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A structural investigation of the Chinese economy with a hybrid monetary policy rule *

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Abstract

In this paper, we aim to understand how monetary policy is conducted in China and what are the main sources of fluctuations in China's business cycle. To this end, we extend a standard New Keynesian dynamic stochastic general equilibrium model with financial frictions and investment-specific technology shocks. We incorporate a hybrid form of monetary policy rule and employ a Bayesian estimation strategy using Chinese data. We find that the People's Bank of China conducts monetary policy by adjusting the policy rate in response to inflation, output growth as well as real money growth. We also find that neutral technology shocks are the main drivers of the fluctuations in output and consumption while the investment-specific technology shock is the primary source of the variation in investment. This paper offers a new way of examining the rule of China's monetary policy and indicates a structural break of the neutral technology development that may have caused the slowing down of the GDP growth since 2010.

JEL classification: E32, E43, E52

Keywords: monetary policy, business fluctuation, Bayesian estimation, dynamic stochastic general equilibrium model, China

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1 Introduction

Since around 2010, China has been experiencing a gradual slow-down of the GDP growth from an average of 10 per cent over the past thirty years to 2010 to a 7.4 per cent in 2014.[1] Chinese President Xi Jinping described it as the 'new normal' of the economy in May 2014. [2] The slowing down of the economic growth has attracted a great deal of attention among policymakers and scholars but so far there has been no consensus on the sources of it. This motivates us to conduct a structural investigation of the Chinese economy to better understand the sources of business fluctuations in China, fluctuations in output in particular.

There is one puzzle that needs to be solved before one can proceed with the structural investigation. China's monetary policy is the puzzle. On one hand, it has been assigned too many objectives—maintaining price stability, promoting economic growth, supporting employment and achieving balance of payments equilibrium. On the other hand, there is no consensus on the form of the policy rules that the People's Bank of China (PBoC) has been employing, leaving aside whether such policy rules are able to achieve all the said objectives. Without a well defined monetary policy rule, it will be difficult to accurately model China's macroeconomy. The transmission mechanism of a monetary policy shock to the economy is uncertain and the effects will be difficult to predict for the central bank.

What is the monetary policy rule of the PBoC? Has the rule changed over time? What do the data say about the actual monetary policy rules at work? What are the main sources of business fluctuations of the Chinese economy given that the monetary policy rules are known? These are the questions the paper aims to address.

To this end, we extend a standard New Keynesian dynamic stochastic general equilibrium (DSGE) model with financial frictions and investment-specific (IS) technology shocks. The financial friction mechanism was first introduced by Bernanke et al. (1999) to model market imperfectness of the financial sector. The investment-specific technology shock was suggested and developed by Greenwood et al. (1988, 1997) as a viable alternative to neutral technology shocks as sources of business cycles. Studies by Kaihatsu and Kurozumi (2014), and Justiniano et al. (2011) find that the financial friction shock and the IS technology shock are important sources of business fluctuations in the United States. There are a number of studies applying DSGE models to the Chinese economy. See, for example, Xu and Chen (2009), Mehrotra et al. (2013), Yuan and Feng (2014), and Zhang et al. (2014). None of these studies have explicitly taken into account financial frictions or shocks to investment.[3] It is reasonable to expect that they are significant drivers of China's business fluctuations.

We propose a hybrid form of monetary policy rule for the extended model. Past studies on China's monetary policy tend to make a choice between the Taylor-type rules and the quantity rules that have been used in studies of advanced economies. For example, Zhang (2009) argues that a Taylor-type rule is likely to be more effective than a quantity-type rule in managing the economy. Liu and Zhang (2010) show that using both rules outperforms using a single rule in a four-equation New Keynesian model.[4] Since there is no consensus on the specific form of the policy rules, we incorporate a general form of monetary policy rule that encompasses the pure Taylor-type rules or quantity-type rules for estimations.

The main findings of the paper are as follows. 1) The central bank of China has been employing a hybrid form of monetary policy rule during 2001-2014 where the PBoC conducted monetary policy by adjusting the policy rate in response to inflation rate, output, output growth as well as real money growth in the economy; 2) The main sources of business fluctuations in output and consumption growths are neutral technology shocks and preference shocks while the fluctuations in investment and loans are primarily driven by IS technology shocks and net worth shocks; 3) While the consistently positive net worth shocks explain the steady growth of the investment, the negative neutral technology shocks have dominantly contributed to the slowing down of China's GDP growth since around 2010.

The remainder of the paper is organized as follows. Section 2 constructs the model. Section 3 proceeds with the estimation. Section 4 reports and discusses the results, followed by the concluding remarks in Section 5.

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[1]The GDP growth rate in 2011, 2012 and 2013 is 9.5%, 7.7% and 7.7%, respectively. Sources: the National Bureau of Statistics of China.

[2]See, for example, the news report of the Xinhua Net titled Xi's "new normal" theory.

[3]Yuan et al. (2011) and Kang and Gong (2014) incorporate financial frictions, but no IS technology shocks, in their models.

[4]Note that Liu and Zhang (2010) use the concept of 'hybrid rule' in their study which actually means that the central bank uses both the quantity rule and the Taylor rule to conduct monetary policy. Because of the small scale of their model, this is mathematically solvable.

2 The Model

The model is very close to that of Kaihatsu and Kurozumi (2014 hereafter KK), except for the central bank's behavior. There are households that consist of worker and entrepreneur members, financial intermediaries, intermediate-good firms, consumption-good firms, investment-good firms, capital-good firms and a central bank in the economy. The financial accelerator mechanism of Bernanke et al.(1999) is employed in the financial sector. The economy is subject to both technology shocks and financial shocks.

Each agent's behavior is described in details as follows.

2.1 Households

The representative household consists of a continuum of members normalized to unity. A proportion of members are workers, denoted by $m \in [0,1]$, and the rest are entrepreneurs. All members are assumed to pool consumption and make joint consumption-saving decisions. The representative household maximizes

$$E_0 \sum_{t=0}^{\infty} \beta^t \exp(z_t^b) \left[\frac{(C_t - \theta C_{t-1})^{1-\sigma}}{1-\sigma} + \exp(z_t^m) \frac{(M_t/P_t)^{1-\sigma}}{1-\sigma} - (Z_t^*)^{1-\sigma} \exp(z_t^h) \int_0^1 \frac{(h_t(m))^{1+\chi}}{1+\chi} dm \right] \tag{1}$$

subject to the budget constraint

$$P_t C_t + M_t + D_t = r_{t-1}^n D_{t-1} + M_{t-1} + P_t \int_0^1 W_t(m) h_t(m) dm + T_t \tag{2}$$

where E_0 is the rational expectation operator, $\beta \in (0,1)$ is the discount factor, $\sigma > 0$ and $\theta \in [0,1]$ are the degrees of relative risk aversion and internal consumption habit persistence, respectively, $\chi > 0$ is the inverse of elasticity of labor supply, z_t^b is the intertemporal preference shock, z_t^h and z_t^m represent labor supply shock and money demand shock, respectively, C_t is the consumption level, M_t/P_t is the real money balance the household is holding, $h(m)$ is the labor supply of worker m to the intermediate-good firms $f \in [0,1]$ and $h_t(m) = \int_0^1 h_t(m,f)df$, Z_t^* is the composite technological level which will be explained later, P_t is the price of consumption goods, D_t is the deposit saved in financial intermediaries, r_t^n is the gross deposit rate which is assumed to be the policy rate, $W_t(m)$ is worker m's real wage, and T_t consists of profits received from firms and a lump-sum public transfer.

The first order conditions with respect to consumption and deposits are [5]

$$\Lambda_t = \exp(z_t^b)(C_t - \theta C_{t-1})^{-\sigma} - \beta\theta E_t \exp(z_{t+1}^b)(C_{t+1} - \theta C_t)^{-\sigma} \tag{3}$$

$$1 = E_t \beta \frac{\Lambda_{t+1}}{\Lambda_t} \frac{r_t^n}{\pi_{t+1}} \tag{4}$$

where Λ_t is the marginal utility of consumption and $\pi_t = P_t/P_{t-1}$ is the gross inflation rate of the consumption-good price.

2.1.1 Workers

The labor market is monopolistically competitive. Demand for worker m's labor services is given by $h_t(m) = h_t\big(W_t(m)/W_t\big)^{-\theta_t^w}$, where $h_t = [\int_0^1 (h_t(m))^{(\theta_t^w-1)/\theta_t^w} dm]^{\theta_t^w/(\theta_t^w-1)}$ is the aggregate labor service with substitution

[5] The first order condition for real money demand M_t/P_t is reported in Section 2.5 as part of the considerations of the central bank when conducting monetary policy.

elasticity $\theta_t^w > 1$ and $W_t = \left[\int_0^1 \left(W_t(m)\right)^{1-\theta_t^w} dm\right]^{1/(1-\theta_t^w)}$ is the aggregate wage. Nominal wage is adjusted according to Calvo (1983) pricing mechanism. In each period a fraction of $1 - \xi_w \in (0, 1)$ of workers gets to reoptimize their wages while the rest fraction ξ_w of workers' wages is set by indexation to both the gross steady-state balanced growth rate z^* and a weighted average of past and steady-state inflation $\pi_{t-1}^{\gamma_w} \pi^{1-\gamma_w}$, where $\gamma_w \in (0, 1)$ is the relative weight on past inflation (z^* will be explained later). Each worker that gets to reset their wage at time t chooses $P_t W_t(m)$ to maximize

$$E_t \sum_{j=0}^{\infty} (\beta\xi_w)^j \left[\Lambda_{t+j} h_{t+j|t}(m) \frac{P_t W_t(m)}{P_{t+j}} \prod_{k=1}^{j} \left(z^* \pi_{t+k-1}^{\gamma_w} \pi^{1-\gamma_w}\right) - \frac{\exp(z_{t+j}^b)(Z_{t+j}^*)^{1-\sigma} \exp(z_{t+j}^h)(h_{t+j|t}(m))^{1+\chi}}{1+\chi}\right] \tag{5}$$

subject to

$$h_{t+j|t}(m) = h_{t+j} \left[\frac{P_t W_t(m)}{P_{t+j} W_{t+j}} \prod_{k=1}^{j} \left(z^* \pi_{t+k-1}^{\gamma_w} \pi^{1-\gamma_w}\right)\right]^{-\theta_{t+j}^w} \tag{6}$$

The first order condition for reoptimized wage W_t^0 is given by

$$1 = \frac{E_t \sum_{j=0}^{\infty} (\beta\xi_w)^j \frac{(1+\lambda_{t+j}^w)\exp(z_{t+j}^b)\exp(z_{t+j}^h)(Z_{t+j}^*)^{1-\sigma}}{\lambda_{t+j}^w} \left(h_{t+j}\left\{\frac{W_t^0 (z^*)^j}{W_{t+j}} \prod_{k=1}^{j} [(\frac{\pi_{t+k-1}}{\pi})^{\gamma_w} \frac{\pi}{\pi_{t+k}}]\right)\right\}^{-\frac{1+\lambda_{t+j}^w}{\lambda_{t+j}^w}}\Big)^{1+\chi}}{E_t \sum_{j=0}^{\infty} (\beta\xi_w)^j \frac{\Lambda_{t+j} W_{t+j}}{\lambda_{t+j}^w} h_{t+j} \left\{\frac{W_t^0 (z^*)}{W_{t+j}} \prod_{k=1}^{j} [(\frac{\pi_{t+k-1}}{\pi})^{\gamma_w} \frac{\pi}{\pi_{t+k}}]\right\}^{-\frac{1}{\lambda_{t+j}^w}}} \tag{7}$$

where $\lambda_t^w = 1/(\theta_t^w - 1) > 0$ is the wage markup.

The aggregate wage in equation (5) is reduced to

$$1 = (1 - \xi_w)\left(\left(\frac{W_t^0}{W_t}\right)^{-\frac{1}{\lambda_t^w}} + \sum_{j=1}^{\infty} \left\{\frac{(z^*)^j W_{t-j}^0}{W_t} \prod_{k=1}^{j} \left[\left(\frac{\pi_{t-k}}{\pi}\right)^{\gamma_w} \frac{\pi}{\pi_{t-k+1}}\right]\right\}^{-\frac{1}{\lambda_t^w}}\right) \tag{8}$$

2.1.2 Entrepreneurs and financial intermediaries

At the end of period $t-1$, entrepreneurs hold real net worth N_{t-1} left from this period and get loan L_{t-1} from financial intermediaries at gross real loan rate $E_{t-1} r_t^E$. They optimally purchase capital K_{t-1} from capital-good firms at price Q_{t-1}, and choose capital utilization rate u_t. Then they provide capital service $u_t K_{t-1}$ to intermediate-good firms at rental rate R_t^k, and sell the rest capital $(1 - u_t)K_{t-1}$ back to capital-good firms at price Q_t. After paying back their loan to the financial intermediaries, a fraction of $1 - \eta_t \in (0, 1)$ of entrepreneurs becomes workers, while the remaining η_t survives into next period.

It is assumed that a higher utilization rate will lead to a higher depreciation rate $\delta(u_t)$ during intermediate-good firms' production. $\delta(.)$ satisfies $\delta' > 0$, $\delta'' > 0$, $\delta(1) = \delta \in (0, 1)$, and $\delta'(1)/\delta''(1) = \tau > 0$. With higher utilization rate, entrepreneurs can provide more capital services but a consequencing higher depreciation rate will result in a lower rental rate.

The first order conditions for optimal decisions on utilization rate and purchasing capital can be derived as

$$R_t^k = Q_t \delta'(u_t) \tag{9}$$

$$E_t \Lambda_{t+1} r_{t+1}^E = E_t \Lambda_{t+1} \frac{u_{t+1} R_{t+1}^k + Q_{t+1}(1 - \delta(u_{t+1}))}{Q_t} \tag{10}$$

where the EF premium function $F(.)$ depends on entrepreneurs' leverage ratio Q_tK_t/N_t and satisfies $F' > 0$ and $\mu = (QK/N)F'(QK/N)/F(QK/N) \geqslant 0$ as in regular DSGE models with financial accelerator mechanism, such as Hirose (2008). z_t^{μ} denotes a shock to the EF premium. The gross real loan rate $E_t r_{t+1}^E$ consists of deposit rate $E_t(r_t^n/\pi_{t+1})$ and the EF premium

$$E_t r_{t+1}^E = E_t \frac{r_t^n}{\pi_{t+1}} F\Big(\frac{Q_tK_t}{N_t}\Big)\exp(z_t^{\mu}) \tag{11}$$

Evolution of the net worth N_t is

$$N_t = \eta_t\Big[r_t^E Q_{t-1}K_{t-1} - \big(E_{t-1}r_{t-1}^E\big)L_{t-1}\Big] + (1-\eta_t)\chi Z_t^* \tag{12}$$

where χ is a constant, χZ_t^* represents the transfer from entrepreneurs who become workers to surviving entrepreneurs, η_t is the probability of surviving and given by $\eta_t = \eta\exp(\tilde{z}_t^{\eta})/(1-\eta+\eta\exp(\tilde{z}_t^{\eta}))$, where $\tilde{z}_t^{\eta}$ is a shock to net worth, r_t^E is the ex-post marginal return on capital and given by

$$r_t^E = \frac{u_t R_t^k + Q_t(1-\delta(u_t))}{Q_{t-1}}. \tag{13}$$

2.2 Intermediate-good firms and Consumption-good firms

Each intermediate-good firm $f \in [0,1]$ produces output $Y_t(f)$ according to the production function

$$Y_t(f) = \big(Z_t h_t(f)\big)^{1-\alpha}\big(K_t(f)\big)^{\alpha} - \phi y Z_t^* \tag{14}$$

where $h_t(f)$ is the labor input from workers at real wage W_t, $K_t(f)$ is the capital input from entrepreneurs at real rental rates R_t, Z_t is the neutral technology and evolves according to a stochastic process

$$\log Z_t = \log z + \log Z_{t-1} + z_t^z$$

$z > 1$ is the gross steady-state rate of neutral technology change and z_t^z represents a non-stationary neutral technology shock. $h_t(f) = [\int_0^1 (h_t(m,f))^{(\theta_t^w-1)/\theta_t^w} dm]^{\theta_t^w/(\theta_t^w-1)}$ denotes the labor input, and $\alpha \in (0,\ 1)$ is the capital elasticity of output. $\phi \in [0,\ 1)$ in the fixed cost term $-\phi y Z_t^*$ is chosen to ensure that zero profit condition holds at steady state, and y is the steady-state value of the detrended output $y_t = Y_t/Z_t^*$. Z_t^* denotes the composite technological level following $Z_t^* = Z_t(\Psi_t)^{\alpha/(1-\alpha)}$ where Ψ_t is the level of IS technological level. Z_t^*/Z_{t-1}^* is the gross rate of balanced growth with steady-state rate $z^* = z\psi^{\alpha/(1-\alpha)}$, derived by equation (14), and ψ is the steady-state rate of Ψ_t.

The first order conditions for optimal labor and capital inputs are

$$\frac{1-\alpha}{\alpha} = \frac{W_t h_t}{R_t^k u_t K_{t-1}} \tag{15}$$

and the real marginal cost is given by

$$mc_t = \Big(\frac{W_t}{(1-\alpha)Z_t}\Big)^{1-\alpha}\Big(\frac{R_t^k}{\alpha}\Big)^{\alpha} \tag{16}$$

where $h_t = \int_0^1 h_t(f)df$ and $u_tK_{t-1} = \int_0^1 K_t(f)df$. Aggregating function (14) over intermediate-good firms yields

$$Y_t d_t = (Z_t h_t)^{1-\alpha}(u_t K_{t-1})^{\alpha} - \phi y Z_t^* \tag{17}$$

where $d_t = \int_0^1 (P_t(f)/P_t)^{-\theta_t^p} df$ is intermediate-good price dispersion.

Each consumption-good firm chooses a combination of intermediate goods $\{Y_t(f)\}$ at price $P_t(f)$ and produces consumption goods Y_t, subject to the production function $Y_t = (\int_0^1 Y_t(f)^{(\theta_t^p-1)/\theta_t^p} df)^{\theta_t^p/(\theta_t^p-1)}$, where $\theta_t^p > 1$ represents elasticity of substitution between intermediate goods. Profit maximization of consumption-good firms yields demand for intermediate-good f as $Y_t(f) = Y_t\big(P_t(f)/P_t\big)^{-\theta_t^p}$.

It is assumed that consumption-good firms are under perfect competition, while intermediate-goods firms face monopolistic competitive market. Hence, the price of consumption-good Y_t is given by

$$P_t = \Big(\int_0^1 P_t(f)^{1-\theta_t^p} df\Big)^{\frac{1}{1-\theta_t^p}} \tag{18}$$

Intermediate-good firms set price under the Calvo-pricing (1983) mechanism, which assumes a fraction of $1-\xi_p \in (0,1)$ of intermediate-good firms reoptimizes price in each period, while price of the rest is set by indexation to a weighted average of past inflation and steady-state inflation, with $\gamma_p \in [0,\ 1]$ the relative weight on past inflation, i.e, $\pi_{t-1}^{\gamma_p}\pi^{1-\gamma_p}$. Price is reoptimized in the current period so as to maximize

$$E_t \sum_{j=0}^{\infty} \xi_p^j \Big(\beta^j \frac{\Lambda_{t+j}}{\Lambda_t}\Big)\Big[\frac{P_t(f)}{P_{t+j}} \prod_{k=1}^{j} (\pi_{t+k-1}^{\gamma_p}\pi^{1-\gamma_p}) - mc_{t+j}\Big] Y_{t+j|t}(f)$$

subject to

$$Y_{t+j|t}(f) = Y_{t+j}\Big[\frac{P_t(f)}{P_{t+j}} \prod_{k=1}^{j} (\pi_{t+k-1}^{\gamma_p}\pi^{1-\gamma_p})\Big]^{-\theta_{t+j}^p}$$

where $\beta^j \frac{\Lambda_{t+j}}{\Lambda_t}$ shows the stochastic discount factor between period t and $t+j$. Solving the above problem, reoptimized price P_t^0 is given by

$$1 = \frac{E_t \sum_{j=0}^{\infty} (\beta\xi_p)^j \frac{(1+\lambda_{t+j}^p) mc_{t+j} \Lambda_{t+j} Y_{t+j}}{\lambda_{t+j}^p} \{\frac{P_t^0}{P_t} \prod_{k=1}^{j} [(\frac{\pi_{t+k-1}}{\pi})^{\gamma_p} \frac{\pi}{\pi_{t+k}}])\}^{-\frac{1+\lambda_{t+j}^w}{\lambda_{t+j}^w}}}{E_t \sum_{j=0}^{\infty} (\beta\xi_p)^j \frac{\Lambda_{t+j} Y t+j}{\lambda_{t+j}^p} \{\frac{P_t^0}{P_t} \prod_{k=1}^{j} [(\frac{\pi_{t+k-1}}{\pi})^{\gamma_p} \frac{\pi}{\pi_{t+k}}]\}^{-\frac{1}{\lambda_{t+j}^p}}} \tag{19}$$

equation (18) can be further reduced to

$$1 = (1-\xi_p)\left(\Big(\frac{P_t^0}{P_t}\Big)^{-\frac{1}{\lambda_t^p}} + \sum_{j=1}^{\infty} (\xi_p)^j \left\{\frac{P_{t-j}^0}{P_{t-j}} \prod_{k=1}^{j} \left[\Big(\frac{\pi_{t-k}}{\pi}\Big)^{\gamma_p} \frac{\pi}{\pi_{t-k+1}}\right]\right\}^{-\frac{1}{\lambda_t^p}}\right) \tag{20}$$

where $\lambda_t^p = 1/(\theta_t^p - 1)$ denotes the intermediate-good price markup.

2.3 Investment-good firms and capital-good firms

Investment-good firm f_i converts one unit of consumption goods into differentiated investment goods equal to Ψ_t units and supply them to capital-good firms. Capital-good firms accumulate capital K_t by choosing an optimal combination of investment goods $\{I_t(f_i)\}$ to make further investment I_t and purchasing $(1-\delta(u_t))K_{t-1}$ capital goods back from entrepreneurs. The accumulated capital K_t is again sold to entrepreneurs. Here, the level of IS technology Ψ_t is identical among investment-good firms and follows the process

$$\log\Psi_t = \log\psi + \log\Psi_{t-1} + z_t^{\psi}$$

where z_t^{ψ} a non-stationary IS technology shock.

Under monopolistic competition, investment-good firm f_i faces demand

$$I_t(f_i) = I_t\Big(\frac{P_t^i(f_i)}{P_t^i}\Big)^{-\theta_t^i} \tag{21}$$

and corresponding aggregate price of investment good price

$$P_t^i = \Big(\int_0^1 P_t^i(f_i)^{1-\theta_t^i} df_i\Big)^{1/(1-\theta_t^i)} \tag{22}$$

where $I_t = (\int_0^1 I_t(f_i)^{(\theta_t^i-1)/\theta_t^i} df_i)^{\theta_t^i/(\theta_t^i-1)}$, with $\theta_t^i > 1$ the substitution elasticity, and $P_t^i(f_i)$ is the price of investment goods produced by firm f_i set by maximizing profit $(P_t^i(f_i)/P_t - 1/\Psi_t)I_t(f_i)$.

Corresponding first order condition gives

$$P_t^i = P_t^i(f_i) = (1+\lambda_t^i)P_t/\Psi_t, \tag{23}$$

where $\lambda_t^i \equiv 1/(\theta_t^i - 1) > 0$ is the investment-good markup. Combining optimal choice of $P_t^i(f_i)$ with (21) and (22) leads to $P_t^i = P_t^i(f_i)$ and $I_t(f_i) = I_t$. Hence, the gross rate of change in the relative price of investment goods to consumption goods is given by

$$r_t^i = \frac{P_t^i/P_t}{P_{t-1}^i/P_{t-1}} = \frac{1+\lambda_t^i}{1+\lambda_{t-1}^i}\frac{\Psi_t}{\Psi_{t-1}}$$

Capital-good firms' problem is to choose optimal combination of investment goods $\{I_t(f_i)\}$ and maximize profit

$$E_t\sum_{j=0}^{\infty}\beta^j\frac{\Lambda_t}{\Lambda_{t-1}}\Big\{Q_{t+j}\Big[K_{t+j} - \big(1-\delta(u_{t+j})\big)K_{t+j-1}\Big] - \frac{P_{t+j}^i}{P_{t+j}}I_{t+j}\Big\}$$

subject to

$$K_t = (1-\delta(u_t))K_{t-1} + \exp(z_t^\nu)\Big(1 - S\Big(\frac{I_t/I_{t-1}}{z^*\psi}\Big)\Big)I_t \tag{24}$$

Here $S((I_t/I_{t-1})/(z^*\psi)) = (\zeta/2)[(I_t/I_{t-1})/(z^*\psi) - 1]^2$ is the adjustment cost with $\zeta > 0$, and z_t^ν represents MEI technology shock that affects the transformation of investment goods into capital goods.

The optimal decision is determined by equation (21) and first order condition

$$\frac{P_t^i}{P_t} = Q_t\exp(z_t^\nu)\Bigg[1 - S\Big(\frac{I_t/I_{t-1}}{z^*\psi}\Big) - S'\Big(\frac{I_t/I_{t-1}}{z^*\psi}\Big)\frac{I_t/I_{t-1}}{z^*\psi}\Bigg]$$

$$+E_t\beta\frac{\Lambda_{t+1}}{\Lambda_t}z^*\psi Q_{t+1}\exp(z_{t+1}^\nu)S'\Big(\frac{I_{t+1}/I_t}{z^*\psi}\Big)\Big(\frac{I_{t+1}/I_t}{z^*\psi}\Big)^2 \tag{25}$$

2.4 Central bank

The central bank is assumed to do two things in the model economy. First, it adjusts the policy rates according to a hybrid rule. Second, it directly controls the nominal money supply in the market according to a quantity rule. Both rules are defined as follows.

Formally, the form of the rule regarding policy rates is a linear combination of the Taylor-type rule proposed by KK (2014)

$$\begin{aligned}\log(r_t^n) &= \phi_r\log(r_{t-1}^n) + (1-\phi_r)\Big(\log r^n + \frac{\phi_\pi}{4}\sum_{j=0}^{3}\log(\frac{\pi_{t-j}}{\pi})\\ &+ \phi_y\log\frac{Y_t/Z_t^*}{y}\Big) + \phi_{\Delta y}\log\frac{Y_t/Y_{t-1}}{z^*} + z_t^r \end{aligned}\tag{26}$$

and the demand condition for real money balance of the representative household

$$\log r_t^n = -\log\left(1 - \frac{1}{\lambda_t} exp(z_t^b) exp\left(z_t^m\right)(m_t)^{-\sigma}\right). \tag{27}$$

Denote $W \in (0,\ 1]$ as the weight of the Taylor-type rule and *the hybrid rule* is given as

$$\begin{aligned}\log(r_t^n) \quad &= \quad (1-W)\Bigg(-\log\left(1 - \frac{1}{\lambda_t} exp(z_t^b) exp\left(z_t^m\right)(m_t)^{-\sigma}\right)\Bigg) \qquad (28)\\ &+ \quad W\Bigg(\phi_r \log(r_{t-1}^n) + (1-\phi_r)\big(\log r^n + \frac{\phi_\pi}{4}\sum_{j=0}^{3}\log(\frac{\pi_{t-j}}{\pi}) + \phi_y \log\frac{Y_t/Z_t^*}{y}\big) + \phi_{\Delta y}\log\frac{Y_t/Y_{t-1}}{z^*}\Bigg) + z_t^r\end{aligned}$$

where r^n is the gross steady-state policy rate, λ_t is the detrended marginal utility of consumption, defined later in Section 3, $m_t = M_t/P_t$ is the real money balance, z_t^m is the real money balance shock, $\phi_r \in [0,\ 1)$ represents the degree of policy rate smoothing, $\phi_\pi,\ \phi_y,\ \phi_{\Delta y} \geqslant 0$ represents the degrees of policy responses to inflation, output, and output growth, and z_t^r represents a policy rate shock and follows an AR(1) stochastic process.

The form of the rule regarding money supply is defined as in Christiano, Eichenbaum and Evan (2005)

$$M_t^s = \mu_t M_{t-1}^s$$

and

$$log\mu_t = log\mu_0 + z_t^{mg} \tag{29}$$

where M_t^s is the nominal money supply at time t and $M_t^s = M_t$ when market clears, μ_t is the gross growth rate of money supply, μ_0 is the gross steady state rate, and z_t^{mg} represents a money supply shock and follows an AR(1) stochastic process.

Discussion:

Equations (28) and (29) fully describe the central bank's behavior of the model economy.

If $0 < W < 1$, the central bank conducts monetary policy by adjusting the policy rates according to Equation (28). It manages the economy not only by responding to the inflation and output conditions like an advanced economy authority according to a pure Taylor rule, it also takes into account the real money demand of the households. Hence, it is a hybrid monetary policy rule. Equation (29) then pins down the nominal money when market clears and completes the model.

If $W = 1$, equation (28) is identical to equation (26) so the monetary policy rule of the model economy is a pure Taylor-type rule. Equation (29) clears the market for nominal money and the model is complete.

If $W = 0$, monetary policy is reduced to be in the pure quantity rule of equation (29). The central bank does not respond to any economic conditions except for determining the quantity of money supply. Households' demand function for real money balance, equation (27), pins down the interest rate and the rest of the economy is determined through the interest rate channel. The model is complete.

In a nutshell, equations (28) and (29) describe the central bank's behavior of the model economy in a generalized form that encompasses the pure Taylor rule and the quantity rule without imposing *ex ante* model restrictions. Results can be easily obtained by statistical readings of the posterior mean estimates of parameters.

2.5 System of equations

Consumption-good market clearing condition is

$$Y_t = C_t + \int_0^1 \frac{I_t(f_i)}{\Psi_t} df_i + gZ_t^* \exp(\tilde{z}_t^g) = C_t + \frac{I_t}{\Psi_t} + gZ_t^* \exp(\tilde{z}_t^g). \tag{30}$$

The system of equations consists of equations (3), (4), (7), (8), (9), (10), (11), (12), (13), (15), (16), (17), (19), (20), (23), (24), (25), (28), (29) and (30), together with the stochastic processes for those of thirteen exogenous shocks z_t^x, $x \in \{b,\ g,\ w,\ p,\ i,\ r,\ z,\ \psi,\ \nu,\ \mu,\ \eta,\ m,\ mg\}$, where z_t^b is the preference shock, $z_t^g = (g/y)\tilde{z}_t^g$ is the exogenous demand shock which is a shock to demand for consumption-good excluding that for consumption and investment, z_t^w is a composite shock to the labor disutility disturbance z_t^h and the wage markup λ_t^w, $z_t^p$and z_t^i are shocks associated with the intermediate-good price markup λ_t^p and the investment-good price markup λ_t^p, z_t^r is shock to monetary policy rate, z_t^z and z_t^ψ are neutral and IS technology shock, respectively, z_t^ν is marginal efficiency of investment shock, z_t^μ is a shock to external finance premium, z_t^η is a shock to net worth of entrepreneurs, and $z_t^\eta = \eta(r^E/z^* - 1)\tilde{z}_t^\eta$. Each of the thirteen exogenous shocks follows an AR(1) stationary stochastic process

$$z_t^x = \rho_x z_{t-1}^x + \varepsilon_t^x, \quad \varepsilon_t^x \sim \text{i.i.d. } N(0, \sigma_x^2), \quad x \in \{b,\ g,\ w,\ p,\ i,\ r,\ z,\ \psi,\ \nu,\ \mu,\ \eta,\ m,\ mg\}.$$

3 Estimation

3.1 Estimation methodology

We adopt a Bayesian likelihood approach from KK with twelve China quarterly time series: output Y_t, consumption C_t, investment I_t, labor (hours worked) h_t, the real wage W_t , the price of consumption goods P_t, the relative price of investment goods P_t^i/P_t, the monetary policy rate r_t^n, the loan rate $E_t(r_{t+1}^E \pi_{t+1})$, real loan L_t, real net worth N_t, and real money balance M_t/P_t. [6]

Before estimation, the equilibrium conditions presented in the previous section are rewritten in terms of detrended variables. As mentioned previously, the model economy consists a non-stationary stochastic technology trend Z_t^* and variables are detrended as $y_t = Y_t/Z_t^*$, $c_t = C_t/Z_t^*$, $w_t = W_t/Z_t^*$, $\lambda_t = \Lambda_t(Z_t^*)^\sigma$, $i_t = I_t/(Z_t^*\Psi_t)$, $k_t = K_t/(Z_t^*\Psi_t)$, $r_t^k = R_t^k\Psi_t^*$, $q_t = Q_t\Psi_t^*$, $n_t = N_t/Z_t^*$, $l_t = L_t/Z_t^*$ and $m_t = M_t/(Z_t^*P_t)$. The stationarized system is then log-linearized around its deterministic steady sate with capital utilization rate of unity (i.e. $u_{ss} = 1$). Details are reported in Appendix.

Following Smets and Wouters (2007), and KK (2014), we use the Kalman filter to evaluate the likelihood function for the log-linearized system and apply the Metropolis–Hastings algorithm to generate draws from the posterior distribution of model parameters.[7]

3.2 The Data

The data are obtained from CEIC China Premium Database and the sample period is 2001:Q1 to 2014:Q2. Data on prices is CPI index. Relative price of investment P_t^i/P_t is proxied using PPI divided by CPI. Data on nominal GDP, consumption, investment and wage is deflated with CPI index. Data on real loan is CPI-deflated. Real net worth is proxied by data on Shanghai Stock Exchange Composite Index deflated by CPI index. Reverse of City Labor Market Demand-Supply Ratio is used as proxy for labor and normalized to be equal to zero like Smets and Wouter (2007). SHIBOR is used as proxy for loan rate, and policy interest rate is household deposit saving rate.

[6]There are studies in the literature that have employed Bayesian estimation strategies for estimating the Chinese economy. Most of the data series are in small-scales. Wang and Tian (2014) apply a Bayesian estimation approach using four data series. Qiu and Zhou (2014) use two data series while Sun and Sen (2012) use seven data series.

[7]Our estimation is done using DYNARE (Adjemianetal, 2011). In each estimation, 200,000 draws were generated and the first half of these draws was discarded. The scale factor for the jumping distribution in the Metropolis–Hastings algorithm was adjusted so that an acceptance rate of around 24% was obtained.

Aggregate money supply is M_2. All series are seasonally adjusted. Corresponding observation equations are

$$\begin{bmatrix} 100\Delta\log Y_t \\ 100\Delta\log C_t \\ 100\Delta\log I_t \\ 100\Delta\log h_t \\ 100\Delta\log W_t \\ 100\Delta\log P_t \\ 100\Delta\log(P_t^i/P_t) \\ 100\Delta\log r_t^n \\ 100\Delta\log(r_t^E)Y_t \\ 100\Delta\log Y_t \\ 100\Delta\log Y_t \\ 100\Delta\log Y_t \end{bmatrix} = \begin{bmatrix} \overline{z^*} \\ \overline{z^*} \\ \overline{z^*}+\overline{\psi} \\ \overline{h} \\ \overline{z^*} \\ \overline{\pi} \\ -\overline{\psi} \\ \overline{r^n} \\ \overline{r^E}+\overline{\pi} \\ \overline{z^*} \\ \overline{z^*} \\ \overline{z^*}+\overline{\pi} \end{bmatrix} + \begin{bmatrix} z_t^* + \hat{y}_t - \hat{y}_{t-1} \\ z_t^* + \hat{c}_t - \hat{c}_{t-1} \\ z_t^* + z_t^{\psi} + \hat{\iota}_t - \hat{\iota}_{t-1} \\ \hat{h}_t \\ z_t^* + \hat{w}_t - \hat{w}_{t-1} \\ \hat{\pi}_t \\ -z_t^{\psi} + z_t^i - z_{t-1}^i \\ \hat{r}_t^n \\ E_t\hat{r}_{t+1}^E + E_t\hat{\pi}_{t+1} \\ z_t^* + \hat{l}_t - \hat{l}_{t-1} \\ z_t^* + \hat{n}_t - \hat{n}_{t-1} \\ z_t^* + \hat{\pi}_t + \hat{m}_t - \hat{m}_{t-1} \end{bmatrix}$$

where $\overline{z_t^*} = 100(z^* - 1)$, $\overline{\psi} = 100(\psi - 1)$, $\overline{\pi} = 100(\pi - 1)$, $\overline{r^n} = 100(r^n - 1)$, $\overline{r^E} = 100(r^E - 1)$, h is normalized to be equal to zero like Smets and Wouters (2007), and hatted variables represent log-deviations from their respective steady-state values.

3.3 Fixed parameters and prior distributions

There are two sets of parameters, one to be estimated while the other is fixed to avoid identification issue. The fixed parameters are depreciation rate δ, wage markup λ_w, the steady state investment-good price markup λ_i, and the steady-state ratio of exogenous demand to output g/y. δ is set to 0.025 per quarter, implying an annual depreciation rate 0.10 which is consistent with most empirical studies on Chinese economy. λ_w and λ_i are borrowed from KK (2014): $\lambda_w = 0.2$, $\lambda_i = 0.2$. g/y is set at the sample mean 0.212.

The prior distributions of the 49 parameters to be estimated are listed in Table 1. The prior distributions of the steady-state rates of balanced growth, IS technological change, inflation, real loan rate and policy rate (i.e., z^*, $\overline{\psi}$, $\overline{\pi}$, $\overline{r^E}$, $\overline{r^n}$) are set to be Gamma distributions with the standard deviation of 0.1 and the mean given by their respective sample mean. The prior distributions of the inter-temporal elasticity of substitution σ and the output elasticity of capital α are identical to those in KK. The prior means of σ and α are assumed to be 2 and 0.6, respectively, following Zhang (2009). The prior distribution of W is set to be Beta distribution with a prior mean 0.5 and domain (0,1), imposing no prior restriction on the hybrid policy rule. For the parameters of shocks, we choose the Beta distribution with the mean of 0.5 and the standard deviation of 0.2 for the persistence of each shock (i.e., ρ_x, $x \in \{b,\ g,\ w,\ p,\ i,\ r,\ z,\ \psi,\ \nu,\ \mu,\ \eta,\ m,\ mg\}$) and an Inverse Gamma distribution with the mean of 0.5 and the standard deviation of infinity for standard deviation of each innovation (i.e.,σ_x, $x \in \{b,\ g,\ w,\ p,\ i,\ r,\ z,\ \psi,\ \nu,\ \mu,\ \eta,\ m,\ mg\}$). The rest of the parameters have the same prior distribution as in KK model.

4 Results

In this section we present the results in three main parts. The first part reports the statistics of the posterior mean estimates of parameters over the sample period, 2001Q1-2014Q2. The possible change of policy rule is also considered in this part. The second part of the section presents variance decomposition of output, consumption, investment and loan based on the estimated model. Forecast error variance decomposition and historical decomposition are both reported. Through this exercise we are able to answer some fundamental questions about the main sources of the economic fluctuations in China. The final part is devoted to present the impulse responses to technology shocks and financial shocks.

4.1 Estimates of W

The first row of Table 1 reports the posterior mean of W and the 90% confidence interval. On the full sample period, W is estimated to be 0.56 and is statistically significant from zero. Equation (28) is in its general form. It is a hybrid monetary policy rule. In the past decade and more, the PBoC conducted monetary policy by adjusting the policy rate according to the real money level, inflation rate, output level and output growth in the economy with assigned weights. Other macroeconomic conditions were subsequently pinned down through the interest rate channel in equilibrium. This finding could serve as a benchmark approach for estimating China's monetary policy rules as macro and financial conditions in China evolve over time.

We also conduct subsample estimations searching for possible policy rule changes. During the sample period, there was a global breakdown of financial system which might cause some policy changes to the PBoC. Most recently, the PBoC officials have made several public speeches discussing the necessity of reforming monetary policy towards more price-tool based practices. These events inspired us. We set 2009Q1 as the potential changing point and estimate the model over the two subsamples, 2001Q1-2008Q4 and 2009Q1-2014Q2. Results are reported in Table 2 and 3.

As shown in Table 2 and 3, the mean estimates of W are nearly identical. There is no significant change of monetary policy around 2009. Even though the Global Financial Crisis has spread itself across nations since 2008-2009, there is no significant evidence that it actually affects the monetary policy practice of the PBoC. This could be true considering the financial size of China and the still restricted capital account managements. One needs to be cautious, however, not to interpret too much to this result. Financial reforms including reforming monetary policy framework and interest rate liberalization are an ongoing agenda in China,[8] although it might be difficult for this paper to examine any most recent possible changes of monetary policy, due to the very limited series of data. This leaves to future research.

4.2 Variance decompositions

This section reports the forecast error decompositions of the variances of output, consumption, investment and loan in Table 4 and historical decompositions of output and investment in Figures 1 and 2 based on the proceeding estimated model.

Table 4 shows the relative contribution of each shock to the variations of the output growth, consumption growth, investment growth and real loan growth at forecast horizons $T = 8$, 32 quarters, evalued at the posterior mean estimates of parameters. The main source of the output fluctuation is the exogenous demand shock. The second two important sources are the neutral technology shock and the preference shock. The investment-specific technology shock plays a small and yet increasing role in contributing to the output fluctuation from short-term (6%) to long-term (11%) horizons. The rest of the shocks are negligible. The preference shock is the dominant source of the consumption fluctuation, taking up nearly 70% of the variation. The neutral technology shock is the secondary source while the rest of the shocks all play minor roles. The variation in the investment growth is 50% explained by the investment-specific shock and 26% contributed by the net worth shock in the short-run. The IS shock becomes even more prominent in the long-run (61%). Intermediate-good markup also plays a small role in affecting the investment activities. The IS and net worth shocks are also playing a primary and secondary role, respectively, in explaining the fluctuations of the real loan. The shock to the marginal efficiency of investment (MEI) contributes marginally to the loan variation.

The results above demonstrate the main sources of the business fluctuations in China. The real sectors, that is, consumption-good sectors, are primarily driven by the neutral technology, preference and external demand shocks while the financial sectors are dominated by the IS technology and net worth shocks.

To get a closer look at the fundamentals of the business fluctuations in China, we present the historical decompositions of the percentage point deviations of the output and investment from their respective steady states in Figure 1 and 2. Figure 1 shows a steady decreasing trend of the output growth from around 2011 and the

[8] Transformation of China's monetary policy framework was included as an important reform agenda in the 12th Five-year Plan of the development and reforms of the financial sector published in September 2012.

neutral technology shock is the main negative contributor. It suggests that a structural break of the neutral technological development, from consistently positive in 2001-2007 to consistently negative in 2010-2014, has primarily contributed to the slowing down of China's GDP growth since 2010 that we discussed at the beginning of the paper. There is a drastic fall of the output growth from around mid-2008 to early 2009 in Figure 1. The time corresponds to the breakout of the global financial crisis. A sudden global meltdown of the financial system and then real economy overseas may affect the technology and production through trade and financial channels.

Figure 2 shows that the investment growth is on average positive and the net worth shock is the primary positive contributor. The IS technology is another key factor but its contribution is largely volatile. This means that the prosperity of investment is driven by the positive valuation of the net worth while the volatility of investment is resulted from its own technological development. Looking forward, one should be cautious about whether the good valuation of the net worth could continue and carefully monitor the evolvement of the investment activities.

Figure 1 and 2 together bring us another perspective of China's growth story: The investment was steadily growing while the economic growth showed a clear sign of slowing-down during the past decade.

4.3 Impulse responses

The section 4.1 has discussed the best-fit monetary policy rules for China. The section 4.2 has taken a variance decomposition view on the main sources of business fluctuations in key macroeconomic variables. In this section, we present the impulse responses to shocks to the monetary policy rate, the neutral technology and the net worth. The variables of interest are the growth rates of output, consumption, labor, investment, real loan, net worth, the deposit rate (policy rate), the loan rate, and the inflation rate. All shocks are positive and in one standard deviation. All figures are plotted at the posterior mean estimates of the respective variables and in 40 periods.

As shown in Figure 3, a positive shock to the monetary policy rate leads to a decrease in the output, consumption, labor (hours worked), investment, real loan, net worth and inflation. Loan rate increases due to the increase of the deposit rate (policy rate). These are the textbook responses to a tightening monetary policy shock.

Figure 4 shows the impulse responses to a production technology improvement shock. The output rises, so does the consumption. Labor services falls due to the improved productivity, so does the investment and loan. Net worth falls since the output is higher but the loan is reduced. Policy rate rises to adjust the economy from overheating. Loan rate rises and price falls consequently.

Figure 5 shows that a positive shock to the net worth increases the investment activities. The output is increasing by less than that of the investment. The consumption falls. Labor services increase to meet the higher production level. The price increases. The real loan decreases due to the rising net worth. The loan rate falls. Deposit rate rises in response to the rising output and inflation.

4.4 Discussions

Before closing this section, we would like to discuss the usefulness of the extended DSGE model we have used in this paper. First, financial frictions are indispensable in the model. We incorporate the financial intermediates and the financial friction into the model as we expect them to be important sources of business fluctuations in China as in the U.S.. The posterior mean estimate of the elasticity of external finance premium (i.e. μ in Table 1) shows statistical significance of the EF premium equation in the model. The important role of the net worth shock in explaining the investment fluctuations also proves this point.

Second, we specify the neutral technology and the IS technology as two types of technology for the consumption-good sector and investment-good sector. As demonstrated in Section 4.2, the neutral technology is the one of the main drivers of the output growth fluctuations while the IS technology and the net worth are the main drivers of the investment activities. Without the specification of the two types of technologies, one would be getting misleading results of the main sources of business fluctuations in China.

Finally, the hybrid monetary policy rule is obtained by constructing a generalized form of rule without imposing ex ante model restrictions and employing a Bayesian estimation strategy using actual Chinese data. This approach obtains the quality of serving as a benchmark for future researchers to estimate China's monetary policy rule as macroeconomic and financial conditions evolve over time.

5 Concluding remarks

Policymakers and scholars concerned about the recent economic slow-down in China. Our findings show that it is the negative neutral technology development that may have caused this output fluctuation. After supporting over thirty years of high-speed economic development, the growth potential of neutral technological advancement has shown a clear sign of slowing down. This has important policy implications of encouraging technological innovations and industrial upgrading in China.

We construct a rich DSGE model in this paper for the structural investigation of the Chinese economy. The results show that it captures important features of the economy that have not been found in previous studies using a simple model. For example, we find that China's monetary policy rule is a hybrid rule. The central bank of China conducts monetary policy by adjusting the policy rates in responses to inflation, output conditions as well as real money growth. Financial friction shocks are indispensable sources of the investment fluctuation. Neutral technology development was a consistently positive contributor to the output growth in 2001-2007 and became a negative contributor after 2010. Future work on sources of business fluctuations in China and China's monetary policy rule can draw on these results here in this paper.

Examining changes of monetary policy rules is left for future research. Although this paper finds no evident change of rules in around 2009, one should expect possible structural breaks of the monetary policy in the future, as China proceeds with the current financial reform agenda including reforming monetary policy framework and interest rate liberalization.

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Table 1: Prior and posterior distributions of parameters - full sample

Parameter		Prior			Posterior	
		Type	Mean	S.D.	Mean	90% interval
W	Weight on Taylor rule	B	0.5	0.1	0.5627	[0.3867 , 0.7318]
σ	Risk aversion	G	2	0.375	1.1618	[0.6637, 1.5714]
θ	Habit persistence	B	0.7	0.1	0.7301	[0.6188, 0.8502]
χ	Inverse of elasticity of labor supply	G	2	0.75	1.7895	[0.8799, 2.6787]
ζ	Elasticity of investment adjustment cost	G	4	1.5	2.3206	[1.2773, 3.3043]
τ	Inverse of elasticity of utilization rate adjustment cost	G	0.22	0.1	0.5012	[0.2414, 0.7439]
ϕ	Output share of fixed production cost	B	0.25	0.125	0.087	[0.0096, 0.1589]
α	Capital elasticity of output	B	0.6	0.1	0.1246	[0.0825, 0.1621]
γ_w	Wage indexation	B	0.5	0.15	0.3358	[0.1448, 0.522]
ξ_w	Wage stickiness	B	0.5	0.1	0.6856	[0.5744, 0.7915]
γ_p	Intermediate-good price indexation	B	0.5	0.15	0.3588	[0.1415, 0.5758]
ξ_p	Intermediate-good price stickiness	B	0.5	0.1	0.9138	[0.8257, 0.9529]
ϕ_r	Monetary policy rate smoothing	B	0.75	0.1	0.6656	[0.5029, 0.8296]
ϕ_π	Monetary policy response to inflation	G	1.5	0.25	1.7358	[1.2726, 2.2006]
ϕ_y	Monetary policy response to output	G	0.125	0.05	0.086	[0.0245, 0.1522]
$\phi_{\Delta y}$	Monetary policy response to output growth	G	0.125	0.05	0.1032	[0.0416, 0.1629]
$\overline{z^*}$	Steady-state rate of balanced growth	G	1.163	0.1	1.2603	[1.1203, 1.397]
$\overline{\psi}$	Steady-state rate of IS technological change	G	0.077	0.04	0.0743	[0.0134, 0.1316]
$\overline{h}$	Normalized steady-state hours worked	N	0	2	-1.5239	[-3.8969, 0.9668]
$\overline{\pi}$	Steady-state inflation rate	G	0.272	0.1	0.392	[0.2297, 0.5497]
$\overline{r^n}$	Steady-state policy rate	G	1.03	0.1	1.0574	[0.9337, 1.1861]
η	Entrepreneur survival probability	B	0.973	0.02	0.978	[0.959, 0.9982]
n/k	Steady-state net worth-capital ratio	B	0.5	0.07	0.3721	[0.2803, 0.4668]
μ	Elasticity of EF premium	G	0.07	0.02	0.0104	[0.0062, 0.0144]
$\overline{r^E}$	Steady-state real loan rate	G	1.242	0.05	1.2272	[1.1394, 1.3075]
ρ_b	Persistence of preference shock	B	0.5	0.2	0.2256	[0.0345, 0.4267]
ρ_g	Persistence of exogenous demand shock	B	0.5	0.2	0.9423	[0.905, 0.9798]
ρ_w	Persistence of wage shock	B	0.5	0.2	0.1834	[0.028, 0.3266]
ρ_p	Persistence of intermediate-good price markup shock	B	0.5	0.2	0.6468	[0.4214, 0.9176]
ρ_i	Persistence of investment-good price markup shock	B	0.5	0.2	0.8999	[0.8333, 0.9666]
ρ_z	Persistence of neutral technology shock	B	0.5	0.2	0.1744	[0.0441, 0.2931]
ρ_ψ	Persistence of IS technology shock	B	0.5	0.2	0.9605	[0.9346, 0.9839]
ρ_ν	Persistence of MEI shock	B	0.5	0.2	0.9777	[0.9689, 0.9869]
ρ_μ	Persistence of EF premium shock	B	0.5	0.2	0.5281	[0.3923, 0.6589]
ρ_η	Persistence of net worth shock	B	0.5	0.2	0.8913	[0.8139, 0.968]
ρ_m	Persistence of real money balance shock	B	0.5	0.2	0.5158	[0.1992, 0.8548]
ρ_r	Persistence of monetary policy shock in hybrid rule	B	0.5	0.2	0.3096	[0.0738, 0.5297]
ρ_{mg}	Persistence of monetary shock in quantity rule	B	0.5	0.2	0.2854	[0.1009, 0.4629]
σ_b	S.D. of preference shock innovation	IG	0.5	Inf	4.6469	[2.0929, 7.718]

Parameter		Prior			Posterior	
		Type	Mean	S.D.	Mean	90% interval
σ_g	S.D. of exogenous demand shock innovation	IG	0.5	Inf	0.9853	[0.8144, 1.1505]
σ_w	S.D. of wage shock innovation	IG	0.5	Inf	0.4934	[0.3762, 0.6043]
σ_p	S.D. of intermediate-good price markup shock innovation	IG	0.5	Inf	0.1905	[0.1206, 0.2597]
σ_i	S.D. of investment-good price markup shock innovation	IG	0.5	Inf	0.5721	[0.4598, 0.6756]
σ_z	S.D. of neutral technology shock innovation	IG	0.5	Inf	1.8033	[1.4941, 2.1381]
σ_ψ	S.D. of IS technology shock innovation	IG	0.5	Inf	0.4539	[0.3375, 0.5721]
σ_ν	S.D. of MEI shock innovation	IG	0.5	Inf	6.5571	[4.7881, 8.3668]
σ_μ	S.D. of EF premium shock innovation	IG	0.5	Inf	0.2748	[0.2196, 0.3239]
σ_η	S.D. of networth shock innovation	IG	0.5	Inf	2.3221	[1.4438, 3.212]
σ_m	S.D. of real money balance shock innovation	IG	0.5	Inf	0.4565	[0.1071, 0.8897]
σ_r	S.D. of monetary policy shock innovation in hybrid rule	IG	0.5	Inf	0.3054	[0.2543, 0.3526]
σ_{mg}	S.D. of monetary policy shock innovation in quantity rule	IG	0.5	Inf	0.5652	[0.4711, 0.6534]

Note: In the type of prior distributions, B, G, IG, and N stand for Beta, Gamma, Inverse Gamma, and Normal distributions, respectively.

Table 2: Prior and posterior distributions of parameters - 2001Q1-2008Q4

Parameter		Prior			Posterior	
		Type	Mean	S.D.	Mean	90% interval
W	Weight on Taylor rule	B	0.5	0.1	0.4312	[0.2765, 0.5841]
σ	Risk aversion	G	2	0.375	1.1247	[0.7471, 1.512]
θ	Habit persistence	B	0.7	0.1	0.554	[0.4117, 0.7026]
χ	Inverse of elasticity of labor supply	G	2	0.75	1.8544	[0.7685, 2.9074]
ζ	Elasticity of investment adjustment cost	G	4	1.5	2.6789	[1.2887, 4.0388]
τ	Inverse of elasticity of utilization rate adjustment cost	G	0.22	0.1	0.2587	[0.0917, 0.4296]
ϕ	Output share of fixed production cost	B	0.25	0.125	0.0772	[0.0092, 0.1399]
α	Capital elasticity of output	B	0.6	0.1	0.2412	[0.1528, 0.3247]
γ_w	Wage indexation	B	0.5	0.15	0.3549	[0.1432, 0.5567]
ξ_w	Wage stickiness	B	0.5	0.1	0.648	[0.5563, 0.7459]
γ_p	Intermediate-good price indexation	B	0.5	0.15	0.3939	[0.1615, 0.6158]
ξ_p	Intermediate-good price stickiness	B	0.5	0.1	0.7461	[0.6475, 0.8409]
ϕ_r	Monetary policy rate smoothing	B	0.75	0.1	0.8821	[0.7873, 0.9784]
ϕ_π	Monetary policy response to inflation	G	1.5	0.25	1.5018	[1.0845, 1.8846]
ϕ_y	Monetary policy response to output	G	0.125	0.05	0.0768	[0.0219, 0.1316]
$\phi_{\Delta y}$	Monetary policy response to output growth	G	0.125	0.05	0.147	[0.0613, 0.2275]
$\overline{z^*}$	Steady-state rate of balanced growth	G	1.163	0.1	1.2614	[1.1087, 1.4089]
$\overline{\psi}$	Steady-state rate of IS technological change	G	0.077	0.04	0.0701	[0.0159, 0.1236]
$\overline{h}$	Normalized steady-state hours worked	N	0	2	-0.4026	[-3.2324, 2.3199]
$\overline{\pi}$	Steady-state inflation rate	G	0.272	0.1	0.3701	[0.2051, 0.5315]
$\overline{r^n}$	Steady-state policy rate	G	1.03	0.1	0.9514	[0.8392, 1.0585]
η	Entrepreneur survival probability	B	0.973	0.02	0.9878	[0.9752, 0.9999]
n/k	Steady-state net worth-capital ratio	B	0.5	0.07	0.3375	[0.2309, 0.4424]

Parameter		Prior			Posterior	
		Type	Mean	S.D.	Mean	90% interval
μ	Elasticity of EF premium	G	0.07	0.02	0.0115	[0.0055, 0.0173]
$\overline{r^E}$	Steady-state real loan rate	G	1.242	0.05	1.2402	[1.1576, 1.3231]
ρ_b	Persistence of preference shock	B	0.5	0.2	0.2782	[0.0585, 0.4787]
ρ_g	Persistence of exogenous demand shock	B	0.5	0.2	0.7979	[0.6785, 0.9192]
ρ_w	Persistence of wage shock	B	0.5	0.2	0.2647	[0.047, 0.4756]
ρ_p	Persistence of intermediate-good price markup shock	B	0.5	0.2	0.8203	[0.689, 0.955]
ρ_i	Persistence of investment-good price markup shock	B	0.5	0.2	0.8399	[0.7274, 0.9619]
ρ_z	Persistence of neutral technology shock	B	0.5	0.2	0.4705	[0.2202, 0.7124]
ρ_ψ	Persistence of IS technology shock	B	0.5	0.2	0.1039	[0.0168, 0.1857]
ρ_ν	Persistence of MEI shock	B	0.5	0.2	0.9645	[0.9401, 0.9917]
ρ_μ	Persistence of EF premium shock	B	0.5	0.2	0.93	[0.8637, 0.9891]
ρ_η	Persistence of net worth shock	B	0.5	0.2	0.5554	[0.3934, 0.7186]
ρ_m	Persistence of real money balance shock	B	0.5	0.2	0.7973	[0.6316, 0.9693]
ρ_r	Persistence of monetary policy shock in hybrid rule	B	0.5	0.2	0.4988	[0.1633, 0.8169]
ρ_{mg}	Persistence of monetary shock in quantity rule	B	0.5	0.2	0.2482	[0.0522, 0.4386]
σ_b	S.D. of preference shock innovation	IG	0.5	Inf	3.3459	[1.576, 5.0406]
σ_g	S.D. of exogenous demand shock innovation	IG	0.5	Inf	1.4293	[1.0548, 1.7822]
σ_w	S.D. of wage shock innovation	IG	0.5	Inf	0.5259	[0.3569, 0.6855]
σ_p	S.D. of intermediate-good price markup shock innovation	IG	0.5	Inf	0.3222	[0.1724, 0.4716]
σ_i	S.D. of investment-good price markup shock innovation	IG	0.5	Inf	0.571	[0.392, 0.7412]
σ_z	S.D. of neutral technology shock innovation	IG	0.5	Inf	0.1356	[0.1058, 0.1646]
σ_ψ	S.D. of IS technology shock innovation	IG	0.5	Inf	1.6263	[1.2403, 2.0048]
σ_ν	S.D. of MEI shock innovation	IG	0.5	Inf	0.5442	[0.3299, 0.735]
σ_μ	S.D. of EF premium shock innovation	IG	0.5	Inf	8.0015	[5.408, 10.5661]
σ_η	S.D. of networth shock innovation	IG	0.5	Inf	0.2883	[0.1911, 0.3805]
σ_m	S.D. of real money balance shock innovation	IG	0.5	Inf	2.5511	[1.3864, 3.712]
σ_r	S.D. of monetary policy shock innovation in hybrid rule	IG	0.5	Inf	0.443	[0.1132, 0.9001]
σ_{mg}	S.D. of monetary policy shock innovation in quantity rule	IG	0.5	Inf	0.4088	[0.3156, 0.4999]

Note: In the type of prior distributions, B, G, IG, and N stand for Beta, Gamma, Inverse Gamma, and Normal distributions, respectively.

Table 3: Prior and posterior distributions of parameters - 2009Q1-2014Q2

Parameter		Prior			Posterior	
		Type	Mean	S.D.	Mean	90% interval
W	Weight on Taylor rule	B	0.5	0.1	0.4341	[0.2909, 0.5703]
σ	Risk aversion	G	2	0.375	1.5145	[1.1545, 1.8673]
θ	Habit persistence	B	0.7	0.1	0.6784	[0.6072, 0.7524]
χ	Inverse of elasticity of labor supply	G	2	0.75	2.0784	[0.9387, 3.1633]
ζ	Elasticity of investment adjustment cost	G	4	1.5	7.2277	[4.524, 9.8457]
τ	Inverse of elasticity of utilization rate adjustment cost	G	0.22	0.1	0.2025	[0.072, 0.3284]
ϕ	Output share of fixed production cost	B	0.25	0.125	0.1006	[0.0149, 0.188]

Parameter		Prior			Posterior	
		Type	Mean	S.D.	Mean	90% interval
α	Capital elasticity of output	B	0.6	0.1	0.2287	[0.1623, 0.2965]
γ_w	Wage indexation	B	0.5	0.15	0.5686	[0.3505, 0.7958]
ξ_w	Wage stickiness	B	0.5	0.1	0.6867	[0.568, 0.8043]
γ_p	Intermediate-good price indexation	B	0.5	0.15	0.72	[0.5482, 0.8927]
ξ_p	Intermediate-good price stickiness	B	0.5	0.1	0.8362	[0.7678, 0.9107]
ϕ_r	Monetary policy rate smoothing	B	0.75	0.1	0.7655	[0.6274, 0.9143]
ϕ_π	Monetary policy response to inflation	G	1.5	0.25	1.5162	[1.1195, 1.914]
ϕ_y	Monetary policy response to output	G	0.125	0.05	0.1087	[0.0382, 0.1745]
$\phi_{\Delta y}$	Monetary policy response to output growth	G	0.125	0.05	0.117	[0.0466, 0.184]
$\overline{z^*}$	Steady-state rate of balanced growth	G	1.163	0.1	1.2308	[1.0867, 1.3811]
$\overline{\psi}$	Steady-state rate of IS technological change	G	0.077	0.04	0.082	[0.0176, 0.1458]
$\overline{h}$	Normalized steady-state hours worked	N	0	2	-1.5403	[-4.0237, 0.9832]
$\overline{\pi}$	Steady-state inflation rate	G	0.272	0.1	0.343	[0.1741, 0.5067]
$\overline{r^n}$	Steady-state policy rate	G	1.03	0.1	1.0838	[0.931, 1.24]
η	Entrepreneur survival probability	B	0.973	0.02	0.968	[0.9425, 0.9944]
n/k	Steady-state net worth-capital ratio	B	0.5	0.07	0.4577	[0.3556, 0.5661]
μ	Elasticity of EF premium	G	0.07	0.02	0.0184	[0.01, 0.0267]
$\overline{r^E}$	Steady-state real loan rate	G	1.242	0.05	1.2339	[1.1548, 1.3144]
ρ_b	Persistence of preference shock	B	0.5	0.2	0.4753	[0.143, 0.7979]
ρ_g	Persistence of exogenous demand shock	B	0.5	0.2	0.9513	[0.9205, 0.9853]
ρ_w	Persistence of wage shock	B	0.5	0.2	0.389	[0.0784, 0.7126]
ρ_p	Persistence of intermediate-good price markup shock	B	0.5	0.2	0.7216	[0.5118, 0.9454]
ρ_i	Persistence of investment-good price markup shock	B	0.5	0.2	0.5812	[0.3211, 0.8481]
ρ_z	Persistence of neutral technology shock	B	0.5	0.2	0.187	[0.0264, 0.3377]
ρ_ψ	Persistence of IS technology shock	B	0.5	0.2	0.1134	[0.0235, 0.1984]
ρ_ν	Persistence of MEI shock	B	0.5	0.2	0.9319	[0.9035, 0.9607]
ρ_μ	Persistence of EF premium shock	B	0.5	0.2	0.9304	[0.8856, 0.9748]
ρ_η	Persistence of net worth shock	B	0.5	0.2	0.5117	[0.3113, 0.7117]
ρ_m	Persistence of real money balance shock	B	0.5	0.2	0.7017	[0.5482, 0.8587]
ρ_r	Persistence of monetary policy shock in hybrid rule	B	0.5	0.2	0.8723	[0.7971, 0.9498]
ρ_{mg}	Persistence of monetary shock in quantity rule	B	0.5	0.2	0.2322	[0.0668, 0.3853]
σ_b	S.D. of preference shock innovation	IG	0.5	Inf	0.4019	[0.1218, 0.7048]
σ_g	S.D. of exogenous demand shock innovation	IG	0.5	Inf	0.683	[0.5012, 0.8515]
σ_w	S.D. of wage shock innovation	IG	0.5	Inf	0.4368	[0.2745, 0.5815]
σ_p	S.D. of intermediate-good price markup shock innovation	IG	0.5	Inf	0.2361	[0.1454, 0.327]
σ_i	S.D. of investment-good price markup shock innovation	IG	0.5	Inf	0.3908	[0.2794, 0.497]
σ_z	S.D. of neutral technology shock innovation	IG	0.5	Inf	0.3661	[0.268, 0.4594]
σ_ψ	S.D. of IS technology shock innovation	IG	0.5	Inf	2.0403	[1.5396, 2.512]
σ_ν	S.D. of MEI shock innovation	IG	0.5	Inf	0.5628	[0.3931, 0.7318]
σ_μ	S.D. of EF premium shock innovation	IG	0.5	Inf	5.4299	[3.7458, 7.036]
σ_η	S.D. of networth shock innovation	IG	0.5	Inf	0.3492	[0.2591, 0.439]

Parameter		Prior Type	Prior Mean	Prior S.D.	Posterior Mean	Posterior 90% interval
σ_m	S.D. of real money balance shock innovation	IG	0.5	Inf	1.641	[0.977, 2.2975]
σ_r	S.D. of monetary policy shock innovation in hybrid rule	IG	0.5	Inf	30.4763	[9.1681, 51.4009]
σ_{mg}	S.D. of monetary policy shock innovation in quantity rule	IG	0.5	Inf	0.7144	[0.5461, 0.8705]

Note: In the type of prior distributions, B, G, IG, and N stand for Beta, Gamma, Inverse Gamma, and Normal distributions, respectively.

Table 4: Forecast error variance decompositions

		Output T=8	Output T=32	Consumption T=8	Consumption T=32	Investment T=8	Investment T=32	Loan T=8	Loan T=32
z^b	Preference	23.78	21.85	69.44	68.13	0.02	0.02	0.05	0.04
z^g	Exogenous demand	34.84	32.37	0.61	0.63	0.33	0.27	0.02	0.03
z^w	Wage	0.01	0.01	0.03	0.03	0.04	0.03	0.05	0.04
z^p	Intermediate-good price markup	4.42	5.01	2.85	3.12	6.85	5.74	5.59	4.5
z^i	Investment-good price markup	0.15	0.18	0	0	0.87	0.7	0.21	0.24
z^z	Neutral technology	23.94	22.43	23.37	23.4	1.42	1.26	1.15	1.78
z^ψ	IS technology	6.09	11.08	2.2	2.48	50.15	61.28	51.78	55.21
z^ν	MEI	2.49	2.51	0.26	0.62	11.8	9.4	8.45	10.12
z^μ	EF premium	0.12	0.12	0	0	0.73	0.48	1.07	0.82
z^η	Net worth	3.16	3.44	0.63	0.96	26.05	19.6	30.05	25.96
z^m	Real money growth	0	0	0	0	0	0	0	0
z^r	Hybrid monetary policy	0.55	0.52	0.29	0.28	1.09	0.72	1.48	1.13
z^{mg}	Quantitative monetary policy	0.46	0.49	0.33	0.34	0.66	0.52	0.1	0.13

Figure 1: Historical decomposition of output growth rate

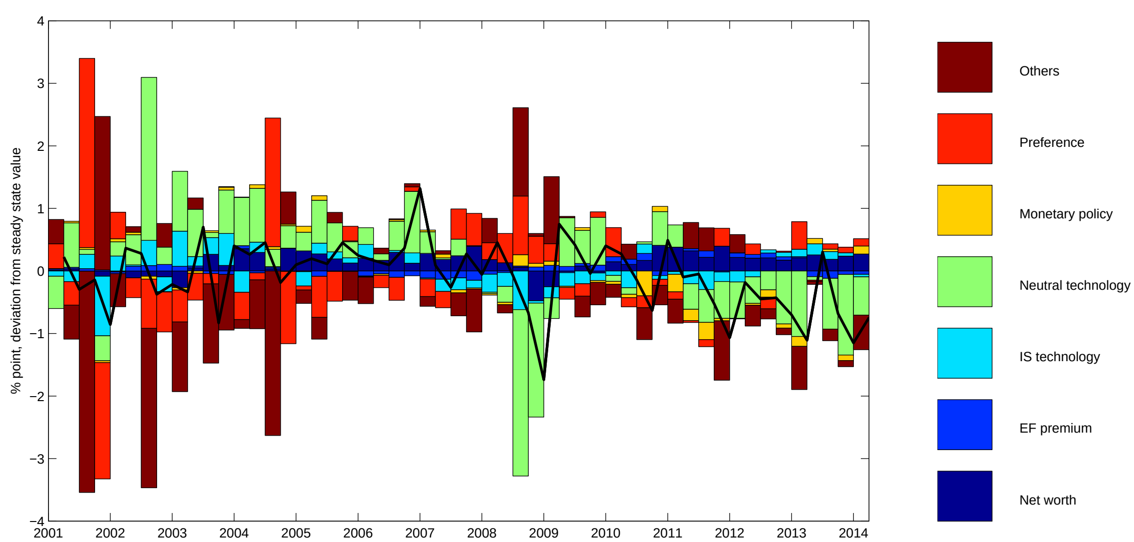


Figure 2: Historical decomposition of investment growth rate

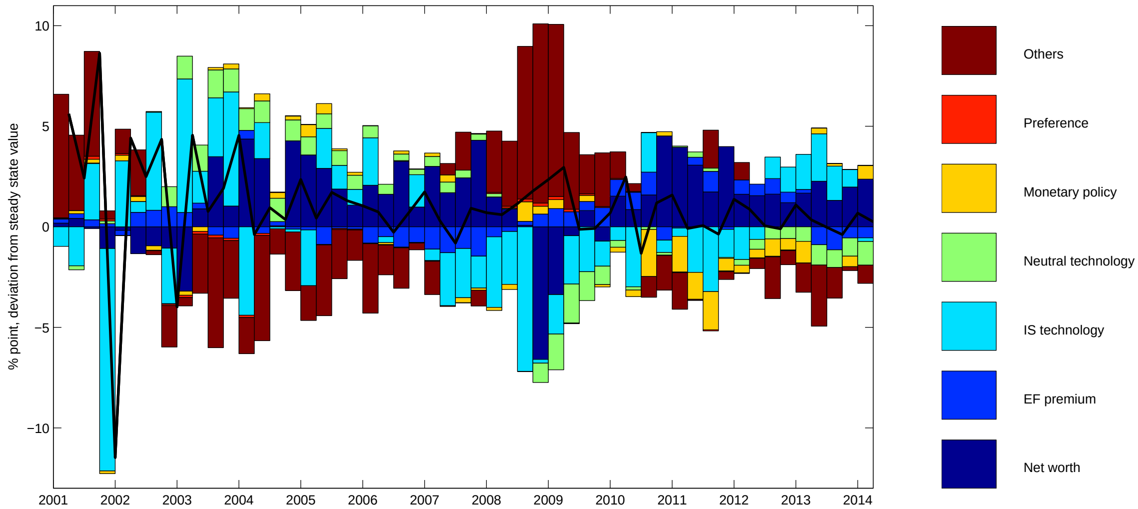


Figure 3: Impulse responses to monetary policy rate shock e_r (+1 s.d.)

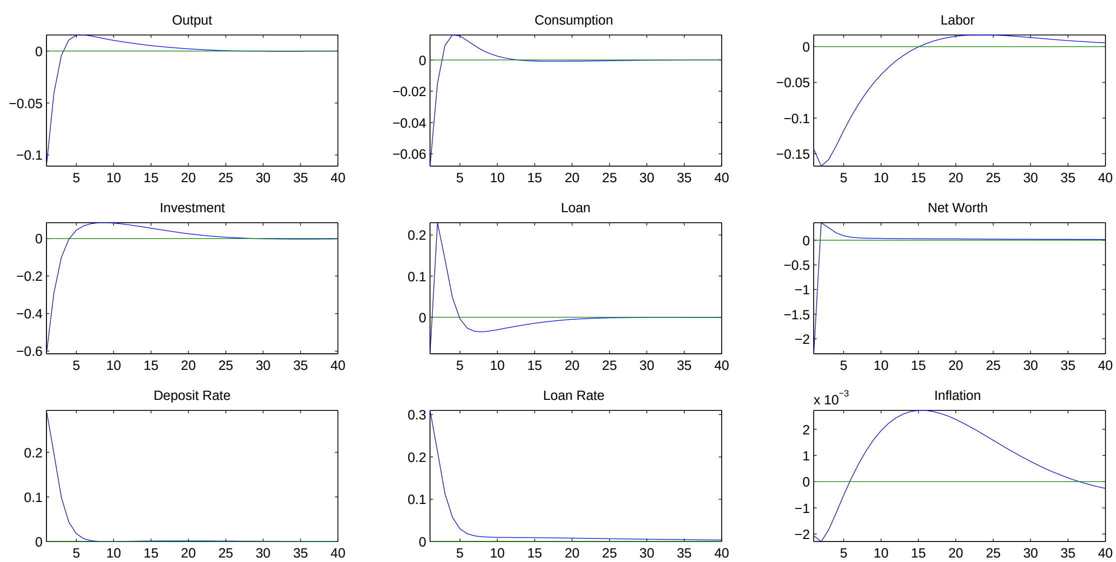


Figure 4: Impulse responses to neutral technology shock e_z (+1 s.d.)

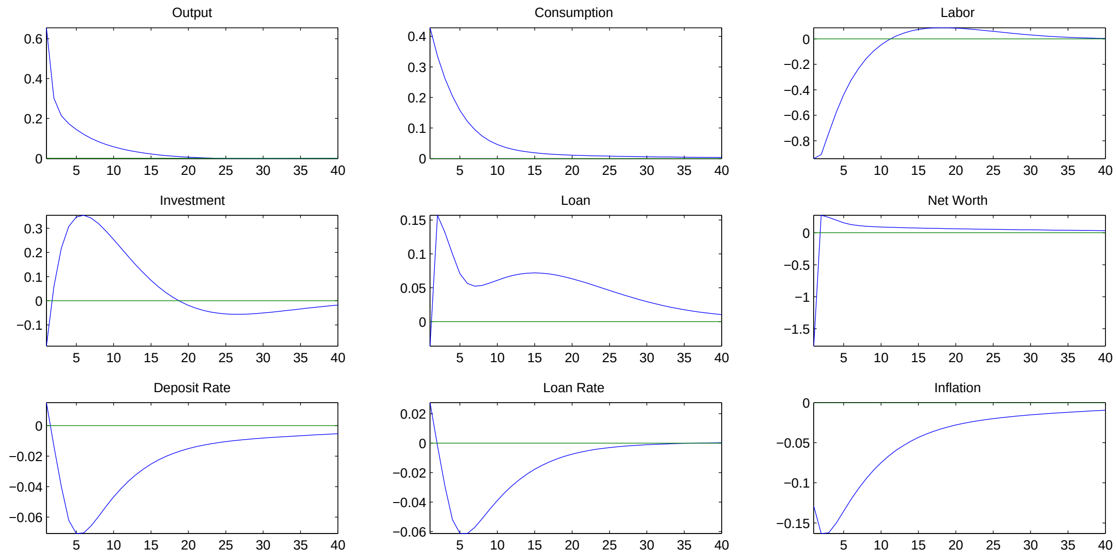
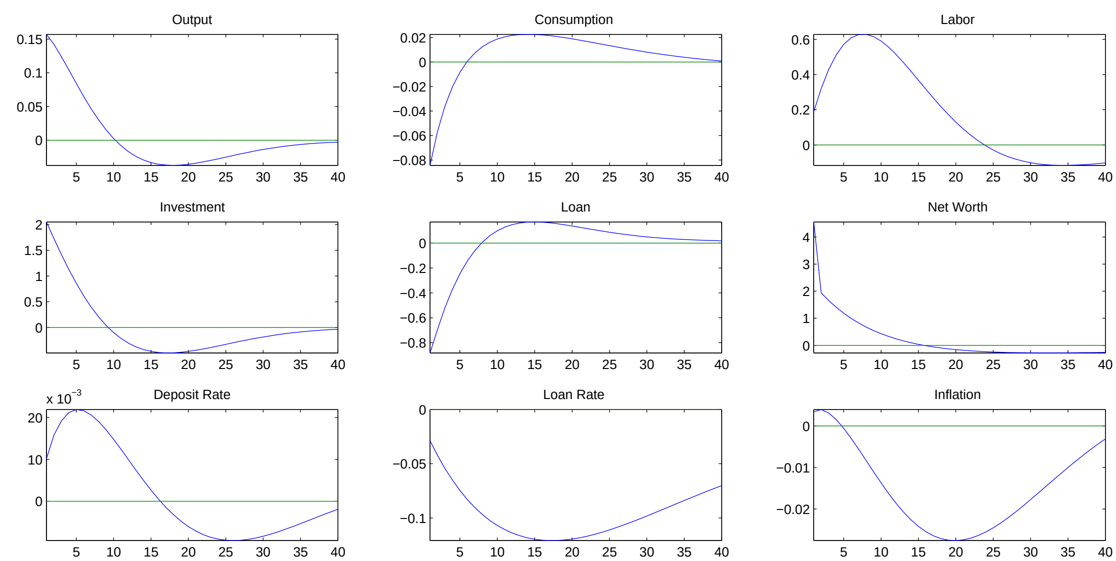


Figure 5: Impulse responses to net worth shock e_η (+1 s.d.)



Appendix

- log-linearized equilibrium conditions

$$\hat{\lambda}_t = -\frac{1}{1-\beta\theta(z^*)^{-\sigma}}\left\{\frac{\sigma}{1-\theta/z^*}\left[\hat{c}_t - \frac{\theta}{z^*}(\hat{c}_{t-1} - z_t^*)\right] - z_t^b\right\} + \frac{\beta\theta(z^*)^{-\sigma}}{1-\beta\theta(z^*)^{-\sigma}}\left[\frac{\sigma}{1-\theta/z^*}\left(E_t\hat{c}_{t+1} + E_t z_{t+1}^* - \frac{\theta}{z^*}\hat{c}_t\right) - E_t z_{t+1}^b\right]$$

$$\hat{\lambda}_t = E_t\hat{\lambda}_{t+1} - \sigma E_t z_{t+1}^* + \hat{r}_t^n - E_t\hat{\pi}_{t+1}$$

$$\hat{m}_t = -\frac{1}{\sigma}\left(\hat{\lambda}_t + \frac{1}{\bar{r}^n}\hat{r}_t^n - z_t^m - z_t^b\right)$$

$$\hat{w}_t = \hat{w}_{t-1} - \hat{\pi}_t + \gamma_w\hat{\pi}_{t-1} - z_t^* + \beta(z^*)^{1-\sigma}\left(E_t\hat{w}_{t+1} - \hat{w}_t + E_t\hat{\pi}_{t+1} - \gamma_w\hat{\pi}_t + E_t z_{t+1}^*\right)$$

$$+\frac{(1-\xi_w)(1-\beta(z^*)^{1-\sigma}\xi_w)}{\xi_w\{1+\chi(1+\lambda_w)/\lambda_w\}}\left(\chi\hat{h}_t - \hat{\lambda}_t - \hat{w}_t + z_t^b\right) + z_t^w$$

$$\hat{l}_t = \frac{1+\lambda^i}{1+\lambda^i - n/k}(\hat{q}_t + \hat{k}_t) + \left(1 - \frac{1+\lambda^i}{1+\lambda^i - n/k}\right)\hat{n}_t$$

$$E_t\hat{r}_{t+1}^E = \left(1 - \frac{1-\delta}{r^E\psi}\right)E_t\hat{r}_{t+1}^k + \frac{1-\delta}{r^E\psi}E_t\hat{q}_{t+1} - \hat{q}_t - E_t z_{t+1}^\psi$$

$$E_t\hat{r}_{t+1}^E = \hat{r}_t^n - E_t\hat{\pi}_{t+1} - \mu(\hat{n}_t - \hat{q}_t - \hat{k}_t) + z_t^\mu$$

$$\hat{n}_t = \frac{\eta r^E}{z^*}\left\{\frac{1+\lambda^i}{n/k}\left[\left(1 - \frac{1-\delta}{r^E\psi}\right)\hat{r}_t^k + \frac{1-\delta}{r^E\psi}\hat{q}_t - \hat{q}_{t-1} - z_t^\psi\right] - \left(\frac{1+\lambda^i}{n/k} - 1\right)E_{t-1}\hat{r}_t^E + \hat{n}_{t-1} - z_t^*\right\} + z_t^\eta$$

$$0 = \hat{w}_t + \hat{h}_t - \left(\hat{r}_t^k + \hat{u}_t + \hat{k}_{t-1} - z_t^* - z_t^\psi\right)$$

$$\hat{u}_t = \tau\left(\hat{r}_t^k - \hat{q}_t\right)$$

$$\widehat{mc}_t = (1-\alpha)\hat{w}_t + \alpha\hat{r}_t^k$$

$$\hat{\pi}_t = \gamma_p\hat{\pi}_{t-1} + \beta(z^*)^{1-\sigma}\left(E_t\hat{\pi}_{t+1} - \gamma_p\hat{\pi}_t\right) + \frac{(1-\xi_p)(1-\beta(z^*)^{1-\sigma}\xi_p)}{\xi_p}\widehat{mc}_t + z_t^p$$

$$\hat{y}_t = (1+\phi)\left[(1-\alpha)\hat{h}_t + \alpha(\hat{u}_t + \hat{k}_{t-1} - z_t^* - z_t^\psi)\right]$$

$$\hat{y}_t = \frac{c}{y}\hat{c}_t + \frac{i}{y}\hat{\imath}_t + z_t^g$$

$$\hat{k}_t = \frac{1-\delta-r^E\psi}{z^*\psi}\hat{u}_t + \frac{1-\delta}{z^*\psi}(\hat{k}_{t-1} - z_t^* - z_t^\psi) + \left(1 - \frac{1-\delta}{z^*\psi}\right)(\hat{\imath}_t + z_t^\nu)$$

$$\hat{q}_t = \zeta(\hat{\imath}_t - \hat{\imath}_{t-1} + z_t^* + z_t^\psi) - \beta(z^*)^{1-\sigma}\zeta\left(E_{t+1}\hat{\imath}_{t+1} - \hat{\imath}_t + z_{t+1}^* + z_{t+1}^\psi\right) - z_t^\nu + z_t^i$$

$$
\begin{cases}
\hat{r}^n_t = (1-W)\,(r^n-1)\left(-\hat{\lambda}_t - \sigma\hat{m}_t + z^b_t + z^m_t\right) & \\
+W\left[\phi_r \hat{r}^n_{t-1} + (1-\phi_r)\left(\frac{\phi_\pi}{4}\sum_{j=0}^{3}\hat{\pi}_{t-j} + \phi_y \hat{y}_t\right) + \phi_{\Delta y}\left(\hat{y}_t - \hat{y}_{t-1} + z^*_t\right)\right] + z^r_t & \text{if } W \in (0,\ 1] \\
\hat{r}^n_t = (1-W)\,(r^n-1)\left(-\hat{\lambda}_t - \sigma\hat{m}_t + z^b_t + z^m_t\right) & \text{if } W = 0
\end{cases}
$$

where hatted variables represent log-deviations from steady state values and $z^*_t = z^z_t + \alpha/(1-\alpha)z^\psi_t$.

- Steady-state conditions used in estimations:

$$
\beta = \frac{(z^*)^\sigma \pi}{r^n}, \qquad r^k = \frac{1+\lambda^i}{u}\left[r^E\psi - 1 + \delta\right], \qquad \lambda^p = \phi, \qquad w = (1-\alpha)\left[\frac{1}{1+\lambda^p}\left(\frac{\alpha}{r^k}\right)\right]^{\frac{1}{1-\alpha}}
$$

$$
\frac{h}{k} = \frac{1-\alpha}{\alpha}\frac{u}{z^*\psi}\frac{r^k}{w}, \qquad \frac{k}{y} = (1+\phi)\left(\frac{z^*\psi}{u}\right)^\alpha\left(\frac{h}{k}\right)^{1-\alpha}, \qquad \frac{i}{k} = 1 - \frac{1-\delta}{z^*\psi}, \qquad \frac{i}{y} = \frac{i}{k}\frac{k}{y}, \qquad \frac{c}{y} = 1 - \frac{g}{y} - \frac{i}{y}
$$