^G_t-1$ each period. In addition, the principal is paid to the holder with probability $1-\theta_g$. This implies that the average duration of the government bond is $(1-\theta_g)^{-1}$. The law of motion of government bonds is therefore:

$$B_t=\theta_g B_{t-1}+B^N_t. \tag{A.25}$$

Without loss of generality, and to use the same notation as with private sector bonds, let's denote $B^N_t=(1-\theta_g)\bar{B}_t$. Then, aggregate real lending to the government evolves as:

$$\begin{aligned} b_t &= (1-\theta_g)\sum_{j=0}^{\infty}(\theta_g)^j\left(\prod_{i=0}^{j-1}\frac{P_{t-i}}{P_{t-1-i}}\right)^{-1}\bar{b}_{t-j} \\ &= (1-\theta_g)\bar{b}_t+\theta_g\frac{P_{t-1}}{P_t}b_{t-1}, \end{aligned} \tag{A.26}$$

where $b_t = B_t/P_t$ and $\bar{b}_t = \bar{B}_t/P_t$, while the real revenues from the portfolio of government bonds are:

$$
\begin{aligned}
rev_t^G &= (1-\theta_g)\sum_{j=0}^{\infty}(\theta_g)^j \bar{R}_{t-j}^G \frac{\bar{B}_{t-j}}{P_t} \\
&= (1-\theta_g)\sum_{j=0}^{\infty}(\theta_g)^j \left(\prod_{i=0}^{j-1}\pi_{t-i}\right)^{-1} \bar{R}_{t-j}^G \bar{B}_{t-j} \\
&= (1-\theta_g)\bar{R}_t^G \bar{b}_t + \theta_g \frac{1}{\pi_t} rev_{t-1}^G. \qquad \text{(A.27)}
\end{aligned}
$$

We define the average return on the private sector loan portfolio by:

$$
R_t^G = \frac{rev_t^G}{b_t}, \qquad \text{(A.28)}
$$

which is a weighted average of past long-term government bond interest rates.

A.4.3 Banking Sector

We proceed to solve the financial intermediaries problem as in Gertler and Karadi (2013). Banks provide loans len_t to intermediate firms and buy government debt b_t. These real asset holdings are financed through the real net worth of the bank n_t and real deposits d_t collected from households. The balance sheet the financial intermediary is given by:

$$
len_t + b_t = n_t + d_t, \qquad \text{(A.29)}
$$

with:

$$
\begin{aligned}
n_t &\equiv \frac{N_t}{P_t} \\
d_t &\equiv \frac{D_t}{P_t}.
\end{aligned}
$$

We solve the model using the same methods as Gertler and Kiyotaki (2010). Net worth of banks (or bank capital) evolves as:

$$
n_t = (1-\tau_B)[R_{t-1}^L \frac{1}{\pi_t} len_{t-1} + R_{t-1}^G \frac{1}{\pi_t} b_{t-1} - R_{t-1}\frac{1}{\pi_t} d_{t-1}] \exp(\varepsilon_{nw,t}) \qquad \text{(A.30)}
$$

where $\varepsilon_{nw,t} \sim \mathcal{N}(0, \sigma_{nw})$ is a shock to bank net worth. Banks earn the average return R^L_{t-1} and R^G_{t-1} on their loan portfolio and government bond holdings, respectively. The funding rate of banks is given by the deposit rate R_{t-1}. We assume that banks pay a fraction τ_B of their assets to an insurance company that manages the transfer of assets from retiring bankers to new bankers. Since bankers have to exit the market at the end of each period with probability $1-\theta_B$, they maximize their expected terminal wealth when they retire:

$$\mathcal{V}_t = (1-\tau_B) E_t \sum_{j=0}^{\infty} (1-\theta_B)(\theta_B)^{j-1} \beta^{t+j} \frac{\Xi_{t+j}}{\Xi_t} n_{t+j}.$$

Whenever a banker retires, $\mathcal{V}_t$ is transferred as a dividend to the household the banker belongs to. We assume an agency problem between banks and depositors, as bankers can divert a certain fraction of assets and transfer them to the household they belong to. When a banker embezzles assets, the bank will be closed and the remaining fraction of assets serves as bankruptcy assets, which are distributed among depositors. Depositors are only willing to provide funding to a bank as long as the banker has no incentive to divert assets. To ensure this, the value of the bank $\mathcal{V}_t$ needs to exceed the gain a banker receives by embezzling assets:

$$\mathcal{V}_t \geq \lambda_t (len_t + \Delta_t b_t), \tag{A.31}$$

with λ_t being the fractions of the loans which can be diverted and $\lambda_t \Delta_t$ being the fraction of the bank's holdings of government bonds that bankers can embezzle. The Bellman equation to the maximization problem of the banker at period $t-1$ satisfies:

$$\mathcal{V}_{t-1}(len_{t-1}, b_{t-1}, d_{t-1}) = E_{t-1} \beta \frac{\Xi_t}{\Xi_{t-1}} \left[(1-\tau_B)(1-\theta_B) n_t + \theta_B \max \mathcal{V}_t (len_t, b_t, d_t) \right]. \tag{A.32}$$

To solve the maximization problem we first guess that the value function can be expressed as a linear function:

$$\begin{aligned} \mathcal{V}_t(len_t, b_t, d_t) &= \mathcal{V}^L_t len_t + \mathcal{V}^B_t b_t - \mathcal{V}^D_t d_t \qquad (A.33) \\ s.t. \mathcal{V}_t(len_t, b_t, d_t) &\geq \lambda_t (len_t + \Delta_t b_t), \end{aligned}$$

where $\mathscr{V}_t^L$, $\mathscr{V}_t^B$, and $\mathscr{V}_t^D$ are the marginal value of loans, the marginal value of government bond, and the marginal costs of deposits, respectively (measured at the end of the period, i.e. after the insurance premium was paid). The maximization problem then takes the following form (after plugging in the balance sheet constraint (A.29)):

$$\max \mathscr{V}_t^L len_t + \mathscr{V}_t^B \left[n_t + d_t - len_t\right] - \mathscr{V}_t^D d_t + \Theta_t \left[\mathscr{V}_t \left(len_t, b_t, d_t\right) - \lambda_t len_t - \lambda_t \Delta_t \left(n_t + d_t - len_t\right)\right],$$

where Θ_t is the Lagrange multiplier associated with the participation constraint (A.31). The FOCs for len_t and d_t become:

$$\begin{aligned} \mathscr{V}_t^L + \Theta_t \left(\mathscr{V}_t^L - \lambda_t\right) &= \mathscr{V}_t^B + \Theta_t \left(\mathscr{V}_t^B - \lambda_t \Delta_t\right) && \text{(A.34)} \\ \mathscr{V}_t^D + \Theta_t \mathscr{V}_t^D &= \mathscr{V}_t^B + \Theta_t \left(\mathscr{V}_t^B - \lambda_t \Delta_t\right). && \text{(A.35)} \end{aligned}$$

Equation (A.34) equates the marginal value of loans and the marginal value of government bonds. Extending loans to the corporate sector increases the value of the bank by $\mathscr{V}_t^L$. At the same time, it relaxes the incentive constraint (A.31) by $\left(\mathscr{V}_t^L - \lambda_t\right)$, which in turn increases the value of the bank by the factor Θ_t. Similarly, an additional unit of government bonds directly increases the value of the bank by $\mathscr{V}_t^B$ with a further increase by $\Theta_t \left(\mathscr{V}_t^B - \lambda_t \Delta_t\right)$ due to the relaxation of the incentive constraint. For $\Delta_t = 1$, corporate loans and government bonds become perfect substitutes and the marginal value of these assets become identical. Equation (A.35) relates the marginal costs of deposits with the marginal value of government bonds. Increased funding via deposits come at costs of $\mathscr{V}_t^D$ and tightens the incentive constraint by the same amount. The latter affects the value of the bank by the factor Θ_t.

The FOC for Θ_t is given by the incentive constraint (A.31):

$$len_t \leq \frac{1}{\lambda_t \left(1 - \Delta_t\right) - \left(\mathscr{V}_t^L - \mathscr{V}_t^B\right)} \left[\left(\mathscr{V}_t^B - \lambda_t \Delta_t\right) n_t + \left(\mathscr{V}_t^B - \mathscr{V}_t^D - \lambda_t \Delta_t\right) d_t\right],$$

which together with equation (A.35) and (A.34) can be expressed as:

$$len_t \leq \frac{\Theta_t}{\mathscr{V}_t^L - \mathscr{V}_t^B} \left[\left(\mathscr{V}_t^B - \lambda_t \Delta_t\right) n_t - \frac{\lambda_t \Delta_t}{1 + \Theta_t} d_t\right]. \tag{A.36}$$

When the incentive constraint is binding, i.e. $\Theta_t > 0$, equation (A.36) holds with equality. We need to solve the optimization problem of bankers in order to relate the marginal values $\mathcal{V}_t^L$ and $\mathcal{V}_t^B$ as well as the marginal cost $\mathcal{V}_t^D$ with the corresponding interest rates R_t^L, R_t^G, and R_t. To do so, we we bring together the value function (A.33) with the FOC (A.35) and (A.36):

$$\begin{aligned}\mathcal{V}_t &= \Theta_t\left[\left(\mathcal{V}_t^B - \lambda_t\Delta_t\right)n_t - \frac{\lambda_t\Delta_t}{1+\Theta_t}d_t\right] + \mathcal{V}_t^B n_t + \frac{\lambda_t\Delta_t\Theta_t}{1+\Theta_t}d_t \\ &= \left[\mathcal{V}_t^B + \Theta_t\left(\mathcal{V}_t^B - \lambda_t\Delta_t\right)\right]n_t.\end{aligned}$$

This expression above can be used to rewrite the Belman equation (A.32):

$$\begin{aligned}\mathcal{V}_{t-1} &= E_{t-1}\beta\frac{\Xi_t}{\Xi_{t-1}}\left\{(1-\tau_B)(1-\theta_B)n_t + \theta_B \max \mathcal{V}_t\right\} \\ &= E_{t-1}\beta\frac{\Xi_t}{\Xi_{t-1}}\left\{(1-\tau_B)(1-\theta_B)n_t + \theta_B\left[\mathcal{V}_t^B + \Theta_t\left(\mathcal{V}_t^B - \lambda_t\Delta_t\right)\right]n_t\right\}.\end{aligned}$$

In order to proceed further, we define the shadow value of a unit of net worth as:

$$\Omega_t \equiv (1-\tau_B)(1-\theta_B) + \theta_B\left[\mathcal{V}_t^B + \Theta_t\left(\mathcal{V}_t^B - \lambda_t\Delta_t\right)\right]. \tag{A.37}$$

The shadow value Ω_t is a weighted average of the marginal value of net worth for exiting and for continuing banks. With probability $1-\theta_B$ a banker exits and pays the bank capital (net of the insurance premium τ_B), which has been accumulated until that period, as a dividend to households. With probability θ_B the bank stays active and an additional unit of net worth can be used to increase the portfolio holdings which increases the value of the bank by $\mathcal{V}_t^B + \Theta_t\left(\mathcal{V}_t^B - \lambda_t\Delta_t\right)$. Together with the law of motion for net worth (A.30) we can finally express the value function as:

$$\mathcal{V}_t = \mathcal{V}_t^L len_t + \mathcal{V}_t^B b_t - \mathcal{V}_t^D D_t = E_t\beta\frac{\Xi_{t+1}}{\Xi_t}\Omega_{t+1}(1-\tau_B)\left[R_t^L\frac{1}{\pi_{t+1}}len_t + R_{t+1}^B\frac{1}{\pi_{t+1}}b_t - R_t\frac{1}{\pi_{t+1}}d_t\right].$$

The product $E_t\beta\frac{\Xi_{t+1}}{\Xi_t}\Omega_{t+1}$ can be interpreted as the *augmented stochastic discount factor*. It includes the standard stochastic discount factor $\beta\frac{\Xi_{t+1}}{\Xi_t}$ weighted by the future marginal value of net worth Ω_{t+1}. Applying the method of undetermined coefficients, we can find the solutions for $\mathcal{V}_t^L$,

$\mathcal{V}_t^B$, and $\mathcal{V}_t^D$:

$$
\begin{aligned}
\mathcal{V}_t^L &= (1-\tau_B)E_t\beta\frac{\Xi_{t+1}}{\Xi_t}\Omega_{t+1}R_t^L\frac{1}{\pi_{t+1}} \\
\mathcal{V}_t^B &= (1-\tau_B)E_t\beta\frac{\Xi_{t+1}}{\Xi_t}\Omega_{t+1}R_t^G\frac{1}{\pi_{t+1}} \\
\mathcal{V}_t^D &= (1-\tau_B)E_t\beta\frac{\Xi_{t+1}}{\Xi_t}\Omega_{t+1}R_t\frac{1}{\pi_{t+1}}.
\end{aligned}
$$

Note that we measure $\mathcal{V}_t^L$, $\mathcal{V}_t^B$, and $\mathcal{V}_t^D$ after the insurance premium was paid. We express the expected excess value of a unit of an asset relative to deposits as:

$$
\begin{aligned}
\mu_t^L &\equiv \mathcal{V}_t^L - \mathcal{V}_t^D = (1-\tau_B)E_t\beta\frac{\Xi_{t+1}}{\Xi_t}\Omega_{t+1}\left(R_t^L - R_t\right)\frac{1}{\pi_{t+1}} \\
\mu_t^B &\equiv \frac{\mathcal{V}_t^B}{Q_t^B} - \mathcal{V}_t^D = (1-\tau_B)E_t\beta\frac{\Xi_{t+1}}{\Xi_t}\Omega_{t+1}\left(R_t^G - R_t\right)\frac{1}{\pi_{t+1}}
\end{aligned}
$$

Together with the two FOCs (A.35) and (A.34) we can show that $\mu_t^B = \Delta_t\mu_t^L$ which implies that expected excess returns on the portfolio and government bonds satisfy:

$$
(1-\tau_B)E_t\beta\frac{\Xi_{t+1}}{\Xi_t}\Omega_{t+1}\left(R_t^L - R_t\right)\frac{P_t}{P_{t+1}} = \lambda_t\frac{\Theta_t}{1+\Theta_t} \tag{A.38}
$$

$$
(1-\tau_B)E_t\beta\frac{\Xi_{t+1}}{\Xi_t}\Omega_{t+1}\left(R_t^G - R_t\right)\frac{P_t}{P_{t+1}} = \lambda_t\Delta_t\frac{\Theta_t}{1+\Theta_t}. \tag{A.39}
$$

According to the equations (A.38)-(A.39), whenever the participation constraint (A.31) holds with equality ($\Theta_t > 0$) the average lending rates for both the public and private sector debt are larger than the short-term funding rate (i.e. the deposit rate). More importantly, combining the two expressions we obtain a relationship between private and public sector spreads:

$$
\left(R_t^G - R_t\right) = \Delta_t\left(R_t^L - R_t\right),
$$

where the relationship is stochastic as long as Δ_t is stochastic.

As a next step, we want to define the optimal leverage ratio. Taking again the incentive constraint for bankers:

$$
\mathcal{V}_t^L len_t + \mathcal{V}_t^B b_t - \mathcal{V}_t^D d_t \geq \lambda_t len_t + \lambda_t\Delta_t b_t
$$

and replacing d_t with the balance sheet identity, using the definition for μ_t^B and μ_t^L, as well as using the fact that $\mu_t^B = \Delta_t \mu_t^L$, we can show that:

$$\left(\lambda_t - \mu_t^L\right) len_t + \left(\lambda_t - \mu_t^L\right) \Delta_t b_t \leq \mathscr{V}_t^D n_t.$$

Expressing the proportion of the government bond holdings relative to the value of the loan portfolio as:

$$x_t = \frac{b_t}{len_t}, \tag{A.40}$$

we can rewrite the expression above as:

$$len_t \leq \frac{\mathscr{V}_t^D}{(1 + x_t \Delta_t)\left(\lambda_t - \mu_t^L\right)} n_t.$$

Finally, we define the optimal leverage ratio (defined as loans to the private sector over bank capital) as:

$$\phi_t \equiv \frac{\mathscr{V}_t^D}{(1 + x_t \Delta_t)\left(\lambda_t - \mu_t^L\right)}. \tag{A.41}$$

We can use the FOC (A.35) and the leverage ratio (A.41) to rewrite the shadow value of a unit of net worth (A.37):

$$\Omega_t = (1 - \tau_B)(1 - \theta_B) + \theta_B \left[\mathscr{V}_t^D + \Theta_t \mathscr{V}_t^D\right].$$

Since $\mu_t^B = \Delta_t \mu_t^L$ together with equation (A.35), we can express the Lagrange parameter as $\Theta_t = \mu_t^L / \left(\lambda_t - \mu_t^L\right)$. Together with the definition of the leverage ratio (A.41) we finally arrive at:

$$\Omega_t = (1 - \tau_B)(1 - \theta_B) + \theta_B \left[\mathscr{V}_t^D + (1 + x_t \Delta_t) \phi_t \mu_t^L\right].$$

Finally, bringing together the balance sheet identity (A.29) and the law of motion for net worth (A.30), net worth evolves as:

$$n_t = (1 - \tau_B) \left[\left(R_{t-1}^L - R_{t-1}\right) \frac{1}{\pi_t} len_{t-1} + \left(R_{t-1}^G - R_{t-1}\right) \frac{1}{\pi_t} b_{t-1} + R_{t-1} \frac{1}{\pi_t} n_{t-1}\right] \exp\left(\varepsilon_{nw,t}\right).$$

Together with the ratio (A.40) and the definition of the optimal leverage ratio (A.41), the law of motion becomes:

$$n_t = (1-\tau_B)\left[\left(R^L_{t-1}-R_{t-1}\right)\phi_{t-1}+\left(R^G_{t-1}-R_{t-1}\right)\phi_{t-1}x_{t-1}+R_{t-1}\right]\frac{1}{\pi_t}n_{t-1}\exp\left(\varepsilon_{nw,t}\right).$$

A.5 The Government

The government sets the nominal interest rates according to a Taylor rule:

$$\frac{R_t}{R}=\left(\frac{R_{t-1}}{R}\right)^{\gamma_R}\left(\frac{\pi_t}{\pi}\right)^{\gamma_\Pi(1-\gamma_R)}\left[\frac{Y_t/Y_{t-1}}{\exp(\Lambda)}\right]^{\gamma_y(1-\gamma_R)}\exp\left(\varepsilon_{m,t}\right), \tag{A.42}$$

where the term $\varepsilon_{m,t}\sim\mathcal{N}(0,\sigma_m)$ is a monetary policy shock.

Government spending to GDP follows a stationary AR(2) process:

$$G_t = g_t Y_t \tag{A.43}$$

with

$$\log g_t = (1-\rho_{g_1}-\rho_{g_2})\log(g)+\rho_{g_1}\log g_{t-1}+\rho_{g_2}\log g_{t-2}+\varepsilon_{g,t}$$

where $\varepsilon_{g,t}\sim\mathcal{N}(0,\sigma_g)$ is a shock to goverment spending. The choice of an AR(2) process is empirical, and we discuss the calibration in the paper.

We also assume that the supply of government bonds is exogenous with an AR(1) process. Implicitly we assume that given a path for exogenous government spending and debt/GDP ratio, the government will adjust lump-sum transfers T_t such that the government budget constraint holds:

$$\frac{b_t}{Y_t}=(1-\rho_b)\frac{b}{Y}+\rho_b\frac{b_{t-1}}{Y_{t-1}}+\varepsilon_{b,t}$$

where $\varepsilon_{b,t}\sim\mathcal{N}(0,\sigma_b)$ is a shock to the supply of government bonds.

A.6 Aggregation

Market clearing:

$$C_t+I_t+G_t+AC^p_t+AC^w_t=Y_t. \tag{A.44}$$

where the expressions for price and wage adjustment costs are given by equation (A.5) and (A.12), respectively. The labor and intermediate goods market clearing conditions are:

$$\int_0^1 L_t^{\mathscr{D}}(h)dh = L_t^{\mathscr{D}} = L_t. \tag{A.45}$$

$$\int_0^1 Y_t^M(h)dh = Y_t^M = Y_t. \tag{A.46}$$

B Equilibrium

The consumption Euler equation:

$$\Xi_t = \frac{\xi_t^{\mathscr{U}}}{C_t - hC_{t-1}} - E_t\beta\xi_{t+1}^{\mathscr{U}}\frac{h}{C_{t+1} - hC_t}$$
$$\Xi_t = \mathbb{E}_t\left(\beta\frac{\Xi_{t+1}}{\pi_{t+1}}R_t\right)$$

Financial Intermediaries:

$$x_t = b_t/len_t$$

$$n_t = (1-\tau_B)[(R_{t-1}^L - R_{t-1})\phi_{t-1} + (R_{t-1}^G - R_{t-1})\phi_{t-1}x_{t-1} + R_{t-1}]\frac{n_{t-1}}{\pi_t}\exp(\varepsilon_{nw,t})$$

$$\begin{aligned}
\mu_t^L &\equiv \mathscr{V}_t^L - \mathscr{V}_t^D = (1-\tau_B)E_t\beta\frac{\Xi_{t+1}}{\Xi_t}\Omega_{t+1}\frac{R_t^L - R_t}{\pi_{t+1}} \\
\mu_t^B &\equiv \frac{\mathscr{V}_t^B}{Q_t^B} - \mathscr{V}_t^D = (1-\tau_B)E_t\beta\frac{\Xi_{t+1}}{\Xi_t}\Omega_{t+1}\frac{R_t^G - R_t}{\pi_{t+1}}
\end{aligned}$$

$$\mu_t^B = \Delta_t\mu_t^L$$

$$\mathscr{V}_t^D = (1-\tau_B)E_t\beta\frac{\Xi_{t+1}}{\Xi_t}\Omega_{t+1}\frac{R_t}{\pi_{t+1}}$$

$$\Omega_t = (1-\tau_B)(1-\theta_B) + \theta_B\left[\mathscr{V}_t^D + (1+x_t\Delta_t)\phi_t\mu_t^L\right]$$

$$len_t = (1-\theta_k)\mathscr{P}_t^K\bar{K}_t + \theta_k\frac{len_{t-1}}{\pi_t}$$

$$rev_t = (1-\theta_k)\,\bar{R}^L_t \mathscr{P}^K_t \bar{K}_t + \theta_k \frac{rev_{t-1}}{\pi_t}$$

$$R^L_t = \frac{rev_t}{len_t}$$

$$b_t = (1-\theta_g)\,\bar{b}_t + \theta_g \frac{b_{t-1}}{\pi_t}$$

$$rev^G_t = (1-\theta_g)\,\bar{R}^G_t \bar{B}_t + \theta_g \frac{rev^G_{t-1}}{\pi_t}$$

$$R^G_t = \frac{rev^G_t}{b_t}$$

$$\phi_t = \frac{len_t}{n_t}$$

$$\phi_t = \frac{\mathscr{V}_t}{(1+x_t\Delta_t)\left(\lambda_t - \mu^L_t\right)}.$$

Wages are given by:

$$\begin{array}{rl}
\varepsilon_{L,t}\xi^{\mathscr{U}}_t\,\psi_t\left(L^{\mathscr{D}}_t\right)^{1+\varphi} + (1-\varepsilon_{L,t})\Xi_t W_t L^{\mathscr{D}}_t & \\
-\Xi_t\left[\theta_w\left(\frac{W_t}{W_{t-1}} - \exp\left(\Lambda_{t-1}\right)^{\chi_w}\exp\left(\Lambda\right)^{1-\chi_w}\pi^{\chi_w}_{t-1}\pi^{1-\chi_w}\right)Y_t\frac{W_t}{W_{t-1}}\pi_t\right] + & = 0 \\
+\beta E_t\left\{\Xi_{t+1}\left[\theta_w\left(\frac{W_{t+1}}{W_t} - \exp\left(\Lambda_t\right)^{\chi_w}\exp\left(\Lambda\right)^{1-\chi_w}\pi^{\chi_w}_t\pi^{1-\chi_w}\right)Y_{t+1}\frac{W_{t+1}}{W_t}\pi_{t+1}\right]\right\} &
\end{array}$$

Prices are set according to:

$$\left\{(1-\varepsilon_{Y,t}) + \varepsilon_{Y,t}\mathscr{P}^M_t - \pi_t\left(\pi_t - \pi^{\chi_p}_{t-1}\pi^{1-\chi_p}\right)\theta_p\right\} +$$
$$+\theta_p E_t\beta\frac{\Xi_{t+1}}{\Xi_t}\left(\pi_{t+1} - \pi^{\chi_p}_t\pi^{1-\chi_p}\right)\pi_{t+1}\frac{Y_{t+1}}{Y_t} = 0$$

The firms problem:

$$Y^M_t = A^{(1-\alpha)}_t Z_t\left(K_{t-1}\right)^{\alpha}\left(L^{\mathscr{D}}_t\right)^{(1-\alpha)}.$$

$$\mathscr{P}^M_t\,(1-\alpha)\,\frac{Y^M_t}{L^{\mathscr{D}}_t} = W_t$$

$$
\begin{aligned}
z_{1,t} &= \left(\bar{r}_t^L + \omega\right) \mathscr{P}_t^K z_{2,t} \\
z_{1,t} &= \beta E_t \left\{ \frac{\Xi_{t+1}}{\Xi_t} \alpha \mathscr{P}_{t+1}^M \left(Z_{t+1}\right)^{\frac{1}{\alpha}} \left[\frac{W_{t+1}}{(1-\alpha) A_{t+1} \mathscr{P}_{t+1}^M} \right]^{-\frac{1-\alpha}{\alpha}} \right\} + \theta_k \beta E_t \left[\frac{\Xi_{t+1}}{\Xi_t} z_{1,t+1} \right] \\
z_{2,t} &= \beta E_t \left\{ \frac{\Xi_{t+1}}{\Xi_t} \frac{1}{\pi_{t+1}} \right\} + \theta_k \beta E_t \left[\frac{\Xi_{t+1}}{\Xi_t} \frac{1}{\pi_{t+1}} z_{2,t+1} \right]
\end{aligned}
$$

where

$$
\bar{r}_t^L = \bar{R}_t^L - 1
$$

$$
K_t = (1-\delta) K_{t-1} + \xi_t^I \left[1 - \digamma \left(\frac{I_t}{I_{t-1}} \right) \right] I_t
$$

$$
K_t = (1-\theta_k) \bar{K}_t + \theta_k K_{t-1}
$$

$$
\begin{aligned}
u_{1,t} &= \omega + \theta_k E_t \left[\beta \frac{\Xi_{t+1}}{\Xi_t} \frac{1}{\pi_{t+1}} u_{1,t+1} \right] \\
1 &= Q_t \xi_t^I \left[1 - \digamma \left(\frac{I_t}{I_{t-1}} \right) - \digamma' \left(\frac{I_t}{I_{t-1}} \right) \frac{I_t}{I_{t-1}} \right] \\
&\quad + \beta E_t \left[\frac{\Xi_{t+1}}{\Xi_t} Q_{t+1} \xi_{t+1}^I \digamma' \left(\frac{I_{t+1}}{I_t} \right) \left(\frac{I_{t+1}}{I_t} \right)^2 \right] \\
Q_t &= u_{2,t} + E_t \left\{ \beta \frac{\Xi_{t+1}}{\Xi_t} \left[(1-\delta) Q_{t+1} - \theta_k u_{2,t+1} \right] \right\} \\
u_{1,t} \mathscr{P}_t^K &= u_{2,t}
\end{aligned}
$$

Government policies:

$$
\frac{R_t}{R} = \left(\frac{R_{t-1}}{R} \right)^{\gamma_R} \left(\frac{\pi_t}{\pi} \right)^{\gamma_\Pi (1-\gamma_R)} \left[\frac{Y_t / Y_{t-1}}{\exp(\Lambda)} \right]^{\gamma_y (1-\gamma_R)} \exp\left(\varepsilon_{m,t}\right)
$$

$$
G_t = g_t Y_t
$$

$$
\frac{b_t}{Y_t} = (1-\rho_b) \frac{b}{Y} + \rho_b \frac{b_{t-1}}{Y_{t-1}} + \varepsilon_{b,t}
$$

Markets clear:

$$
C_t + I_t + G_t + AC_t^p + AC_t^w = Y_t .
$$

where

$$AC_t^p = \frac{\theta_p}{2}\left(\pi_t - \pi_{t-1}^{\chi_p}\pi^{1-\chi_p}\right)^2 Y_t$$

$$AC_t^w = \frac{\theta_w}{2}\left(\frac{W_t}{W_{t-1}}\frac{P_t}{P_{t-1}} - \exp\left(\Lambda_{t-1}\right)^{\chi_w}\exp\left(\Lambda\right)^{1-\chi_w}\pi_{t-1}^{\chi_w}\pi^{1-\chi_w}\right)^2 Y_t$$

and

$$L_t^{\mathscr{D}} = L_t$$

$$Y_t^M = Y_t$$

Shock Processes:

$$\begin{aligned}
d\log\left(A_t\right) &= (1-\rho_A)\Lambda + \rho_A d\log\left(A_{t-1}\right) + \varepsilon_{A,t} \\
\log\left(Z_t\right) &= \rho_Z \log\left(Z_{t-1}\right) + \varepsilon_{Z,t} \\
\log\left(\xi_t^I\right) &= \rho_I \log\left(\xi_{t-1}^I\right) + \varepsilon_{I,t} \\
\log\left(\xi_t^{\mathscr{U}}\right) &= \rho_{\mathscr{U}} \log\left(\xi_{t-1}^{\mathscr{U}}\right) + \varepsilon_{\mathscr{U},t} \\
\log\left(\psi_t\right) &= \left(1-\rho_\psi\right)\psi + \rho_\psi \log\left(\psi_{t-1}\right) + \varepsilon_{\psi,t} \\
\log\left(\lambda_t\right) &= \left(1-\rho_\lambda\right)\lambda + \rho_\lambda \log\left(\lambda_{t-1}\right) + \varepsilon_{\lambda,t} \\
\log\left(\varepsilon_{L,t}\right) &= \log\left(\varepsilon_L\right) + \varepsilon_{L,t} \\
\log\left(\varepsilon_{Y,t}\right) &= \left(1-\rho_{\varepsilon Y}\right)\log\left(\varepsilon_Y\right) + \rho_{\varepsilon Y}\log\left(\varepsilon_{Y,t-1}\right) + \varepsilon_{Y,t} \\
\log(\Delta_t) &= \left(1-\rho_\Delta\right)\log(\Delta) + \rho_\Delta \log(\Delta_{t-1}) + \varepsilon_{\Delta,t} \\
\log(g_t) &= \left(1-\rho_{g_1}-\rho_{g_2}\right)\log(g) + \rho_{g_1}\log(g_{t-1}) + \rho_{g_2}\log(g_{t-2}) + \varepsilon_{g,t} \\
\frac{b_t}{Y_t} &= \left(1-\rho_b\right)\frac{b}{Y} + \rho_b \frac{b_{t-1}}{Y_{t-1}} + \varepsilon_{b,t}
\end{aligned}$$

As in Justiniano *et al.* (2013), we assume in the estimation that the shock to the elasticity of substitution of labor types is iid, and hence $\rho_{\varepsilon L} = 0$.

C Stationary Equilibrium

Since we include a unit-root shock in technology, we normalize all variables which inherit the unit root behavior. So, for instance,

$$\tilde{C}_t \equiv C_t/A_t.$$

Also, we define

$$\Lambda_t = d\log(A_t)$$

where $d\log(.)$ is the first-difference log operator.

The first order conditions of the household:

$$\tilde{\Xi}_t = \frac{\xi_t^{\mathscr{U}}}{\tilde{C}_t - h\frac{\tilde{C}_{t-1}}{\exp(\Lambda_t)}} - E_t\beta\xi_{t+1}^{\mathscr{U}}\frac{h}{\exp(\Lambda_{t+1})\tilde{C}_{t+1} - h\tilde{C}_t} \tag{C.1}$$

$$\tilde{\Xi}_t = \mathbb{E}_t\left(\beta\frac{\tilde{\Xi}_{t+1}}{\exp(\Lambda_{t+1})\pi_{t+1}}R_t\right) \tag{C.2}$$

Financial Intermediaries:

$$x_t = \tilde{b}_t/\widetilde{len_t} \tag{C.3}$$

$$\tilde{n}_t = (1-\tau_B)[(R_{t-1}^L - R_{t-1})\phi_{t-1} + (R_{t-1}^G - R_{t-1})\phi_{t-1}x_{t-1} + R_{t-1}]\frac{\tilde{n}_{t-1}}{\exp(\Lambda_t)\pi_t}\exp(\varepsilon_{nw,t}) \tag{C.4}$$

$$\mu_t^L \equiv (1-\tau_B)E_t\beta\frac{\tilde{\Xi}_{t+1}}{\tilde{\Xi}_t\exp(\Lambda_{t+1})}\Omega_{t+1}\frac{\left(R_t^L - R_t\right)}{\pi_{t+1}} \tag{C.5}$$

$$\mu_t^B \equiv (1-\tau_B)E_t\beta\frac{\tilde{\Xi}_{t+1}}{\tilde{\Xi}_t\exp(\Lambda_{t+1})}\Omega_{t+1}\frac{\left(R_t^G - R_t\right)}{\pi_{t+1}} \tag{C.6}$$

$$\mu_t^B = \Delta_t\mu_t^L \tag{C.7}$$

$$\mathscr{V}_t^D = (1-\tau_B)E_t\beta\frac{\tilde{\Xi}_{t+1}}{\tilde{\Xi}_t\exp(\Lambda_{t+1})}\Omega_{t+1}\frac{R_t}{\pi_{t+1}} \tag{C.8}$$

$$\Omega_t = (1-\tau_B)(1-\theta_B) + \theta_B\left[\mathscr{V}_t^D + (1+x_t\Delta_t)\phi_t\mu_t^L\right] \tag{C.9}$$

$$\widetilde{len}_t = (1-\theta_k)\,\mathscr{P}_t^K \bar{K}_t + \frac{\theta_k}{\pi_t}\frac{\widetilde{len}_{t-1}}{\exp(\Lambda_t)} \tag{C.10}$$

$$\widetilde{rev}_t = (1-\theta_k)\,\bar{R}_t^L \mathscr{P}_t^K \bar{K}_t + \frac{\theta_k}{\pi_t}\frac{\widetilde{rev}_{t-1}}{\exp(\Lambda_t)} \tag{C.11}$$

$$R_t^L = \frac{\widetilde{rev}_t}{\widetilde{len}_t} \tag{C.12}$$

$$\tilde{b}_t \quad = \quad (1-\theta_g)\,\tilde{\bar{b}}_t + \frac{\theta_g}{\pi_t}\frac{\tilde{b}_{t-1}}{\exp(\Lambda_t)} \tag{C.13}$$

$$\widetilde{rev}_t^G \quad = \quad (1-\theta_g)\,\bar{R}_t^G \tilde{\bar{b}}_t + \frac{\theta_g}{\pi_t}\frac{\widetilde{rev}_{t-1}^G}{\exp(\Lambda_t)} \tag{C.14}$$

$$R_t^G = \frac{\widetilde{rev}_t^G}{\tilde{b}_t} \tag{C.15}$$

$$\phi_t = \frac{\widetilde{len}_t}{\tilde{n}_t} \tag{C.16}$$

$$\phi_t = \frac{\mathscr{V}_t}{(1+x_t\Delta_t)\left(\lambda_t - \mu_t^L\right)}. \tag{C.17}$$

Wages are given by:

$$\left\{ \begin{array}{c} \varepsilon_{L,t}\xi_t^{\mathscr{U}}\,\psi_t\left(L_t^{\mathscr{D}}\right)^{1+\varphi} + (1-\varepsilon_{L,t})\tilde{\Xi}_t\tilde{W}_t L_t^{\mathscr{D}} \\ -\tilde{\Xi}_t\left[\theta_w\left(\frac{\tilde{W}_t}{\tilde{W}_{t-1}}\exp(\Lambda_t)\pi_t - \exp\left(\Lambda_{t-1}\right)^{\chi_w}\exp\left(\Lambda\right)^{1-\chi_w}\pi_{t-1}^{\chi_w}\pi^{1-\chi_w}\right)\frac{\tilde{W}_t}{\tilde{W}_{t-1}}\pi_t\tilde{Y}_t\exp(\Lambda_t)\right] + \\ +\beta E_t\left\{\tilde{\Xi}_{t+1}\left[\theta_w\left(\frac{\tilde{W}_{t+1}}{\tilde{W}_t}\exp(\Lambda_{t+1})\pi_{t+1} - \exp\left(\Lambda_t\right)^{\chi_w}\exp\left(\Lambda\right)^{1-\chi_w}\pi_t^{\chi_w}\pi^{1-\chi_w}\right)\frac{\tilde{W}_{t+1}}{\tilde{W}_t}\pi_{t+1}\tilde{Y}_{t+1}\exp(\Lambda_{t+1})\right]\right\} \end{array} \right\} = 0 \tag{C.18}$$

Prices are set according to:

$$\begin{aligned} &\left\{(1-\varepsilon_{Y,t}) + \varepsilon_{Y,t}\mathscr{P}_t^M - \pi_t\left(\pi_t - \pi_{t-1}^{\chi_p}\pi^{1-\chi_p}\right)\theta_p\right\} + \\ &+\theta_p E_t\beta\frac{\tilde{\Xi}_{t+1}}{\tilde{\Xi}_t}\left(\pi_{t+1} - \pi_t^{\chi_p}\pi^{1-\chi_p}\right)\pi_{t+1}\frac{\tilde{Y}_{t+1}}{\tilde{Y}_t} = 0 \end{aligned} \tag{C.19}$$

The firms problem:

$$\tilde{Y}_t^M = [\exp(\Lambda_t)]^{-\alpha} Z_t \left(\tilde{K}_{t-1}\right)^{\alpha} \left(L_t^{\mathscr{D}}\right)^{(1-\alpha)}. \tag{C.20}$$

$$\mathscr{P}_t^M (1-\alpha) \frac{\tilde{Y}_t^M}{L_t^{\mathscr{D}}} = \tilde{W}_t \tag{C.21}$$

$$\begin{aligned}
z_{1,t} &= \left(\bar{R}_t^L - 1 + \omega\right) \mathscr{P}_t^K z_{2,t} && \text{(C.22)}\\
z_{1,t} &= \beta E_t \left\{ \frac{\tilde{\Xi}_{t+1}}{\exp(\Lambda_{t+1})\tilde{\Xi}_t} \alpha \mathscr{P}_{t+1}^M (Z_{t+1})^{\frac{1}{\alpha}} \left[\frac{\tilde{W}_{t+1}}{(1-\alpha) A_{t+1} \mathscr{P}_{t+1}^M}\right]^{-\frac{1-\alpha}{\alpha}} \right\} \\
&\quad + \theta_k \beta E_t \left[\frac{\tilde{\Xi}_{t+1}}{\exp(\Lambda_{t+1})\tilde{\Xi}_t} z_{1,t+1}\right] && \text{(C.23)}\\
z_{2,t} &= \beta E_t \left\{\frac{\tilde{\Xi}_{t+1}}{\exp(\Lambda_{t+1})\tilde{\Xi}_t \pi_{t+1}}\right\} + \theta_k \beta E_t \left[\frac{\tilde{\Xi}_{t+1}}{\exp(\Lambda_{t+1})\tilde{\Xi}_t \pi_{t+1}} z_{2,t+1}\right] && \text{(C.24)}
\end{aligned}$$

$$\tilde{K}_t = (1-\delta) \frac{\tilde{K}_{t-1}}{\exp(\Lambda_t)} + \xi_t^I \left[1 - F\left(\frac{\exp(\Lambda_t)\tilde{I}_t}{\tilde{I}_{t-1}}\right)\right] \tilde{I}_t \tag{C.25}$$

$$\tilde{K}_t = (1-\theta_k) \tilde{\bar{K}}_t + \theta_k \frac{\tilde{K}_{t-1}}{\exp(\Lambda_t)} \tag{C.26}$$

$$\begin{aligned}
u_{1,t} &= \omega + \theta_K E_t \left[\beta \frac{\tilde{\Xi}_{t+1}}{\exp(\Lambda_{t+1})\tilde{\Xi}_t \pi_{t+1}} u_{1,t+1}\right] && \text{(C.27)}\\
1 &= Q_t \xi_t^I \left[1 - F\left(\frac{\exp(\Lambda_t)\tilde{I}_t}{\tilde{I}_{t-1}}\right) - F'\left(\frac{\exp(\Lambda_t)\tilde{I}_t}{\tilde{I}_{t-1}}\right) \frac{\exp(\Lambda_t)\tilde{I}_t}{\tilde{I}_{t-1}}\right] \\
&\quad + \beta E_t \left[\Lambda_{t,t+1} Q_{t+1} \xi_{t+1}^I F'\left(\frac{\exp(\Lambda_{t+1})\tilde{I}_{t+1}}{\tilde{I}_t}\right) \left(\frac{\exp(\Lambda_{t+1})\tilde{I}_{t+1}}{\tilde{I}_t}\right)^2\right] && \text{(C.28)}\\
Q_t &= u_{2,t} + E_t \left\{\beta \frac{\tilde{\Xi}_{t+1}}{\exp(\Lambda_{t+1})\tilde{\Xi}_t} \left[(1-\delta) Q_{t+1} - \theta_K u_{2,t+1}\right]\right\} && \text{(C.29)}\\
u_{1,t} \mathscr{P}_t^K &= u_{2,t} && \text{(C.30)}
\end{aligned}$$

Government policies:

$$\frac{R_t}{R} = \left(\frac{R_{t-1}}{R}\right)^{\gamma_R} \left(\frac{\pi_t}{\pi}\right)^{\gamma_\Pi (1-\gamma_R)} \left[\frac{\left(\tilde{Y}_t / \tilde{Y}_{t-1}\right) \exp(\Lambda_t)}{\exp(\Lambda)}\right]^{\gamma_y (1-\gamma_R)} \exp(\varepsilon_{m,t}) \tag{C.31}$$

$$\tilde{G}_t = g_t \tilde{Y}_t \tag{C.32}$$

$$\frac{\tilde{b}_t}{\tilde{Y}_t} = (1-\rho_b)\,\frac{\tilde{b}}{\tilde{Y}} + \rho_b \frac{\tilde{b}_{t-1}}{\tilde{Y}_{t-1}} + \varepsilon_{b,t} \tag{C.33}$$

Markets clear:

$$\tilde{C}_t + \tilde{I}_t + \frac{\theta_p}{2}\left(\pi_t - \pi_{t-1}^{\chi_p}\pi^{1-\chi_p}\right)^2 \tilde{Y}_t + \frac{\theta_w}{2}\left(\frac{\tilde{W}_t}{\tilde{W}_{t-1}}\pi_t \exp(\Lambda_t) - \exp(\Lambda_{t-1})^{\chi_w}\exp(\Lambda)^{1-\chi_w}\pi_{t-1}^{\chi_w}\pi^{1-\chi_w}\right)^2 \tilde{Y}_t + \tilde{G}_t = \tilde{Y}_t. \tag{C.34}$$

$$L_t^{\mathscr{D}} = L_t \tag{C.35}$$

$$\tilde{Y}_t^M = \tilde{Y}_t. \tag{C.36}$$

Shock Processes:

$$\begin{aligned}
d\log(A_t) &= (1-\rho_A)\Lambda + \rho_A d\log(A_{t-1}) + \varepsilon_{A,t}\\
\log(Z_t) &= \rho_Z \log(Z_{t-1}) + \varepsilon_{Z,t}\\
\log\left(\xi_t^I\right) &= \rho_I \log\left(\xi_{t-1}^I\right) + \varepsilon_{I,t}\\
\log\left(\xi_t^{\mathscr{U}}\right) &= \rho_{\mathscr{U}} \log\left(\xi_{t-1}^{\mathscr{U}}\right) + \varepsilon_{\mathscr{U},t}\\
\log(\psi_t) &= \left(1-\rho_\psi\right)\psi + \rho_\psi \log(\psi_{t-1}) + \varepsilon_{\psi,t}\\
\log(\lambda_t) &= (1-\rho_\lambda)\,\lambda + \rho_\lambda \log(\lambda_{t-1}) + \varepsilon_{\lambda,t}\\
\log(\varepsilon_{L,t}) &= \log(\varepsilon_L) + \varepsilon_{L,t}\\
\log(\varepsilon_{Y,t}) &= (1-\rho_{\varepsilon Y})\log(\varepsilon_Y) + \rho_{\varepsilon Y}\log(\varepsilon_{Y,t-1}) + \varepsilon_{Y,t}\\
\log(\Delta_t) &= (1-\rho_\Delta)\log(\Delta) + \rho_\Delta \log(\Delta_{t-1}) + \varepsilon_{\Delta,t}\\
\log(g_t) &= (1-\rho_{g_1}-\rho_{g_2})\log(g) + \rho_{g_1}\log(g_{t-1}) + \rho_{g_2}\log(g_{t-2}) + \varepsilon_{g,t}\\
\frac{\tilde{b}_t}{\tilde{Y}_t} &= (1-\rho_b)\,\frac{\tilde{b}}{\tilde{Y}} + \rho_b \frac{\tilde{b}_{t-1}}{\tilde{Y}_{t-1}} + \varepsilon_{b,t}
\end{aligned}$$

As in Justiniano *et al.* (2013), we assume in the estimation that the shock to the elasticity of substitution of labor types is iid, and hence $\rho_{\varepsilon L} = 0$.

D Steady State

From the Euler equation of households (C.1) we get an expression for the nominal deposit rate:

$$R = \exp(\Lambda)\frac{\pi}{\beta}.$$

Given the spreads over the risk-free deposit rates, we compute the corporate lending rate R^L and the return to government bonds R^G. In steady state re-negotiated interest rates are equal to the average return on the respective portfolio, i.e. $R^L = \bar{R}^L$ and $R^G = \bar{R}^G$.

From the optimal investment decision of capital goods producers (C.28), we obtain that $Q = 1$. The steady-state value of the Lagrange multipliers u_1 and u_2 are (derived from equation C.27 and C.29):

$$\begin{aligned}
u_1 &= \frac{\omega}{1-\theta_k \frac{\beta}{\exp(\Lambda)\pi}} \\
u_2 &= \frac{1-(1-\delta)\frac{\beta}{\exp(\Lambda)}}{1-\theta_k \frac{\beta}{\exp(\Lambda)}}.
\end{aligned}$$

The price of capital is the ratio of these two auxiliary variables (derived from equation C.30):

$$\mathscr{P}^K = \frac{u_2}{u_1}.$$

The auxiliary variables in the capital demand equation of intermediate goods producers are (derived from equation C.22 and C.24):

$$\begin{aligned}
z_2 &= \frac{\beta}{\exp(\Lambda)\pi - \theta_k \beta} \\
z_1 &= \left(R^L - 1 + \omega\right)\mathscr{P}^K z_2.
\end{aligned}$$

Given the elasticity of substitution for retail goods, the price for intermediate goods is the inverse of the mark-up (derived from equation C.19):

$$\mathscr{P}^M = \frac{\varepsilon_y - 1}{\varepsilon_y},$$

which together with the capital demand by intermediate goods producers (C.23) allows us to get an expression for the steady-state real wage:

$$\tilde{W} = (1-\alpha)\left[\frac{z_1\left(\exp(\Lambda)-\theta_k\beta\right)}{\alpha\beta\left(\mathscr{P}^M\right)^{\frac{1}{\alpha}}}\right]^{-\frac{\alpha}{1-\alpha}}.$$

Since we calibrate the steady state labor supply to be equal to one and since $L^{\mathscr{D}} = L$ (equation C.35), from the labor demand by intermediate goods producers (C.21) we obtain that:

$$\tilde{Y}^M = \frac{\tilde{W}L}{(1-\alpha)\mathscr{P}^M} = \frac{\tilde{W}}{(1-\alpha)\mathscr{P}^M}.$$

From the market clearing condition (C.36) we get that $\tilde{Y} = \tilde{Y}^M$. The production function (C.20) can be used to determine the steady state capital stock:

$$\tilde{K} = \exp(\Lambda)\left(\frac{\tilde{Y}}{L^{1-\alpha}}\right)^{\frac{1}{\alpha}} = \exp(\Lambda)\tilde{Y}^{\frac{1}{\alpha}}.$$

The amount of capital, which is adjusted on average every period is (derived from equation C.26):

$$\tilde{\tilde{K}} = \frac{1-\frac{\theta_k}{\exp(\Lambda)}}{1-\theta_k}\tilde{K}.$$

The law of motion for the capital stock (C.25) determines steady state investment:

$$\tilde{I} = \left(1-\frac{1-\delta}{\exp(\Lambda)}\right)\tilde{K}.$$

Given the ratio of average government spending $g = \frac{G}{Y}$, consumption in steady state can now be backed out of the market clearing condition (C.34):

$$\tilde{C} = \tilde{Y} - \tilde{I} - g\tilde{Y}.$$

From the wage setting equation (C.18) together with the definition for the marginal utility of consumption (C.2), and using the fact that $L = 1$, we can back out the value for ψ:

$$\psi = \frac{\exp(\Lambda)-h\beta}{\tilde{C}(\exp(\Lambda)-h)}\frac{\tilde{W}}{L^{\varphi}}\frac{\varepsilon_L-1}{\varepsilon_L} = \frac{\tilde{W}(\exp(\Lambda)-h\beta)}{\tilde{C}(\exp(\Lambda)-h)}\frac{\varepsilon_L-1}{\varepsilon_L}.$$

From the law of motion (C.10) for aggregate lending to the private sector we get:

$$\widetilde{len} = \frac{(1-\theta_k)\,\mathscr{P}^K \tilde{\tilde{K}}}{1-\frac{\theta_k}{\exp(\Lambda)\pi}} = \mathscr{P}^K \tilde{K}.$$

Given the definition for the average return (C.12) on the private sector loan, total revenues earned on this portfolio are given by:

$$\widetilde{rev} = R^L \widetilde{len}.$$

Since we calibrate the debt-to-GDP ratio, together with $\tilde{Y}$, we obtain the amount of real outstanding debt $\tilde{b}$. From the definition for aggregate lending to the government (C.13) we get an expression for bonds which are re-negotiated every period:

$$\tilde{\tilde{b}} = \frac{(1-\frac{\theta_g}{\exp(\Lambda)\pi})\tilde{b}}{1-\theta_g}.$$

In steady state revenues from the portfolio of government bonds are equal to (derived from equation C.14):

$$\widetilde{rev^G} = \frac{(1-\theta_g)R^G\tilde{b}}{1-\frac{\theta_g}{\exp(\Lambda)\pi}}\tilde{\tilde{b}}.$$

For a given calibration of the steady-state leverage ratio, we can express net worth as (derived from equation C.16):

$$\tilde{n} = \frac{\widetilde{len}}{\phi},$$

and the proportion of value of the government bond holdings relative to the value of the loan portfolio is given by equation (C.3):

$$x = \frac{\tilde{b}}{\widetilde{len}}.$$

Since the fraction of assets which can be diverted differ across asset classes, we need to find an expression for the fraction λ of corporate loans as well as the fraction $\lambda\Delta$ of government bonds which can be diverted. The scaling factor Δ is determined by the ratio of the two premia (equations C.5-C.7):

$$\Delta = \frac{R^G - R}{R^L - R}.$$

The tax bankers pay as a premium to an insurance agency can be backed out of the law of motion for net worth (C.4):

$$\tau_B = 1 - \frac{\exp(\Lambda)\pi}{(R^L - R)\,\phi + (R^G - R)\,\phi x + R}.$$

The steady state stochastic marginal value of net worth is defined as (derived from equation C.5, C.8, C.9):

$$\Omega = \frac{(1-\tau_B)(1-\theta_B)}{1-\theta_B\left(1-\tau_B+(1+\Delta x)\,\phi\,(1-\tau_B)\,\beta\,\frac{R^L-R}{\exp(\Lambda)\pi}\right)}.$$

The excess value of a unit of an asset relative to deposits are given by the equations (C.5) and (C.6):

$$\begin{aligned}
\mu^L &= (1-\tau_B)\,\beta\Omega\frac{R^L-R}{\exp(\Lambda)\pi} \\
\mu^G &= (1-\tau_B)\,\beta\Omega\frac{R^G-R}{\exp(\Lambda)\pi},
\end{aligned}$$

whereas the marginal cost of deposits is equal to (equation C.8):

$$\mathscr{V}^D = (1-\tau)\,\Omega.$$

Given these expressions above, we can also back out the fraction λ of corporate loans, which can be diverted (derived from equation C.17):

$$\lambda = \mu^L + \frac{\mathscr{V}^D}{(1+x\Delta)\,\phi}.$$

E Model Estimation

E.1 Measurement Equations

The link between variables in the model and in the data (i.e. the measurement equations) is done as follows. For real variables such as real GDP, real consumption and real investment, the link between the model and the data is as follows:

$$d\log(GDP_t) = 100[d\log(A_t) + d\log(\tilde{Y}_t)]$$
$$d\log(CONS_t) = 100[d\log(A_t) + d\log(\tilde{C}_t)]$$
$$d\log(INV_t) = 100[d\log(A_t) + d\log(\tilde{I}_t)]$$

For inflation and the interest rate, the relationships are as follows:

$$d\log(DEFL_t/DEFL_{t-1}) = 100\log(\pi_t)$$
$$FFR_t/4 = 100\log(R_t)$$

where $DEFL_t$ is the GDP deflator and FFR_t is the Federal Funds rate. For nominal wage growth, we use nominal compensation per hour (NCH) in the total economy, from NIPA.[3] The measurement equation is:

$$d\log(NCH_t) = 100[d\log(A_t) + d\log(\widetilde{w}_t) + \pi_t]$$

A widely used variable to proxy for a market long-term rate for corporate credit is to look at the BAA-rated corporate bond yields, as in the case of Christiano *et al.* (2014):

$$(BAA_t - FFR_t)/4 = 100[\log(R_t^L) - \log(R_t)]$$

Finally, the measurement equation for government bonds includes the rate on a 10 year government bond ($10Y_t$):

$$(10Y_t - FFR_t)/4 = 100[\log(R_t^B) - \log(R_t)]$$

Hence, in all cases we use quarterly growth rates or quarterly interest rates, and we transform the data accordingly.

[3] Justiniano *et al.* (2013) and Gali *et al.* (2012) also use average hourly earnings of production and non-supervisory employees, which is computed by the Bureau of Labor Statistics from the Establishment Survey. Both papers stress that business cycle implications can be very different depending on which series is used to estimate the model. We found that in the context of our model, using one series or the other did not make a big difference because wage mark-ups are not an important driver of business cycles.

F Implementing UMP in the Model

F.1 Direct Lending to Firms

Similar to Gertler and Karadi (2011), the central bank provides financing to firms by extending credit directly (or, what is equivalent in the context of this model, by purchasing corporate debt). Gertler and Karadi (2011) assume that the public credit policy is to provide a fraction Ψ_t of the stock of credit for firms to borrow. Here, we assume that the central bank UMP rule is in terms of the level of credit (which is more consistent with central banks statements which describe actual amounts rather than fractions).

Aggregate lending is given by equation (A.22):

$$len_t = (1-\theta_k)\,\mathscr{P}_t^K \bar{K}_t + \theta_k \frac{1}{\pi_t} len_{t-1},$$

where:

$$len_t = len_t^p + len_t^{cb}.$$

Lending intermediated by private banks is

$$\phi_t = \frac{len_t^p}{N_t},$$

where the optimal leverage ratio is given by equation (A.41). The ratio (A.40) of government bonds over private lending become:

$$x_t = \frac{B_t}{len_t^p}.$$

Lending intermediated by the central bank is given by the following rule:

$$len_t^{cb} = \rho_\Psi len_{t-1}^{cb} + \gamma_\Psi (R_t^L/R_t - R^L/R)$$

We also experiment with a rule that reacts to the spread on *new* lending rates rather than *average* rates (i.e. to $\bar{R}_t^L/R_t - R^L/R$).

F.2 Purchases of Government Bonds

In this case the central bank buys government bonds and tries to affect the corporate spread. The law of motion of government bonds is given by equation (A.26):

$$B_t = (1-\theta_g)\bar{B}_t + \theta_g \frac{1}{\pi_t} B_{t-1},$$

where:

$$B_t = B_t^p + B_t^{cb}.$$

Lending intermediated by private banks is

$$\phi_t = \frac{len_t}{N_t},$$

where the optimal leverage ratio is given by equation (A.41). The ratio (A.40) of government bonds over private lending become:

$$x_t = \frac{B_t^p}{len_t}.$$

Central bank government purchases are given by the following rule:

$$B_t^{cb} = \rho_\Psi B_{t-1}^{cb} + \gamma_\Psi (R_t^L/R_t - R^L/R)$$

We also experiment with a rule that reacts to the spread on *new* lending rates rather than *average* rates, as well as rules that react to the spread between government bond rates and short-term rates (both average and new).

G Welfare Analysis

In this section we report expanded versions of Tables 9 and 10 in the main text, in particular the coefficients of the reaction function and the value of the welfare function under the six possible cases that we examine. The main text only reports the optimal value.

Table 9: Optimal UMP Policy, Inflation Targeting

Policy	ρ_Ψ	γ_Ψ	$\mathbb{W}_t$	C.E. (in %)
Corp., $\bar{R}_t^L - R_t$	0.14	9.62	-553.83	1.45
Corp., $R_t^L - R_t$	0	0	-559.91	0
Gov., $\bar{R}_t^L - R_t$	0	22.6	-554.49	1.3
Gov., $R_t^L - R_t$	0	0	-559.91	0
Gov., $\bar{R}_t^B - R_t$	0.22	1.16	-554.15	1.38
Gov., $R_t^B - R_t$	0	0	-559.91	0

Table 9 (cont.): Optimal UMP Policy, Inflation Targeting, Conditional

Policy	ρ_Ψ	γ_Ψ	$\mathbb{W}_t$	C.E. (in %)
Demand shocks				
Corp., $\bar{R}^L_t - R_t$	0.11	11985.5	-576.96	.11
Corp., $R^L_t - R_t$	0	0	-577.40	0
Gov., $\bar{R}^L_t - R_t$	0.1	11396.18	-577.00	.10
Gov., $R^L_t - R_t$	0	0	-577.40	0
Gov., $\bar{R}^B_t - R_t$	0	0	-577.40	0
Gov., $R^B_t - R_t$	0.84	1000000	-576.16	0.31
Supply Shocks				
Policy	ρ_Ψ	γ_Ψ	$\mathbb{W}_t$	C.E. (in %)
Corp., $\bar{R}^L_t - R_t$	0	0	-553.67	0
Corp., $R^L_t - R_t$	0	0	-553.67	0
Gov., $\bar{R}^L_t - R_t$	0	0	-553.67	0
Gov., $R^L_t - R_t$	0	0	-553.67	0
Gov., $\bar{R}^B_t - R_t$	0	0	-553.67	0
Gov., $R^B_t - R_t$	0	0	-553.67	0
Financial Shocks				
Policy	ρ_Ψ	γ_Ψ	$\mathbb{W}_t$	C.E.
Corp., $\bar{R}^L_t - R_t$	0.89	11390.7	-575.75	1.17
Corp., $R^L_t - R_t$	0.81	19553.3	-575.75	1.17
Gov., $\bar{R}^L_t - R_t$	0.97	9163.7	-575.74	1.18
Gov., $R^L_t - R_t$	0.97	9292.1	-575.75	1.17
Gov., $\bar{R}^B_t - R_t$	0	1.3	-580.13	0.06
Gov., $R^B_t - R_t$	0.94	44968.6	-575.84	1.1

Table 10: Optimal UMP Policy, Optimized Taylor

Policy	ρ_Ψ	γ_Ψ	$\mathbb{W}_t$	C.E. (in %)
Corp., $\bar{R}^L_t - R_t$	0	0	-554.49	0
Corp., $R^L_t - R_t$	0	0	-554.49	0
Gov., $\bar{R}^L_t - R_t$	0	0	-554.49	0
Gov., $R^L_t - R_t$	0	0	-554.49	0
Gov., $\bar{R}^B_t - R_t$	0	0	-554.49	0
Gov., $R^B_t - R_t$	0	0	-554.49	0

Table 10 (cont.): Optimal UMP Policy, Optimized Taylor, Conditional

Demand shocks				
Policy	ρ_Ψ	γ_Ψ	$\mathbb{W}_t$	C.E. (in %)
Corp., $\bar{R}_t^L - R_t$	0.03	19128.8	-577.02	.09
Corp., $R_t^L - R_t$	0	0	-577.41	0
Gov., $\bar{R}_t^L - R_t$	0.08	1.68	-577.06	.09
Gov., $R_t^L - R_t$	0	0	-576.01	0
Gov., $\bar{R}_t^B - R_t$	0	0	-576.01	0
Gov., $R_t^B - R_t$	0	0	-576.01	0

Supply Shocks				
Policy	ρ_Ψ	γ_Ψ	$\mathbb{W}_t$	C.E. (in %)
Corp., $\bar{R}_t^L - R_t$	0	0	-548.18	0
Corp., $R_t^L - R_t$	0	0	-548.18	0
Gov., $\bar{R}_t^L - R_t$	0	0	-548.18	0
Gov., $R_t^L - R_t$	0	0	-548.18	0
Gov., $\bar{R}_t^B - R_t$	0	0	-548.18	0
Gov., $R_t^B - R_t$	0	0	-548.18	0

Financial Shocks				
Policy	ρ_Ψ	γ_Ψ	$\mathbb{W}_t$	C.E.
Corp., $\bar{R}_t^L - R_t$	0.99	895757.0	-580.47	0.11
Corp., $R_t^L - R_t$	0.40	$2.3 * 10^{-6}$	-580.47	0.11
Gov., $\bar{R}_t^L - R_t$	0	0	-580.94	0
Gov., $R_t^L - R_t$	0	0	-580.94	0
Gov., $\bar{R}_t^B - R_t$	0	1.39	-580.25	0.17
Gov., $R_t^B - R_t$	0.19	$8.3 * 10^{-8}$	-580.47	0.11

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