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CAMA Working Paper 10/2015  
April 2015

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### Abstract

In this paper, we aim to understand how monetary policy is conducted in China and what the main sources of fluctuations in China's business cycle are. 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 GDP growth since 2010.

## **Keywords**

Monetary policy, business fluctuation, Bayesian estimation, dynamic stochastic general equilibrium model, China

## **JEL Classification**

E32, E43, E52

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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 the main sources of fluctuations in China's business cycle are. 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 GDP growth since 2010.

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\*We are greatly indebted to Ipeei Fujiwara for his invaluable guidance. We are also grateful to Shiro Armstrong, Yiping Huang and Paul Kitney for their useful suggestions and comments at various stages of this work. All errors are those of the authors.

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# 1 Introduction

Since around 2010, China has been experiencing a gradual slow-down of GDP growth from an average of 10 per cent over the thirty years to 2010 to 7.4 per cent in 2014.<sup>1</sup> Chinese President Xi Jinping described this as the 'new normal' of the Chinese economy in May 2014.<sup>2</sup> 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 its sources. This motivates us to conduct a structural investigation of the Chinese economy to better understand the sources of business fluctuations in China, especially fluctuations in output.

There is one puzzle that needs to be solved before we can proceed with the structural investigation. China's monetary policy is the puzzle. On the 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, let alone 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.<sup>3</sup> 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 Taylor-type rules and 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 outperform a single rule in a four-equation New Keynesian model.<sup>4</sup> 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. Firstly, the central bank of China has been employing a hybrid 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; secondly, 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; thirdly, while the consistently positive net worth shocks explain the steady growth of the investment, the negative neutral technology shocks have been the main contributor 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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<sup>1</sup>The GDP growth rate in 2011, 2012 and 2013 are 9.5%, 7.7% and 7.7%, respectively. Source: the National Bureau of Statistics of China.

<sup>2</sup>See, for example, the Xinhua news report titled Xi's "new normal" theory. [http://news.xinhuanet.com/english/china/2014-11/09/c\\_133776839.htm](http://news.xinhuanet.com/english/china/2014-11/09/c_133776839.htm)

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

<sup>4</sup>Note that Liu and Zhang (2010) use the concept of a '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

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

subject to the budget constraint

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

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 the elasticity of labor supply,  $z_t^b$  is the intertemporal preference shock,  $z_t^h$  and  $z_t^m$  represent the 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 <sup>5</sup>

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

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

where  $\Lambda_t$  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  $h_t(m) = h_t (W_t(m)/W_t)^{-\theta_t^w}$ , 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

<sup>5</sup>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  $W_t = \left[ \int_0^1 (W_t(m))^{1-\theta_t^w} dm \right]^{1/(1-\theta_t^w)}$  is the aggregate wage. The nominal wage is adjusted according to a 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 remaining fraction  $\xi_w$  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

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

subject to

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

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

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

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

The aggregate wage in equation (5) is reduced to

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

## 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 obtain a 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 the 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 of their 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  $1 - \eta_t \in (0, 1)$  of entrepreneurs becomes workers, while the remaining  $\eta_t$  survives into the 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.  $\delta(\cdot)$  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 the resultant 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

$$R_t^k = Q_t \delta'(u_t) \quad (9)$$

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

where the EF premium function  $F(\cdot)$  depends on entrepreneurs' leverage ratio  $Q_t K_t / N_t$  and satisfies  $F' > 0$  and  $\mu = (QK/N)F'(QK/N)/F(QK/N) \geq 0$  as in regular DSGE models with a financial accelerator mechanism, such as in Hirose (2008).  $z_t^\mu$  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

$$E_t r_{t+1}^E = E_t \frac{r_t^n}{\pi_{t+1}} F\left(\frac{Q_t K_t}{N_t}\right) \exp(z_t^\mu) \quad (11)$$

Evolution of net worth  $N_t$  is

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

where  $\chi$  is a constant,  $\chi Z_t^*$  represents the transfer from entrepreneurs who become workers to surviving entrepreneurs,  $\eta_t$  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, and  $r_t^E$  is the ex-post marginal return on capital and given by

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

## 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

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

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.  $h_t(f) = \left[ \int_0^1 (h_t(m, f))^{\theta_t^w - 1} / \theta_t^w dm \right]^{\theta_t^w / (\theta_t^w - 1)}$  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 the zero profit condition holds at the 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  $\Psi_t$  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  $\psi$  is the steady-state rate of  $\Psi_t$ .

From the first order conditions for optimal labor and capital inputs we obtain

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

and the real marginal cost is given by

$$mc_t = \left( \frac{W_t}{(1 - \alpha) Z_t} \right)^{1-\alpha} \left( \frac{R_t^k}{\alpha} \right)^\alpha \quad (16)$$

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

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

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  $Y_t(f) = Y_t(P_t(f)/P_t)^{-\theta_t^p}$ .

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

$$P_t = \left( \int_0^1 P_t(f)^{1-\theta_t^p} df \right)^{\frac{1}{1-\theta_t^p}} \quad (18)$$

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

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

subject to

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

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

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

equation (18) can be further reduced to

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

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

### 2.3 Investment-good firms and capital-good firms

The investment-good firm  $f_i$  converts one unit of consumption goods into differentiated investment goods equal to  $\Psi_t$  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  $\Psi_t$  is identical across investment-good firms and follows the process

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

where  $z_t^\psi$  is a non-stationary IS technology shock.



Under monopolistic competition, the investment-good firm  $f_i$  faces demand

$$I_t(f_i) = I_t \left( \frac{P_t^i(f_i)}{P_t^i} \right)^{-\theta_t^i} \quad (21)$$

and corresponding aggregate price of investment good price

$$P_t^i = \left( \int_0^1 P_t^i(f_i)^{1-\theta_t^i} df_i \right)^{1/(1-\theta_t^i)} \quad (22)$$

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

The corresponding first order condition gives

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

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

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

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

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

subject to

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

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  $z_t^\nu$  represents an MEI technology shock that affects the transformation of investment goods into capital goods.

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

$$\begin{aligned} \frac{P_t^i}{P_t} &= Q_t \exp(z_t^\nu) \left[ 1 - S\left(\frac{I_t/I_{t-1}}{z^*\psi}\right) - S'\left(\frac{I_t/I_{t-1}}{z^*\psi}\right) \frac{I_t/I_{t-1}}{z^*\psi} \right] \\ &+ E_t \beta \frac{\Lambda_{t+1}}{\Lambda_t} z^*\psi Q_{t+1} \exp(z_{t+1}^\nu) S'\left(\frac{I_{t+1}/I_t}{z^*\psi}\right) \left(\frac{I_{t+1}/I_t}{z^*\psi}\right)^2 \end{aligned} \quad (25)$$

## 2.4 Central bank

The central bank is assumed to do two things in the model economy. First, it adjusts the policy rate 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 the policy rate is a linear combination of the Taylor-type rule proposed

by KK (2014)

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

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

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

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

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

where  $r^n$  is the gross steady-state policy rate,  $\lambda_t$  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,  $\phi_\pi, \phi_y, \phi_{\Delta y} \geq 0$  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 the money supply is defined as in Christiano, Eichenbaum and Evan (2005)

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

and

$$\log \mu_t = \log \mu_0 + z_t^{mg} \quad (29)$$

where  $M_t^s$  is the nominal money supply at time  $t$  and  $M_t^s = M_t$  when the market clears,  $\mu_t$  is the gross growth rate of the money supply,  $\mu_0$  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 in the model economy.

If  $0 < W < 1$ , the central bank conducts monetary policy by adjusting the policy rate according to Equation (28). It manages the economy not only by responding to inflation and output conditions like an advanced economy's authority according to a pure Taylor rule, but also by taking into account the real money demand of households. Hence, it is a hybrid monetary policy rule. Equation (29) then pins down the nominal money when the 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 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 for real money balances, given by 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 in 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

The consumption-good market clearing condition is

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

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 the 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 the consumption-good excluding that for consumption  $C_t$  and investment  $I_t/\Psi_t$ ,  $z_t^w$  is a composite shock to the labor disutility disturbance  $z_t^h$  and the wage markup  $\lambda_t^w$ ,  $z_t^p$  and  $z_t^i$  are shocks associated with the intermediate-good price markup  $\lambda_t^p$  and the investment-good price markup  $\lambda_t^i$ ,  $z_t^r$  is a shock to the monetary policy rate,  $z_t^z$  and  $z_t^\psi$  are neutral and IS technology shocks, respectively,  $z_t^\nu$  is the marginal efficiency of investment shock,  $z_t^\mu$  is a shock to the external finance premium,  $z_t^\eta$  is a shock to the net worth of entrepreneurs, with  $z_t^\eta = \eta(r^E/z^* - 1)\tilde{z}_t^\eta$ . 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 loans  $L_t$ , real net worth  $N_t$ , and real money balances  $M_t/P_t$ .<sup>6</sup>

Before estimation, the equilibrium conditions presented in the previous section are rewritten in terms of detrended variables. As mentioned previously, the model economy consists of 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 state with a capital utilization rate of unity (i.e.  $u_{ss} = 1$ ). Details are reported in the 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<sup>7</sup>.

### 3.2 The Data

The data are obtained from the CEIC China Premium Database and the sample period is 2001:Q1 to 2014:Q2.

<sup>6</sup>There are studies in the literature that have employed Bayesian estimation strategies for estimating the Chinese economy. Most of the data series are small-scale. 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.

<sup>7</sup>Our estimation is done using DYNARE (Adjemian et al., 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.

Data on prices is from the CPI. The relative price of investment  $P_t^i/P_t$  is proxied with the PPI divided by CPI. Data on nominal GDP, consumption, investment and wages is deflated with the CPI. Data on real loans is CPI-deflated. Real net worth is proxied by data on the Shanghai Stock Exchange Composite Index deflated by CPI. The inverse of the City Labor Market Demand-Supply Ratio is used as a proxy for labor and normalized to be equal to zero as in Smets and Wouter (2007). SHIBOR is used as a proxy for the loan rate, and the policy interest rate is the household deposit saving rate. The aggregate money supply is  $M_2$ . All series are seasonally adjusted. Corresponding observation equations are

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

where  $\overline{z_t^*} = 100(z^* - 1)$ ,  $\overline{\psi} = 100(\psi - 1)$ ,  $\overline{\pi} = 100(\pi - 1)$ ,  $\overline{r^n} = 100(r^n - 1)$ ,  $\overline{r^E} = 100(r^E - 1)$ , 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 any identification issue. The fixed parameters are the depreciation rate  $\delta$ , the wage markup  $\lambda_w$ , the steady state investment-good price markup  $\lambda_i$ , and the steady-state ratio of exogenous demand to output  $g/y$ .  $\delta$  is set to 0.025 per quarter, implying an annual depreciation rate of 0.10 which is consistent with most empirical studies on the Chinese economy.  $\lambda_w$  and  $\lambda_i$  are taken 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, the real loan rate and the policy rate (i.e.,  $z^*$ ,  $\overline{\psi}$ ,  $\overline{\pi}$ ,  $\overline{r^E}$ ,  $\overline{r^n}$ ) are set to be Gamma distributions with a standard deviation of 0.1 and the mean given by their respective sample mean. The prior distributions of the inter-temporal elasticity of substitution  $\sigma$  and the output elasticity of capital  $\alpha$  are identical to those in KK. The prior means of  $\sigma$  and  $\alpha$  are assumed to be 2 and 0.6, respectively, following Zhang (2009). The prior distribution of  $W$  is set to be a 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 a mean of 0.5 and a standard deviation of 0.2 for the persistence of each shock (i.e.,  $\rho_x$ ,  $x \in \{b, g, w, p, i, r, z, \psi, \nu, \mu, \eta, m, mg\}$ ) and an Inverse Gamma distribution with a mean of 0.5 and a standard deviation of infinity for the standard deviation of each innovation (i.e.,  $\sigma_x$ ,  $x \in \{b, g, w, p, i, r, z, \psi, \nu, \mu, \eta, m, mg\}$ ). The rest of the parameters have the same prior distribution as in the 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. A possible change of policy rule is also considered in this part. The second part of the section presents variance decompositions of output, consumption, investment and loans based on the estimated model. Both forecast error variance decompositions and historical decompositions are reported. Through this exercise we are able to answer some fundamental questions about the main sources of economic fluctuations in China. The final part presents 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 different from zero. Equation (28) is in its general form. It is a hybrid monetary policy rule. Over the past decade or so, 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 the financial system which might have caused some policy changes to the PBoC. Most recently, PBoC officials have made several public speeches discussing the necessity of reforming monetary policy towards more price-tool based practices. We set 2009Q1 as the potential change 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 had major impacts on many nations since 2008, there is no significant evidence that it has actually affected the monetary policy practice of the PBoC. This could be true considering the financial size of China and the still restricted capital account management. One needs to be cautious, however, not to interpret too much in this result. Financial reform, including reforming monetary policy framework and interest rate liberalization, are an ongoing agenda in China,<sup>8</sup> although examining any recent changes to monetary policy is outside the scope of this paper due to limited data. This would be a useful extension of this paper and is a fruitful avenue for future research.

### 4.2 Variance decompositions

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

Table 4 shows the relative contribution of each shock to the variations of output growth, consumption growth, investment growth and real loan growth at forecast horizons  $T = 8, 32$  quarters, evaluated 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, making up nearly 70% of the variation. The neutral technology shock is the secondary source while the rest of the shocks all play minor roles. Half of the variation in investment growth is explained by the investment-specific shock, while 26% is explained by the net worth shock in the short-run. The IS shock becomes even more prominent in the long-run (61%). The intermediate-good markup also plays a small role in affecting investment activities. The IS and net worth shocks also play a primary and secondary role, respectively, in explaining the fluctuations of real loans. The shock to the marginal efficiency of investment (MEI) contributes marginally to the loan variation.

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

The results above demonstrate the main sources of 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 business fluctuations in China, we present the historical decompositions of the percentage point deviations of output and investment from their respective steady states in Figure 1 and 2. Figure 1 shows a steady decreasing trend of output growth from around 2011 and the neutral technology shock is the main negative contributor. It suggests that a structural break of neutral technological development, from consistently positive in 2001-2007 to consistently negative in 2010-2014, has been the primary driver of the slowing down of China's GDP growth since 2010 that we discussed at the beginning of the paper. There is a drastic fall in output growth from around mid-2008 to early 2009 in Figure 1. This corresponds to the onset of the global financial crisis. A sudden global meltdown of the financial system and then of the real economy overseas may affect technology and production through trade and financial channels.

Figure 2 shows that 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 volatile. This means that growth in investment is driven by the positive valuation of net worth while the volatility of investment is driven by its own technological development. Looking forward, we should be cautious about whether these valuation effects on net worth can continue and carefully monitor the evolution of investment activities.

Figure 1 and 2 together bring us another perspective on China's growth story: investment was steadily growing while economic growth showed clear signs of slowing down over the past decade.

### 4.3 Impulse responses

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

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

Figure 4 shows the impulse responses to a production technology improvement shock. Output rises, so does consumption. Labor services fall due to improved productivity, as do investment and loans. Net worth falls since output is higher but loans are reduced. The policy rate rises to prevent the economy from overheating. The loan rate rises and prices fall as a result.

Figure 5 shows that a positive shock to net worth increases investment activities. Output is increasing by less than investment. Consumption falls. Labor services increase to meet the higher production level. The price level increases. Real loans decrease due to rising net worth. The loan rate falls. The deposit rate rises in response to 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 financial intermediates and financial frictions 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.  $\mu$  in Table 1) shows that EF premium equation is statistically significant in the model. The important role of the net worth shock in explaining investment fluctuations also proves this point.

Second, we specify neutral technology and 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 output growth fluctuations while the IS technology and net worth are the main drivers of investment activities. Without the specification of the two types of technologies, we would obtain misleading results of the main sources of business fluctuations in China.

Finally, a 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 can serve 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 are increasingly concerned with the recent economic slow-down in China. Our findings show that it is the negative neutral technology development that has caused this output fluctuation. After over thirty years of driving high-speed economic development, the growth potential of neutral technological advancement has shown a clear sign of slowing down. This has the important policy implication 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 rate in response to inflation, output conditions as well as real money growth. Financial friction shocks are indispensable sources of investment fluctuation. Neutral technology development was a consistently positive contributor to output growth during the period 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 in this paper.

Examining possible changes of monetary policy rules is left for future research. Although this paper finds no evidence for change of rules around 2009, one should expect possible structural breaks of the monetary policy in the future, as China proceeds with its current financial reform agenda including reforming the 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 ]
$\sigma$	Risk aversion	G	2	0.375	1.1618	[0.6637, 1.5714]
$\theta$	Habit persistence	B	0.7	0.1	0.7301	[0.6188, 0.8502]
$\chi$	Inverse of elasticity of labor supply	G	2	0.75	1.7895	[0.8799, 2.6787]
$\zeta$	Elasticity of investment adjustment cost	G	4	1.5	2.3206	[1.2773, 3.3043]
$\tau$	Inverse of elasticity of utilization rate adjustment cost	G	0.22	0.1	0.5012	[0.2414, 0.7439]
$\phi$	Output share of fixed production cost	B	0.25	0.125	0.087	[0.0096, 0.1589]
$\alpha$	Capital elasticity of output	B	0.6	0.1	0.1246	[0.0825, 0.1621]
$\gamma_w$	Wage indexation	B	0.5	0.15	0.3358	[0.1448, 0.522]
$\xi_w$	Wage stickiness	B	0.5	0.1	0.6856	[0.5744, 0.7915]
$\gamma_p$	Intermediate-good price indexation	B	0.5	0.15	0.3588	[0.1415, 0.5758]
$\xi_p$	Intermediate-good price stickiness	B	0.5	0.1	0.9138	[0.8257, 0.9529]
$\phi_r$	Monetary policy rate smoothing	B	0.75	0.1	0.6656	[0.5029, 0.8296]
$\phi_\pi$	Monetary policy response to inflation	G	1.5	0.25	1.7358	[1.2726, 2.2006]
$\phi_y$	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]
$\bar{z}^*$	Steady-state rate of balanced growth	G	1.163	0.1	1.2603	[1.1203, 1.397]
$\bar{\psi}$	Steady-state rate of IS technological change	G	0.077	0.04	0.0743	[0.0134, 0.1316]
$\bar{h}$	Normalized steady-state hours worked	N	0	2	-1.5239	[-3.8969, 0.9668]
$\bar{\pi}$	Steady-state inflation rate	G	0.272	0.1	0.392	[0.2297, 0.5497]
$\bar{r}^n$	Steady-state policy rate	G	1.03	0.1	1.0574	[0.9337, 1.1861]
$\eta$	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]
$\mu$	Elasticity of EF premium	G	0.07	0.02	0.0104	[0.0062, 0.0144]
$\bar{r}^E$	Steady-state real loan rate	G	1.242	0.05	1.2272	[1.1394, 1.3075]
$\rho_b$	Persistence of preference shock	B	0.5	0.2	0.2256	[0.0345, 0.4267]
$\rho_g$	Persistence of exogenous demand shock	B	0.5	0.2	0.9423	[0.905, 0.9798]
$\rho_w$	Persistence of wage shock	B	0.5	0.2	0.1834	[0.028, 0.3266]
$\rho_p$	Persistence of intermediate-good price markup shock	B	0.5	0.2	0.6468	[0.4214, 0.9176]
$\rho_i$	Persistence of investment-good price markup shock	B	0.5	0.2	0.8999	[0.8333, 0.9666]
$\rho_z$	Persistence of neutral technology shock	B	0.5	0.2	0.1744	[0.0441, 0.2931]
$\rho_\psi$	Persistence of IS technology shock	B	0.5	0.2	0.9605	[0.9346, 0.9839]
$\rho_\nu$	Persistence of MEI shock	B	0.5	0.2	0.9777	[0.9689, 0.9869]
$\rho_\mu$	Persistence of EF premium shock	B	0.5	0.2	0.5281	[0.3923, 0.6589]
$\rho_\eta$	Persistence of net worth shock	B	0.5	0.2	0.8913	[0.8139, 0.968]
$\rho_m$	Persistence of real money balance shock	B	0.5	0.2	0.5158	[0.1992, 0.8548]
$\rho_r$	Persistence of monetary policy shock in hybrid rule	B	0.5	0.2	0.3096	[0.0738, 0.5297]
$\rho_{m.g}$	Persistence of monetary shock in quantity rule	B	0.5	0.2	0.2854	[0.1009, 0.4629]
$\sigma_b$	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
$\sigma_g$	S.D. of exogenous demand shock innovation	IG	0.5	Inf	0.9853	[0.8144, 1.1505]
$\sigma_w$	S.D. of wage shock innovation	IG	0.5	Inf	0.4934	[0.3762, 0.6043]
$\sigma_p$	S.D. of intermediate-good price markup shock innovation	IG	0.5	Inf	0.1905	[0.1206, 0.2597]
$\sigma_i$	S.D. of investment-good price markup shock innovation	IG	0.5	Inf	0.5721	[0.4598, 0.6756]
$\sigma_z$	S.D. of neutral technology shock innovation	IG	0.5	Inf	1.8033	[1.4941, 2.1381]
$\sigma_\psi$	S.D. of IS technology shock innovation	IG	0.5	Inf	0.4539	[0.3375, 0.5721]
$\sigma_\nu$	S.D. of MEI shock innovation	IG	0.5	Inf	6.5571	[4.7881, 8.3668]
$\sigma_\mu$	S.D. of EF premium shock innovation	IG	0.5	Inf	0.2748	[0.2196, 0.3239]
$\sigma_\eta$	S.D. of networth shock innovation	IG	0.5	Inf	2.3221	[1.4438, 3.212]
$\sigma_m$	S.D. of real money balance shock innovation	IG	0.5	Inf	0.4565	[0.1071, 0.8897]
$\sigma_r$	S.D. of monetary policy shock innovation in hybrid rule	IG	0.5	Inf	0.3054	[0.2543, 0.3526]
$\sigma_{mg}$	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]
$\sigma$	Risk aversion	G	2	0.375	1.1247	[0.7471, 1.512]
$\theta$	Habit persistence	B	0.7	0.1	0.554	[0.4117, 0.7026]
$\chi$	Inverse of elasticity of labor supply	G	2	0.75	1.8544	[0.7685, 2.9074]
$\zeta$	Elasticity of investment adjustment cost	G	4	1.5	2.6789	[1.2887, 4.0388]
$\tau$	Inverse of elasticity of utilization rate adjustment cost	G	0.22	0.1	0.2587	[0.0917, 0.4296]
$\phi$	Output share of fixed production cost	B	0.25	0.125	0.0772	[0.0092, 0.1399]
$\alpha$	Capital elasticity of output	B	0.6	0.1	0.2412	[0.1528, 0.3247]
$\gamma_w$	Wage indexation	B	0.5	0.15	0.3549	[0.1432, 0.5567]
$\xi_w$	Wage stickiness	B	0.5	0.1	0.648	[0.5563, 0.7459]
$\gamma_p$	Intermediate-good price indexation	B	0.5	0.15	0.3939	[0.1615, 0.6158]
$\xi_p$	Intermediate-good price stickiness	B	0.5	0.1	0.7461	[0.6475, 0.8409]
$\phi_r$	Monetary policy rate smoothing	B	0.75	0.1	0.8821	[0.7873, 0.9784]
$\phi_\pi$	Monetary policy response to inflation	G	1.5	0.25	1.5018	[1.0845, 1.8846]
$\phi_y$	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]
$\bar{z}^*$	Steady-state rate of balanced growth	G	1.163	0.1	1.2614	[1.1087, 1.4089]
$\bar{\psi}$	Steady-state rate of IS technological change	G	0.077	0.04	0.0701	[0.0159, 0.1236]
$\bar{h}$	Normalized steady-state hours worked	N	0	2	-0.4026	[-3.2324, 2.3199]
$\bar{\pi}$	Steady-state inflation rate	G	0.272	0.1	0.3701	[0.2051, 0.5315]
$\bar{r}^n$	Steady-state policy rate	G	1.03	0.1	0.9514	[0.8392, 1.0585]
$\eta$	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
$\mu$	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]
$\rho_b$	Persistence of preference shock	B	0.5	0.2	0.2782	[0.0585, 0.4787]
$\rho_g$	Persistence of exogenous demand shock	B	0.5	0.2	0.7979	[0.6785, 0.9192]
$\rho_w$	Persistence of wage shock	B	0.5	0.2	0.2647	[0.047, 0.4756]
$\rho_p$	Persistence of intermediate-good price markup shock	B	0.5	0.2	0.8203	[0.689, 0.955]
$\rho_i$	Persistence of investment-good price markup shock	B	0.5	0.2	0.8399	[0.7274, 0.9619]
$\rho_z$	Persistence of neutral technology shock	B	0.5	0.2	0.4705	[0.2202, 0.7124]
$\rho_\psi$	Persistence of IS technology shock	B	0.5	0.2	0.1039	[0.0168, 0.1857]
$\rho_\nu$	Persistence of MEI shock	B	0.5	0.2	0.9645	[0.9401, 0.9917]
$\rho_\mu$	Persistence of EF premium shock	B	0.5	0.2	0.93	[0.8637, 0.9891]
$\rho_\eta$	Persistence of net worth shock	B	0.5	0.2	0.5554	[0.3934, 0.7186]
$\rho_m$	Persistence of real money balance shock	B	0.5	0.2	0.7973	[0.6316, 0.9693]
$\rho_r$	Persistence of monetary policy shock in hybrid rule	B	0.5	0.2	0.4988	[0.1633, 0.8169]
$\rho_{mg}$	Persistence of monetary shock in quantity rule	B	0.5	0.2	0.2482	[0.0522, 0.4386]
$\sigma_b$	S.D. of preference shock innovation	IG	0.5	Inf	3.3459	[1.576, 5.0406]
$\sigma_g$	S.D. of exogenous demand shock innovation	IG	0.5	Inf	1.4293	[1.0548, 1.7822]
$\sigma_w$	S.D. of wage shock innovation	IG	0.5	Inf	0.5259	[0.3569, 0.6855]
$\sigma_p$	S.D. of intermediate-good price markup shock innovation	IG	0.5	Inf	0.3222	[0.1724, 0.4716]
$\sigma_i$	S.D. of investment-good price markup shock innovation	IG	0.5	Inf	0.571	[0.392, 0.7412]
$\sigma_z$	S.D. of neutral technology shock innovation	IG	0.5	Inf	0.1356	[0.1058, 0.1646]
$\sigma_\psi$	S.D. of IS technology shock innovation	IG	0.5	Inf	1.6263	[1.2403, 2.0048]
$\sigma_\nu$	S.D. of MEI shock innovation	IG	0.5	Inf	0.5442	[0.3299, 0.735]
$\sigma_\mu$	S.D. of EF premium shock innovation	IG	0.5	Inf	8.0015	[5.408, 10.5661]
$\sigma_\eta$	S.D. of network shock innovation	IG	0.5	Inf	0.2883	[0.1911, 0.3805]
$\sigma_m$	S.D. of real money balance shock innovation	IG	0.5	Inf	2.5511	[1.3864, 3.712]
$\sigma_r$	S.D. of monetary policy shock innovation in hybrid rule	IG	0.5	Inf	0.443	[0.1132, 0.9001]
$\sigma_{mg}$	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]
$\sigma$	Risk aversion	G	2	0.375	1.5145	[1.1545, 1.8673]
$\theta$	Habit persistence	B	0.7	0.1	0.6784	[0.6072, 0.7524]
$\chi$	Inverse of elasticity of labor supply	G	2	0.75	2.0784	[0.9387, 3.1633]
$\zeta$	Elasticity of investment adjustment cost	G	4	1.5	7.2277	[4.524, 9.8457]
$\tau$	Inverse of elasticity of utilization rate adjustment cost	G	0.22	0.1	0.2025	[0.072, 0.3284]
$\phi$	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
$\alpha$	Capital elasticity of output	B	0.6	0.1	0.2287	[0.1623, 0.2965]
$\gamma_w$	Wage indexation	B	0.5	0.15	0.5686	[0.3505, 0.7958]
$\xi_w$	Wage stickiness	B	0.5	0.1	0.6867	[0.568, 0.8043]
$\gamma_p$	Intermediate-good price indexation	B	0.5	0.15	0.72	[0.5482, 0.8927]
$\xi_p$	Intermediate-good price stickiness	B	0.5	0.1	0.8362	[0.7678, 0.9107]
$\phi_r$	Monetary policy rate smoothing	B	0.75	0.1	0.7655	[0.6274, 0.9143]
$\phi_\pi$	Monetary policy response to inflation	G	1.5	0.25	1.5162	[1.1195, 1.914]
$\phi_y$	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]
$\bar{z}^*$	Steady-state rate of balanced growth	G	1.163	0.1	1.2308	[1.0867, 1.3811]
$\bar{\psi}$	Steady-state rate of IS technological change	G	0.077	0.04	0.082	[0.0176, 0.1458]
$\bar{h}$	Normalized steady-state hours worked	N	0	2	-1.5403	[-4.0237, 0.9832]
$\bar{\pi}$	Steady-state inflation rate	G	0.272	0.1	0.343	[0.1741, 0.5067]
$\bar{r}^n$	Steady-state policy rate	G	1.03	0.1	1.0838	[0.931, 1.24]
$\eta$	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]
$\mu$	Elasticity of EF premium	G	0.07	0.02	0.0184	[0.01, 0.0267]
$\bar{r}^E$	Steady-state real loan rate	G	1.242	0.05	1.2339	[1.1548, 1.3144]
$\rho_b$	Persistence of preference shock	B	0.5	0.2	0.4753	[0.143, 0.7979]
$\rho_g$	Persistence of exogenous demand shock	B	0.5	0.2	0.9513	[0.9205, 0.9853]
$\rho_w$	Persistence of wage shock	B	0.5	0.2	0.389	[0.0784, 0.7126]
$\rho_p$	Persistence of intermediate-good price markup shock	B	0.5	0.2	0.7216	[0.5118, 0.9454]
$\rho_i$	Persistence of investment-good price markup shock	B	0.5	0.2	0.5812	[0.3211, 0.8481]
$\rho_z$	Persistence of neutral technology shock	B	0.5	0.2	0.187	[0.0264, 0.3377]
$\rho_\psi$	Persistence of IS technology shock	B	0.5	0.2	0.1134	[0.0235, 0.1984]
$\rho_\nu$	Persistence of MEI shock	B	0.5	0.2	0.9319	[0.9035, 0.9607]
$\rho_\mu$	Persistence of EF premium shock	B	0.5	0.2	0.9304	[0.8856, 0.9748]
$\rho_\eta$	Persistence of net worth shock	B	0.5	0.2	0.5117	[0.3113, 0.7117]
$\rho_m$	Persistence of real money balance shock	B	0.5	0.2	0.7017	[0.5482, 0.8587]
$\rho_r$	Persistence of monetary policy shock in hybrid rule	B	0.5	0.2	0.8723	[0.7971, 0.9498]
$\rho_{mg}$	Persistence of monetary shock in quantity rule	B	0.5	0.2	0.2322	[0.0668, 0.3853]
$\sigma_b$	S.D. of preference shock innovation	IG	0.5	Inf	0.4019	[0.1218, 0.7048]
$\sigma_g$	S.D. of exogenous demand shock innovation	IG	0.5	Inf	0.683	[0.5012, 0.8515]
$\sigma_w$	S.D. of wage shock innovation	IG	0.5	Inf	0.4368	[0.2745, 0.5815]
$\sigma_p$	S.D. of intermediate-good price markup shock innovation	IG	0.5	Inf	0.2361	[0.1454, 0.327]
$\sigma_i$	S.D. of investment-good price markup shock innovation	IG	0.5	Inf	0.3908	[0.2794, 0.497]
$\sigma_z$	S.D. of neutral technology shock innovation	IG	0.5	Inf	0.3661	[0.268, 0.4594]
$\sigma_\psi$	S.D. of IS technology shock innovation	IG	0.5	Inf	2.0403	[1.5396, 2.512]
$\sigma_\nu$	S.D. of MEI shock innovation	IG	0.5	Inf	0.5628	[0.3931, 0.7318]
$\sigma_\mu$	S.D. of EF premium shock innovation	IG	0.5	Inf	5.4299	[3.7458, 7.036]
$\sigma_\eta$	S.D. of networth shock innovation	IG	0.5	Inf	0.3492	[0.2591, 0.439]

Parameter		Prior			Posterior	
		Type	Mean	S.D.	Mean	90% interval
$\sigma_m$	S.D. of real money balance shock innovation	IG	0.5	Inf	1.641	[0.977, 2.2975]
$\sigma_r$	S.D. of monetary policy shock innovation in hybrid rule	IG	0.5	Inf	30.4763	[9.1681, 51.4009]
$\sigma_{mg}$	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		Consumption		Investment		Loan	
		T=8	T=32	T=8	T=32	T=8	T=32	T=8	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
$z^\psi$	IS technology	6.09	11.08	2.2	2.48	50.15	61.28	51.78	55.21
$z^\nu$	MEI	2.49	2.51	0.26	0.62	11.8	9.4	8.45	10.12
$z^\mu$	EF premium	0.12	0.12	0	0	0.73	0.48	1.07	0.82
$z^\eta$	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

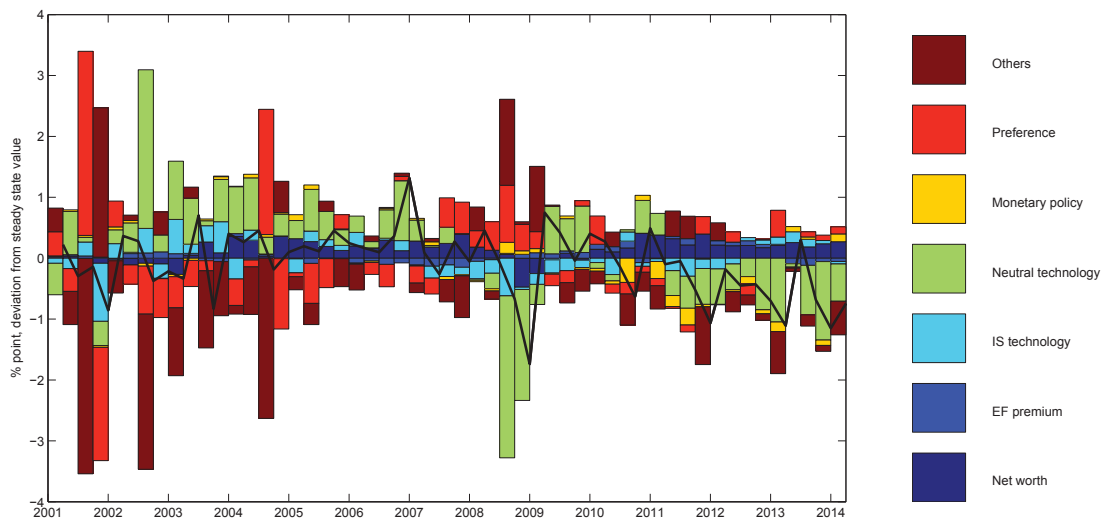


Figure 2: Historical decomposition of investment growth rate

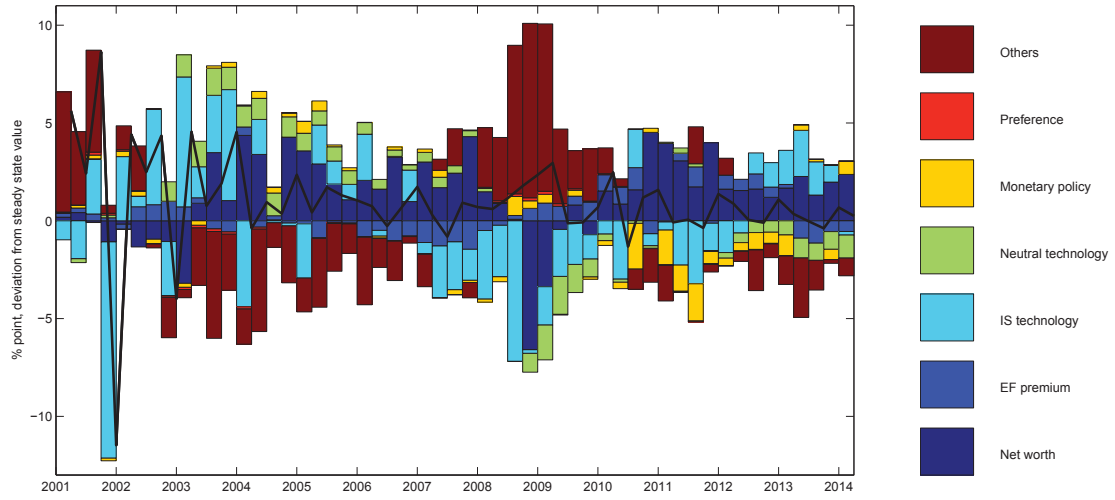


Figure 3: Impulse responses to monetary policy rate shock  $e_r$  (+1 s.d.)

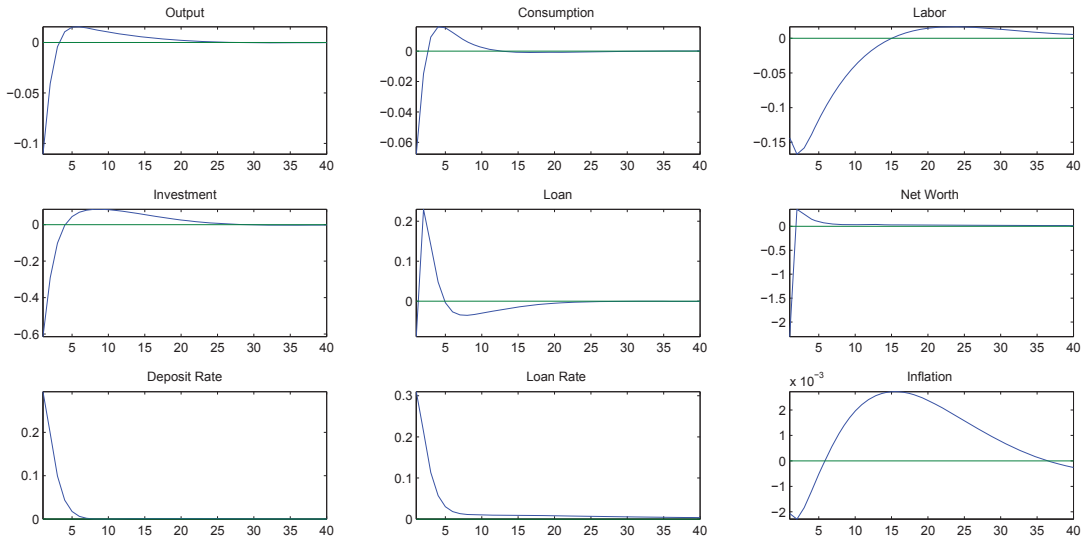


Figure 4: Impulse responses to neutral technology shock  $e_z$  (+1 s.d.)

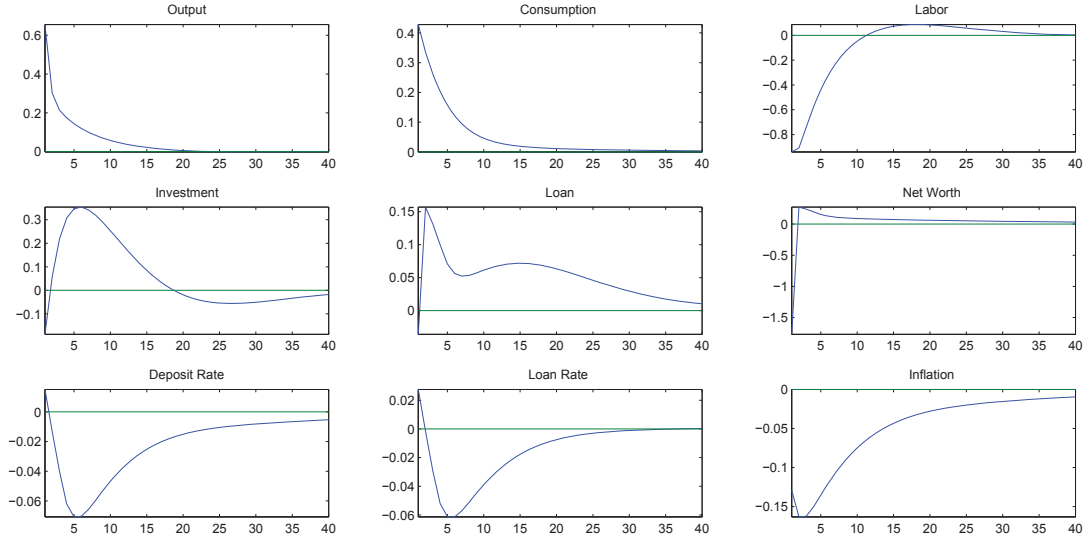
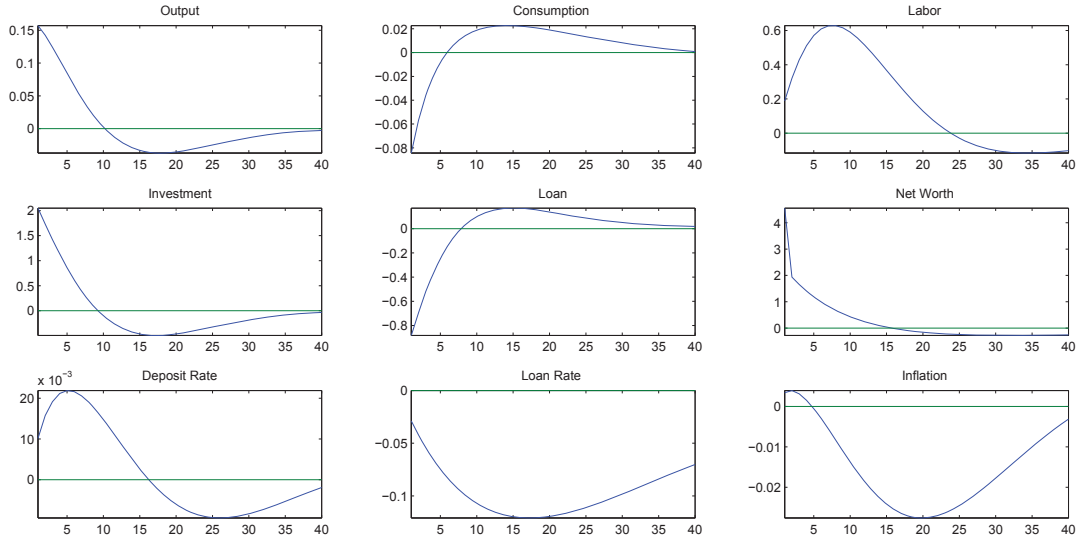


Figure 5: Impulse responses to net worth shock  $e_\eta$  (+1 s.d.)



## Appendix

- log-linearized equilibrium conditions

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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



$$\left\{ \begin{array}{ll} \hat{r}_t^n = (1 - W) (r^n - 1) \left( -\hat{\lambda}_t - \sigma \hat{m}_t + z_t^b + z_t^m \right) & \text{if } W \in (0, 1] \\ +W \left[ \phi_r \hat{r}_{t-1}^n + (1 - \phi_r) \left( \frac{\phi_\pi}{4} \sum_{j=0}^3 \hat{\pi}_{t-j} + \phi_y \hat{y}_t \right) + \phi_{\Delta y} (\hat{y}_t - \hat{y}_{t-1} + z_t^*) \right] + z_t^r & \\ \hat{r}_t^n = (1 - W) (r^n - 1) \left( -\hat{\lambda}_t - \sigma \hat{m}_t + z_t^b + z_t^m \right) & \text{if } W = 0 \end{array} \right.$$

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

- Steady-state conditions used in estimations:

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

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