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Oil Price Shocks and Inflation Targeting in China

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ABSTRACT
We develop a small open economy DSGE-based New Keynesian model incorporating the demand for oil, to focus on whether the PBoC targets core inflation or headline inflation including oil price inflation, and investigating the macroeconomic effect of oil price shocks. Based on both counterfactual simulations and welfare evaluations, our results indicate that targeting both core inflation and non-core inflation are inferior to the one purely pegged to core inflation, suggesting the central bank should target core inflation instead of headline inflation. Our paper contributes to a growing literature on monetary policy in China and other emerging market economies.

KEYWORDS
Inflation targeting; core inflation; headline inflation; Chinese monetary policy

SUBJECT CLASSIFICATION CODES
E31; E43; E47

1. Introduction

As noted in Mishkin (2010), there were two global IT waves in the last 10 or so years of the twentieth century: the information technology (IT) wave and the inflation targeting (IT) wave in the context of monetary policy. Currently, the countries using relatively mature inflation targeting policies have made great achievements with reliable evidence. Not only has the long-term inflation been significantly reduced, but the fluctuations in inflation rates have also decreased (Bernanke 2001).

As the largest emerging market economy, in the process of reform and opening over the past three decades, China's inflation has undergone a transformation, moving from high inflation to a soft landing, followed by deflation and then mild inflation. During the deflationary period, from 1997 to 2002, a proactive monetary policy was largely ineffective because financial invocation in China and the acceleration of the opening up process led to an erratic money multiplier, which in turn decreased the effectiveness of the money supply as an intermediate target. Subsequently, China's economy entered another phase of rapid growth, and although the PBoC continued to increase its benchmark lending rate and statutory deposit reserve ratio, it was unable to effectively curb the acute fluctuations in property prices or their continued overall rise. Following the financial crisis in 2008, China's contractionary monetary policy was moderately eased, finally becoming

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stable. The broad money supply, or M2, grew at an average of 18% per year, which was much higher than GDP growth rate, but the injection of large amounts of money did not alleviate the slump in the real economy. Although monetary credit is circulating internally, the proportion of credit circulating in vain is growing, which greatly reduces the effectiveness of a monetary policy that has money supply as its intermediate target. In such complicated context, exploring the choices of inflation targeting sheds light on the design and implementation of optimal monetary policy for the Chinese economy.

According to the Law of the People's Republic of China on the PBoC, the objective of the monetary policy is to maintain the stability of the value of the currency and thereby promote economic growth. In that case, the optimal objective of monetary policy is concerned with what inflation indicator to target, i.e. whether the focus should be on headline inflation or core inflation. Headline inflation measures changes in the cost of living and includes a weighted average based on an expenditure ratio of the prices of all goods and services consumed by residents. The commonly used Consumer Price Index (CPI) is an example of a headline inflation measure. According to Eckstein (1981) and Bryan and Cecchetti (1993), headline inflation, which is represented by the CPI, can be separated into two major components. One is the underlying rate determined by aggregate demand and aggregate supply, which is known as core inflation. The other is a temporary rate caused by particularly volatile items like food and energy, which is known as non-core inflation. Because core inflation attempt to smooth volatile changes in the CPI to distinguish the inflation signal from the transitory noise, it is viewed as the long-term underlying trend indicator of the CPI.

Mishkin (2007, 2008) suggests that monetary policy should focus on core inflation instead of headline one including transitory, highly volatile part. Dhawan and Jeske (2007) build an energy economy NK-DSGE model incorporating durable goods consumption, and they conclude it is better to use core inflation than headline inflation in the context of the alternative Taylor rule. Based upon the Ramsey optimal policy rules, Kormilitsina (2011) verifies that the negative impact of monetary policy on the economy will be worsened by rising energy prices, suggesting that monetary policy needs to be targeted on core inflation. In the case of China's food price, Hou and Gong (2013) demonstrate targeting core inflation can significantly reduce welfare loss in response to an increase in food price.

In practice, even among countries that practice inflation targeting, the inflation indicators used differ greatly. The majority of countries continue to use headline CPI, which includes short-term variable components, as their target. The use of headline CPI shows that on this issue, theoretical knowledge and practice are not aligned, and in formulating policies, each country also takes into consideration its circumstances before making certain trade-offs. Food and energy form a major part of residents' expenditure and can affect overall prices through transmission. Hence, the monetary policy pegging headline inflation will not only help stabilise price fluctuations but also reduce consumer welfare losses. Catão and Chang (2015) show that the high volatility of world food prices causes headline CPI inflation targeting to dominate core CPI inflation targeting in the context of a small open economy. Anand and Prasad (2010) establish a two-sector two-good closed economy NK-DSGE model with financial frictions to find that a welfare-maximising central bank should adopt targeting headline inflation rather than the core inflation for emerging markets, which can also help keep the credibility of monetary policy and stabilise inflation expectations. But on the other side, the prices of such items are vulnerable to non-market factors such as climate change. Therefore, the frequent adjustment of monetary policy will hurt the economy due to the long lags between monetary policy actions and changes in economic activity (Mishkin 2007).

There are very few studies that have concerned about the question of how monetary policymakers should assess the efficacy of inflation targeting in China under both headline inflation targeting regime and core inflation targeting regime. As the Chinese economy grows and matures, the PBoC will need to restructure itself to deal with these types of important institutional issues. We develop a sticky-price DSGE model here that provides an analytical framework for assessing the implications of alternative monetary policies in response to oil shocks, as well as to evaluate optimal monetary policy to answer which inflation measure is the more appropriate focus of policy for China. This paper makes three main contributions.

First, due to the unique nature of China's economy, this paper relies on the Bayesian method to solve parameters for the following reasons. First, unlike developed economies such as US, comprehensive quarterly data on major macroeconomic variables are only available for China after 1992. Classical models using econometric methods such as OLS or MLE are often not robust for lacking macroeconomic data, while Bayesian techniques are useful for the short-time series problem. Second, there exist statistical inconsistencies and a certain amount of measurement error in China's macroeconomic data, while the Bayesian method can treat as random disturbances that can be given some prior information structure, thereby overcoming to some extent these shortcomings. Finally, in a transition economy such as that in China, there are often structural breakpoints in its operation, and it is easy for jumps to appear in the process of generating macroeconomic data. By keep updating the probabilistic inference of the model parameters, the Bayes theorem fully accounts for the transience of the economy in various regimes, thereby addressing structural changes in economic parameters.

Second, we provide a more analytical framework that can be used to compare the pros and cons of two types of inflation for the PBoC to target. Moreover, two exercises are conducted to test robustness from a welfare point of view: one is to cumulate the sum of the impulse response function under 'first moment' and the other is to evaluate the utility-based welfare metric under 'second moment'. Various sensitivity experiments have been done to all the above results. Our findings suggest that China's monetary policy should focus on core inflation instead of headline inflation.

Finally, as the second-largest oil consumer in the world today, China is fairly reliant on imports. Oil prices volatility in China may be highly correlated with international markets, which may influence each other. In that case, simply assuming that oil prices in the Chinese domestic market are entirely dependent on changes in the international market, i.e. that the price of oil in China is completely exogenous, somewhat lacks adequate theoretical and evidentiary support. Thus, in our model, oil price is determined endogenously beyond the traditional works of exogenous oil/energy price (Kormilitsina 2011; Finn 2000; Wang and Zhu 2015), so the model enables us to study various channels through which shocks that cause oil price hikes and China's other macroeconomic variables interact.

In recent related work, Anand, Prasad, and Zhang (2015) give a similar debate over headline versus core inflation targeting by introducing financial frictions. They conclude that in the presence of financial frictions, headline targeting is superior, and point out this is more relevant to emerging market countries in which many households are often credit constrained. But in fact, for consumers in China there is relatively abundant supply of credit, and in China's urban–rural dual structure the 'credit constraints' are untenable.[1] The relative abundance of credit supply in China is reflected in an increase in financial support, through housing loans, consumer loans and financing scale as follows: (1) Housing loans: According to statistics from the People's Bank of China, new loans to China's real estate industry increased from 2.02 trillion yuan in 2010 to 5.17 trillion yuan in 2020, a cumulative increase of 156%. New loans to the real estate sector will account for nearly 30% of new bank loans in 2020. (2) Consumer loans: According to the China Consumer Finance Company Development Report (2021) released by the China Banking Association, by the end of 2020, the asset size of China's consumer finance companies reached 524.649 billion yuan, a year-on-year increase of 5.18%; the loan balance was 492.78 billion yuan, a year-on-year increase of 4.34%; the cumulative number of customers served was 163.3947 million, a year-on-year increase of 28.37%. The main targets of consumer finance companies are low- and middle-income long-tail customers, such as farmers, blue-collar workers and young white-collar workers, who are not effectively reached by traditional commercial banks, and are mainly young people with contradictions between their consumption needs and disposable income. (3) Financing scale, according to the data from the People's Bank of China, the increase in the scale of social financing increased from RMB 1.402 billion in 2010 to RMB 3.135 billion in 2021. The cumulative increase was 124%; the incremental size of RMB loans increased from RMB 795 million in 2010 to RMB 1994 million in 2021, a cumulative increase of 151%, indicating a clear increase in financial assistance to the real economy.

On the other hand, our model adds oil as a factor input in Cobb–Douglas production function (with labour) different from a linear technology only including labour in their model. Contrary to the conventional method of taking the oil price variable as an exogenous process, we explicitly model it endogenously with the DSGE model. More importantly, by introducing inflation in oil price into the Taylor rule to indicate non-core inflation, we investigate more intuitively the 'pros and cons of headline and core inflation' in extended Taylor rule.

The paper is organised as follows. The next section outlines the structure of the SOE model. Section 3 reports on estimation exercise and model parameters. Section 4 performs a dynamic analysis of the model and moreover, Section 5 discusses which inflation to target. Section 6 concludes the paper.

2. The Small Open Economy Model

In this section, we build a small open economy (SOE) DSGE-based New Keynesian model based on the work of Galí and Monacelli (2005)[2] (GM thereafter) and Unalmis, Unalmis, and Unsal (2009).[3] Specifically, we assume that the world economy is composed of a domestic SOE (like China) and a continuum of other small open economies (the rest of world, or ROW), all distributed on [0, 1] uniformly. China and the ROW are completely identical in terms of consumer preferences, firm technologies and market structure including the Calvo price-setting mechanism and the assumption of complete financial markets. The representative household consumes domestic and imported goods, supplies labour, earns wages and shares dividends derived from the firms. Firms produce differentiated goods, decide on labour and oil inputs and set prices according to Calvo mechanism. The government sets fiscal and monetary policy.

2.1. Households

A representative household is infinitely-lived and seeks to maximise

$$E_0 \sum_{t=0}^{\infty} \beta^t [U(C_t) - V(N_t)], \tag{1}$$

$$U(C_t) = log(C_t), \tag{2}$$

$$V(N_t) = \frac{N_t^{1+\psi}}{1+\psi}, \tag{3}$$

where N_t denotes hours of labour and C_t is a composite consumption index defined by

$$C_t = \frac{1}{(1-\alpha)^{1-\alpha}\alpha^{\alpha}} C_{H,t}^{1-\alpha} C_{F,t}^{\alpha},$$

where $C_{H,t}$ and $C_{F,t}$ are CES consumption indices of domestic and foreign goods, given by

$$C_{H,t} = \left(\int_0^1 C_{H,t}(i)^{\frac{\varepsilon-1}{\varepsilon}} di \right)^{\frac{\varepsilon}{\varepsilon-1}}; \ C_{F,t} = \left(\int_0^1 C_{F,t}(i)^{\frac{\varepsilon-1}{\varepsilon}} di \right)^{\frac{\varepsilon}{\varepsilon-1}}, \tag{4}$$

where $i \in (0, 1]$ indicates the goods varieties, $\varepsilon > 1$ is the elasticity of substitution among goods produced within a country, $\alpha \in (0, 1)$ represents the expenditure share of the imported goods in households consumption basket, and is thus a natural index of openness. ψ is the inverse of the elasticity of labour supply.

The maximisation (1) is subject to a budget constraint of the form

$$P_t C_t + E_t\{Q_{t,t+1} D_{t+1}\} \leq D_t + W_t N_t + T_t \tag{5}$$

where $P_t = P_{H,t}^{1-\alpha} P_{F,t}^{\alpha}$ is the consumer price index (CPI) and the price indices for domestically produced and imported goods are

$$P_{H,t} = \left(\int_0^1 P_{H,t}(i)^{1-\varepsilon} di \right)^{\frac{1}{1-\varepsilon}}; \ P_{F,t} = \left(\int_0^1 P_{F,t}(i)^{1-\varepsilon} di \right)^{\frac{1}{1-\varepsilon}},$$

where D_{t+1} is the nominal payoff in the period $t+1$ of the portfolio held at the end of period t including the shares in firms, $Q_{t,t+1}$ is the stochastic discount factor, W_t is the nominal wage and T_t is lump-sum transfers or taxes.

Solving the household's utility-maximisation problem gives a labour supply equation and an intertemporal Euler equation, respectively:

$$C_t N_t^{\psi} = \frac{W_t}{P_t}, \tag{6}$$

$$\beta R_t E_t \left\{ \left(\frac{C_{t+1}}{C_t}\right)^{-1} \left(\frac{P_t}{P_{t+1}}\right) \right\} = 1, \tag{7}$$

where $R_t^{-1} = E_t\{Q_{t,t+1}\}$ is the return on a riskless bond paying off one unit of domestic currency in period $t+1$. Notice that (6) and (7) can be respectively written in log-linearised form as

$$w_t - p_t = c_t + \psi n_t \tag{8}$$

$$c_t = E_t\{c_{t+1}\} - (r_t - E_t\{\pi_{t+1}\} - \rho) \tag{9}$$

where lowercase letters denote the logs of respective variables in uppercase letters, $\rho = -\log \beta$, $\pi_t = p_t - p_{t-1}$ is the CPI inflation between t and $t-1$.

2.2. The Terms of Trade, Inflation, Real Exchange Rate and UIP Condition

The (log) terms of trade, i.e. the price of foreign goods in terms of home goods, are given by

$$s_t = p_{F,t} - p_{H,t} \tag{10}$$

Log-linearisation of the CPI formula around a symmetric steady state satisfying the purchasing power parity (PPP) condition $P_{H,t} = P_{F,t}$ yields

$$p_t = p_{H,t} + \alpha s_t. \tag{11}$$

It follows that domestic inflation, $\pi_{H,t} \equiv p_{H,t} - p_{H,t-1}$, and CPI inflation are linked according to

$$\pi_t = \pi_{H,t} + \alpha \Delta s_t. \tag{12}$$

In addition, we define the real exchange rate $Q_t \equiv \frac{\Xi_t P_t^*}{P_t}$, where Ξ_t is the nominal exchange rate (foreign currency in terms of home currency) and P_t^* is the foreign price index (where a star denotes foreign variables or parameters henceforth). Combining (10) and (11), we derive the log-linearised formula for the CPI, domestic price level and real exchange rate

$$p_t = p_{H,t} + \frac{\alpha}{1-\alpha} q_t. \tag{13}$$

Under complete international financial markets assumption, an Euler equation analogous to (7) must also hold for consumers in the foreign country, $\beta \left(\frac{C_{t+1}^*}{C_t^*}\right)^{-1} \left(\frac{P_t^*}{P_{t+1}^*}\right) \left(\frac{\Xi_t}{\Xi_{t+1}}\right) = Q_{t,t+1}$. Together with (7), it follows (after iterating) $C_t = \kappa C_t^* Q_t$ around symmetric equilibrium where κ is a constant that depends upon initial conditions, the log-linearised version of the risk-sharing equation can be written as

$$c_t = c_t^* + q_t.$$

Combine Euler equations of both countries to yield the uncovered interest parity condition (UIP)

$$r_t - r_t^* = E_t\{\Delta e_{t+1}\}, \tag{14}$$

where $e_t \equiv \log \Xi_t - \log \Xi$. Finally, we can derive the terms of trade in terms of the UIP condition as

$$s_t = E_t\left\{\sum_{k=0}^{\infty}[(r_{t+k}^* - \pi_{t+k+1}^*) - (r_{t+k} - \pi_{H,t+k+1})]\right\}. \tag{15}$$

2.3. Firms

The home final good can be obtained by assembling intermediate goods varieties, indexed by $i \in (0, 1]$: $Y_t = \left[\int_0^1 Y_t(i)^{\frac{\varepsilon-1}{\varepsilon}} di\right]^{\frac{\varepsilon}{\varepsilon-1}}$, where ε is the elasticity of substitution between domestic varieties. Minimising the cost of producing the aggregate implies that the demand for each variety is given by $Y_t(i) = \left(\frac{P_{H,t}(i)}{P_{H,t}}\right)^{-\varepsilon} Y_t$.

Intermediate good $i \in (0, 1]$ is produced by a monopolist according to the Cobb–Douglas function:

$$Y_t(i) = (A_t N_t(i))^{\eta}(O_t^d(i))^{1-\eta}, \tag{16}$$

where η is the share of labour in the production, so that the share of oil is $1 - \eta$. Here, $O_t^d(i)$ is the amount of oil consumed in production by firm i, and the (log) labour productivity $a_t = \log(A_t)$ follows a stationary AR(1) process, i.e. $a_t = \rho_a a_{t-1} + \epsilon_{a,t}$, where ρ_a is the parameters of persistence and $\epsilon_{\mathrm{a,t}} \sim \mathrm{N}(0, \ \sigma_{\mathrm{a}})$.

Under the assumption that firms take the price of each input as given, cost minimisation of the firm implies

$$(1-\eta)(1-\tau)W_t N_t(i) = \eta P_t^o O_t^d(i), \tag{17}$$

$$MC_t = \frac{(1-\tau)\dfrac{W_t}{P_{H,t}}}{\eta A_t^{\eta}(N_t(i))^{\eta-1}(O_t^d(i))^{1-\eta}}, \tag{18}$$

where P_t^o denotes the nominal oil price which is determined endogenously in our model, while making $\tilde{P}_t^o = \frac{P_t^o}{P_t}$ as its real price. τ is an employment subsidy rate designed to allow the flexible price economy to be efficient.

We assume that firms set prices in a staggered fashion in the spirit of Calvo mechanism. In particular, in each period, a firm faces a constant probability, $1 - \xi$ of being able to reoptimise its nominal price. Thus ξ is the probability that a firm does not change its price. As shown in Galí and Monacelli (2005), the firm's optimal price-setting strategy implies the following marginal cost-based (log-linearised) Phillips curve.

$$\pi_{H,t} = \beta E_t\{\pi_{H,t}\} + \frac{(1-\xi)(1-\beta\xi)}{\xi} mc_t \tag{19}$$

2.4. Government

We assume that the governments of both domestic and foreign countries are home-biased. Similar to consumption index, the government spending index can be written as $G_t = \left(\int_0^1 G_t(i)^{\frac{\varepsilon-1}{\varepsilon}} dj \right)^{\frac{\varepsilon}{\varepsilon-1}}$ Moreover, expenditure minimisation leads to the government demand equation: $G_t(j) = \left(\frac{P_{H,t(i)}}{P_{H,t}} \right)^{-\varepsilon} G_t$. Moreover, the government follows a balanced budget policy and finances its expenditures by lump-sum taxation, $T_t = P_{H,t}G_t$. Also, (log) government spending $g_t = \log(G_t)$ follows a stationary AR(1) process, i.e. $g_t = \rho_g g_{t-1} + \epsilon_{g,t}$, where ρ_g is the parameters of persistence, the random error $\epsilon_{g,t}$ is i.i.d., and satisfies $\epsilon_{g,t} \sim N(0,\ \sigma_g)$.

Xie and Luo (2002) applied Chinese monetary policy to test the Taylor rule, regarding that Taylor rule can serve as a measure of China's monetary policy. Based on this, while drawing research of Clarida, Galí, and Gertler (2001), Mohanty and Klau (2004), Mei and Gong (2011), Zhao et al. (2016), the paper set China's Taylor interest rate rule (log-linearised) as follows:

$$r_t = \rho_r r_{t-1} + (1-\rho_r)[\phi_\pi \pi_t + \phi_x x_t] + \upsilon_t \tag{20}$$

where $x_t = y_t - \overline{y_t}$ ($\overline{y_t}$ denotes output under flexible prices) is the output gap. Assume ρ_r, ϕ_π and ϕ_x are non-negative coefficients associated with the interest rate rule. Note that interest rate shock follows a stationary AR(1) process, i.e. $\upsilon_t = \rho_\upsilon \upsilon_{t-1} + \epsilon_{\upsilon,t}$, where ρ_υ is the parameters of persistence, the random error $\epsilon_{\upsilon,t}$ is i.i.d., and satisfies $\epsilon_{\upsilon,t} \sim N(0,\ \sigma_\upsilon)$.

2.5. Equilibrium Dynamics

2.5.1. Domestic Demand Determination and IS Curve

Let $C^*_{H,t}(i)$ denote the world demand for the domestic good i, i.e. export for domestic country. Then market clearing in the small economy requires

$$\begin{aligned} Y_t(i) &= C_{H,t}(i) + C^*_{H,t}(i) + G_t(i) \\ &= \left(\frac{P_{H,t}(i)}{P_{H,t}} \right)^{-\varepsilon} \left[\left(\frac{P_{H,t}}{P_t} \right)^{-1} (1-\alpha)C_t + \left(\frac{P_{H,t}}{\Xi_t P^*_t} \right)^{-1} \alpha^* C^*_t + G_t \right] \end{aligned} \tag{21}$$

Using $Y_t = \left(\int_0^1 Y_t(i)^{\frac{\varepsilon-1}{\varepsilon}} dj\right)^{\frac{\varepsilon}{\varepsilon-1}}$ and the law-of-one-price, we obtain

$$Y_t = G_t + \left(\frac{P_{H,t}}{P_t}\right)^{-1} C_t \tag{22}$$

Substituting it into the Euler equation (9) of consumers, together with Equation (13), one can write the domestic output curve (IS Curve)

$$\begin{aligned} y_t = {} & E_t\{y_{t+1}\} - (1-G_y)(r_t - E_t\{\pi_{t+1}\}) - G_y E_t\{g_{t+1} - g_t\} \\ & - (1-G_y)\frac{\alpha}{1-\alpha} E_t\{q_{t+1} - q_t\} \end{aligned} \tag{23}$$

where $G_y = \frac{G}{Y}$ denotes share of government spending in output.

2.5.2. World IS Curve and Aggregate Supply

Market clearing in the world economy requires

$$Y_t^* = C_t^* + G_t^* \tag{24}$$

Then the log-linearised version is $y_t^* = (1-G_y)c_t^* + G_y g_t^*$. Similarly, we can obtain IS curve of the world output

$$y_t^* = E_t\{y_{t+1}^*\} - (1-G_y)(r_t^* - E_t\{\pi_{t+1}^*\}) - G_y E_t\{g_{t+1}^* - g_t^*\} \tag{25}$$

Based on the staggered price setting Calvo mechanism, the dynamics of inflation in the world economy is

$$\pi_t^* = \beta E_t\{\pi_{t+1}^*\} + \frac{(1-\xi^*)(1-\beta\xi^*)}{\xi^*} mc_t^* \tag{26}$$

2.6. Oil Market Equilibrium and Determination of Endogenous oil Price

In recent years, oil coming from abroad has accounted for an increasing proportion of China's aggregate amount. Chinese external dependence on petroleum and crude oil both broke the point of 55% in 2011, surpassing the U.S.A. as the highest in the world. Thus oil price volatility in China may be highly correlated with international markets, implying that they react to each other. In that case, it is not appropriate for us to assume that China's oil price is exogenous and entirely dependent on changes in the international market. Therefore, a departure from traditional literature, we treat oil prices endogenously as follows.

Assume that at each point in time, the international oil supply o_t^s is exogenous and its log-linearised variables follow AR(1) process such that $o_t^s = \rho_o o_{t-1}^s + \epsilon_{o,t}$, of which $\epsilon_{o,t}$ is i.i.d. and satisfies $\epsilon_{o,t} \sim N(0, \sigma_o)$.[4] As a small economy in the model, China's oil demands are relatively small compared to the ROW. To simplify, we assume that the market-clearing condition of the world oil market is that oil demand equals oil supply, i.e. $o_t^{d*} = o_t^s$. Together with the world labour supply condition, the world production function, cost minimisation of the world firm and clearing conditions in the world economy, as well as real world oil prices as $\tilde{p}_t^{o*} = p_t^{o*} - p_t^*$, we can obtain the world oil price expression (after log-linearisation):

$$\tilde{p}_t^{o*} = \left[\frac{1}{1-G_y} + \frac{1+\psi^*}{\eta^*}\right]y_t^* - \frac{G_y}{1-G_y}g_t^* - (1+\psi^*)a_t^* - \left[\frac{1+\psi^*(1-\eta^*)}{\eta^*}\right]o_t^s. \quad (27)$$

Using $\Xi_t P_t^{o*} = P_t^o$ and the definition of real exchange rate, we obtain the real price of oil endogenously:

$$\tilde{p}_t^o = \tilde{p}_t^{o*} + q_t \quad (28)$$

In recent years, one focus of the research into international oil prices has been the re-examination of structural reasons for fluctuations in oil prices (Hamilton 2008; Kilian 2009). A series of important studies in Kilian (2008, 2009) indicate that the causes are not limited to the supply side, but also closely linked to macroeconomic factors related to the demand side. This proposition can be verified using the above two Equations (27) and (28). On the one hand, on the supply side, oil prices in China are inversely related to the world oil supply; that is to say, as oil supply increases, oil prices will decrease, which is in line with the classic supply and demand theory. On the other hand, from the demand side, positive world government expenditure and labour technology shocks will give rise to a decrease in domestic oil prices, implying that they share an inverse relationship.[5] Also, we found that an increase in world output and real exchange rates pushes world real oil prices up.

3. Estimation of Parameters

Bayesian techniques are the principal strategy for solving parameters. However, if we resort to Bayesian estimation of all parameters, some cannot be identified (Canova and Sala 2009; Iskrev 2010). Therefore, we follow Smets and Wouters (2003, 2007) by using the Bayesian approach to estimate most other parameters after calibrating a few non-identified parameters.

3.1. Calibration

First, the discount factor β depends on the risk-free return due to the intertemporal consumption Euler Equation. Take the average treasury yield 4% during the sample periods 1996Q1–2015Q3 as the measurement, therefore the quarterly discount factor satisfies $\beta = 0.99$. Second, set the parameter η of labour compensation share to be 0.95, indicating that the oil share in output is $1 - \eta = 0.05$, which is slightly larger than setting of 1.7% for the US economy by Blanchard and Gali (2007). Make $\varepsilon = 6$, implying a steady-state price markup of 20%, which is consistent with the estimate studied by Huang (2011). Finally, we find $G_y = 0.2$ in steady state by using the average data of government expenditures and outputs in the sample period.

3.2. Bayesian Estimation

The Bayesian estimation fits the complete, solved DSGE model as opposed to methods such as ordinary least squares (OLS), instrumental variables (IV), generalised method of moments (GMM) and so on. Bayesian estimation is a bridge that links calibration to maximum likelihood, which has been widely used this method in increasing literature, i.e. Smets and Wouters (2003, 2007), Lubik and Schorfheide (2007) and Christiano, Motto, and Rostagno (2010). We use the DYNARE toolbox of MATLAB to estimate parameters.

For a linearised DSGE model around steady state, the economic system can be described by the spatial form of the state vector:

$$S_t = AS_{t-1} + Bv_t \tag{29}$$

$$obs_t = CS_t \tag{30}$$

Equations (29) and (30) are the state equation and the measurement equation, respectively. With the observable variable $obs_t \equiv \{y_1, \cdots, y_T\}$ and the variable S_t, a recursive procedure can be applied by Kalman filtering. Given some parameters Θ, the joint conditional density function is $L(y_1, \cdots, y_T|\Theta)$. We apply Bayesian estimation to obtain the posterior probability density function

$$\pi(\Theta|y_1, \cdots, y_T) \propto \pi(\Theta)L(y_1, \cdots, y_T|\Theta).$$

Hence, the posterior probability density and distribution can be obtained by giving estimated value $\pi(\Theta)$ of prior marginal probability density. It is difficult to solve such integral equations, while we resort to numerical simulation based on Metropolis–Hastings algorithm (see Lubik and Schorfheide 2007), which is indeed adopted by Dynare.

3.2.1. Description of the Data

A total of 79 quarterly data are sampled between 1996Q1 and 2015Q3 from two databases of WIND and Macrochina.[6] There are three reasons. First, China has officially complied quarterly data since the 1990s. Second, the PBoC has legally conducted monetary policy since 1995. Third, in 1996 the PBoC set up a unified national inter-bank lending market and officially announced the inter-bank offered rate (referred as Chibor). We use weighted average interest rate of Chibor (90 days) as the nominal interest rate. According to monthly CPI data month-on-month and year-on-year published by the National Bureau of Statistics (NBS) of China, quarterly fixed base ratio can be drawn based on the first quarter of 1996, characterising the quarterly GDP deflator, and calculating the actual value of relevant economic variables.

(1) China output: Due to the lack of official seasonal adjustment of GDP for China, we get use of the Census X12 method proposed by Findley, Monsell, and Bell (1998). To be specific, the actual GDP is nominal GDP divided by the quarterly GDP deflator, and then filter seasonal component by Census X12 method to gain the output series. Moreover, we follow Smets and Wouters (2007) by taking the log difference of the above series to obtain the observable variable of China output.
(2) World output: Given the important influence of the U.S.A. in the global economy, as general literature handled, we use the seasonal adjustment of quarterly US GDP provided by the Bureau of Economic Analysis (BEA) as the measurement of the world's output. Then we take the log difference of the above series to obtain the observable variable of world output.

(3) China interest rate: Taylor (1993) uses the nominal interest rate of the Fed, in his research, but China has not finished its interest liberalisation. Except those of high market-oriented level rates including interbank lending rate, the bond repo rate, bill discounted rate and private lending rate, the others are regulated rates. Since data for private lending rates are not readily available and the size of the secondary market for treasury bonds is relatively small, China's interest rate does not accurately reflect the relationship between supply and demand in the money markets. Therefore, following studies conducted by Xie and Luo (2002), Li and Li (2010), we take weighted average (90-day) of the Chibor as the interest rate indicator in the Bayesian estimation. Quarterly data are obtained from the Chibor using the three-month arithmetic average.
(4) China inflation: Based on the estimated quarterly GDP deflator from CPI, we take the log difference of the series to obtain observable variable of inflation.
(5) Nominal exchange rate: According to the monthly average exchange rate series of US/RMB provided by the PBoC, we take the geometric average to get the quarterly series, then calculate the log difference of the above one to obtain corresponding observable variable.
(6) Actual oil prices: Use spot crude oil prices in the West Texas oil price (WTI)[7] as the standard, in which monthly data will be transformed into quarterly data through a geometric average summation, then converted to RMB price, and then actual oil prices will be obtained when divided by the quarterly GDP deflator. Finally, we take the log difference of series to get the corresponding observable variable.

In conclusion, we select China output, world output, China interest rate, China inflation, nominal exchange rate and actual oil price as observable variables for Bayesian estimation. Thus we have seven exogenous shock variables and six groups of observable variables in the economy, which meet to the condition of identification.

Prior to parameter estimation, descriptive statistics and stationarity tests were first performed on the variables, as described in Table 1. Each data has been processed according to the above steps. All variables, except for the interest rate data, are volatility data after taking log first-order differences.

China's output fluctuation and interest rates are higher than the world's output fluctuation and interest rates. The standard deviation of China's output fluctuation (0.4505) is smaller than the standard deviation of world output fluctuation (0.5706), while the volatility of China's interest rate (0.6890) is higher than world interest rate volatility (0.5389). The fluctuation of China's inflation shows a negative skew distribution (skewness equal to −0.7249), indicating that the fluctuation of China's inflation is mostly greater than the mean value of 0.5017. On 11 August 2015, the People's Bank of China announced that it would modify the RMB mid-price generation method and that the mid-price would refer to the closing exchange rate of the previous day's interbank foreign exchange market. After the adjustment, the nominal exchange rate generally showed a downward trend, so the mean (−0.3588) and median (−0.0205) of its fluctuation were negative. The actual oil price fluctuated around the mean value(0.1414), but the fluctuation range was large, and the standard deviation reached 6.7369.

Table1. Descriptive statistics and stationarity tests of variables.

	China output	World output	China inflation	China interest rate	World interest rate	Nominal exchange rate	Actual oil price
Max	2.8940	1.7092	4.9504	3.2642	1.5050	2.3046	15.0010
Min	0.0771	−1.8639	−4.1300	0.3675	0.0037	−3.6988	−31.2348
Mean	1.0812	0.5861	0.5017	1.2095	0.5929	−0.3588	0.1414
Median	1.0733	0.5640	0.6975	1.0108	0.4291	−0.0205	0.6952
Std	0.4505	0.5706	1.5050	0.6890	0.5389	0.7775	6.7369
ADF	−4.5948	−3.8860	−5.0971	−3.2353	−4.1876	−2.5865	−6.654
	(0.0001)***	(0.0001)***	(0.0001)***	(0.0231)**	(0.0001)***	(0.0109)**	(0.0001)***

Values in parentheses are *p*-values.
***, ** and * denote significance levels of 1%, 5% and 10% respectively.

From the results of the ADF stationarity test, each variable cannot reject the null hypothesis at the 5% significance level, so it can be considered that each variable is stationary.

3.2.2. Prior Distributions

Since the settings of the prior distribution influence the accuracy and efficiency of the estimation, we explain the choice of the prior distribution to the deep parameters:

First, as to openness index, price inertia, lagged interest rate of Taylor rules and all seven exogenous shocks AR (1) coefficients, which range from 0 to 1, those parameters are assumed to be Beta distributed. In particular, we set the prior mean of openness index to be 0.4, which is consistent with some of the estimates on the small open economy (i.e. GM). We follow Smets and Wouters (2003), Christiano, Motto, and Rostagno (2010) by setting the prior mean of price inertia equal to 0.75, implying that the average length of the contract is 1 year. According to Zhang (2009), in reality the PBoC usually applies monetary policy instruments of both quantity and price, implying its lagged interest rate coefficient lower than advanced economies. Ma (2011) estimates the interest rate rule response function of China via GMM and finds the lagged interest rate coefficient at 0.50, so we set such value as the prior mean of lagged interest rate of China's Taylor rules. Furthermore, we follow Christiano, Motto, and Rostagno (2010) by setting the prior mean of the world lagged interest rate coefficient at 0.8. Finally, in line with Smets and Wouters (2003), we set the prior mean of AR(1) coefficients of all seven exogenous shocks at 0.85.

Second, the inverse of the elasticity of labour supply and the weight on inflation and output gap of Taylor rule are assumed to be Normal distributed. In particular, we set the prior mean of the inverse of the elasticity of labour supply at 3, which falls in a wide range of calibrations between 2 and–6 in the literature. The prior mean of the weight on inflation gap is set equal to 1.75, which trades off in between 1.31 and 3 suggested by Liu (2008), Wang and Zhu (2015) respectively. The prior mean of the weight on output gap is equal to 0.7, which falls in between the estimates of Liu (2008) and Huang, Chen, and Gong (2011). Following the estimate by Taylor (1993) for the United States, we set the prior means of the weight on world inflation and output gap to be 1.5 and 0.5, respectively.

Finally, all the variances of the shocks are assumed to be inverted Gamma distribution, which guarantees a positive variance with a rather large domain. Moreover, selections of all standard deviations are based on our trials.

We complete the estimation with DYNARE toolbox in MATLAB. Figure 1 summarises the density of the prior and posterior distribution as well as the posterior mode. First, the posterior distributions display smoothed shape with no significant uneven part, which corresponds to the form of the prior distributions. Second, the posterior and the prior distributions for most parameters are neither too close nor too far, implying a very accurate reflection of the information in the data.[8] In addition, the posterior distributions are close to normal, and the green mode is not too far away from the mode of posterior distribution. Moreover, from the MCMC univariate diagnostics in DYNARE, almost all the red and blue lines of deep parameters are convergent as conducting 2 million iterations of simulations, and thus the estimations are reliable.

Table 2 summarises the results regarding the parameter estimates. The two columns on the left contain the symbols and descriptions of the parameters. The third column shows the prior distribution (the first argument is the prior mean; the second argument is the standard deviation). The fourth and fifth columns show the posterior mean and 5%–95% posterior intervals, respectively. All these values have been obtained through MCMC simulation, using the Metropolis-Hastings algorithm for sampling 2 million iterations.[9]

We find that economic openness parameter, $\alpha = 0.2024$, is estimated to be smaller than the assumed in the prior distribution (0.4), implying that since China adopted the reform and opening-up policy in 1978, it has rapidly integrated the world economy globalisation with rising openness. However, compared to advanced economies, it still has a large room for increasing economy openness in the future.

The estimate of ψ is 4.8252, which is greater than 4.3014 of the world, implying a small estimation of the elasticity of labour supply to China. Chinese labour supply is also relatively insensitive to wages, probably because as a country with the largest population in the world, China has an abundance of labour supply.

The estimate of the price stickiness, ξ (0.4339), is smaller than the mean assumed in the prior distribution, which means that prices are re-optimised frequently once every two quarters. This is quite consistent with the market-oriented reforms of Chinese government in recent years. Chinese government accelerates the market-oriented reform on energy, transportation, electricity, communications and other large monopoly enterprises, which is gradually decreasing the degree of stickiness in the entire society.

Finally, we move now to the parameters regarding monetary policy rules. The posterior mean ρ_r of the interest rate smoothing coefficient is 0.5486, which is higher than the prior mean. Interest rate policy of China has shown greater consistency since the RMB exchange rate reform in 2005. Since then, the PBoC has more consideration to interest rate smoothing in formulating interest rate policies, to avoid the excessive disturbance of capital market caused by abrupt changes in interest rates.

Meanwhile, we find a relatively small response to inflation and output gap ($\phi_\pi = 1.6805$ and $\phi_x = 0.6746$) with respect to their prior distributions, indicating that monetary policy in terms of interest rates rule operates insufficiency response. One possible reason could be that the effects of a quantity rule on the Chinese economy seem to have more significant than those of a price-based rule. This result is in line with the findings of empirical studies on China's monetary policy rules, reported by Xie and Luo (2002) and Zhang (2009).

According to the previous studies, the pattern of real oil prices between 1979 and 1986 can be well replicated by an AR(1) process. Therefore, as a validation, this paper

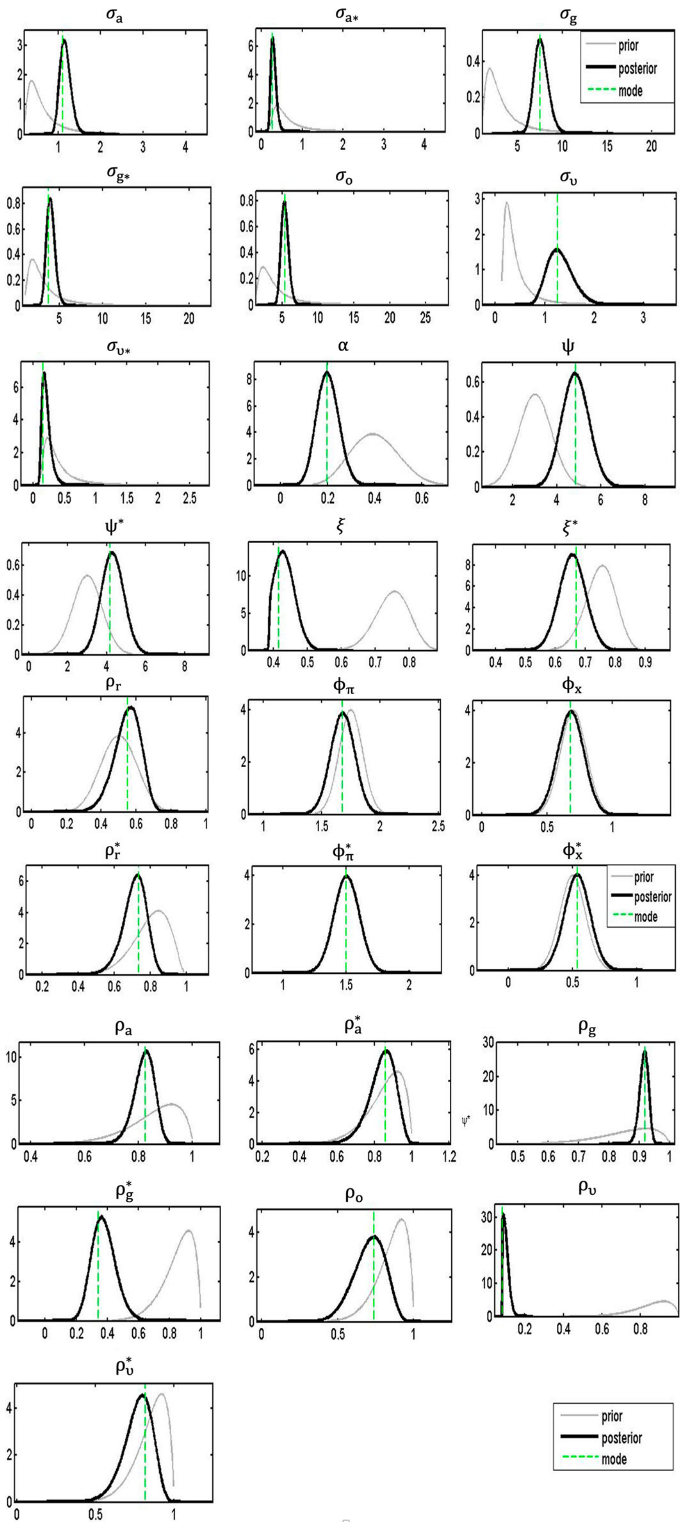

Figure 1. Prior and posterior distributions for parameters.

Table 2. Parameter estimates.

Parameters	Description	Prior distribution	Posterior mean	5%–95% Posterior Interval
σ_a	China's productivity shock	INV_GAMMA [0.8, ∞]	1.1710	[0.9568,1.3711]
σ_{a*}	World's productivity shock	INV_GAMMA [0.8, ∞]	0.2898	[0.1848,0.3860]
σ_g	China's gov. spending shock	INV_GAMMA [4.0, ∞]	7.6256	[6.3650,8.9067]
σ_{g*}	World's gov. spending shock	INV_GAMMA [4.0, ∞]	3.9959	[3.1646,4.7512]
σ_υ	China's interest rate shock	INV_GAMMA [0.5, ∞]	1.3154	[0.8822,1.7230]
$\sigma_{\upsilon*}$	World's interest rate shock	INV_GAMMA [0.5, ∞]	0.2128	[0.1082,0.3100]
σ_o	International oil supply shock	INV_GAMMA [5.0, ∞]	5.3464	[4.5218,6.1980]
α	Degree of Openness	BETA [0.40, 0.1]	0.2024	[0.1255,0.2791]
ψ	Inverse elasticity of China's labour supply	NORMAL [3.0, 0.75]	4.8252	[3.8553,5.8157]
ψ^*	Inverse elasticity of world's labour supply	NORMAL [3.0, 0.75]	4.3014	[3.3879,5.2538]
ξ	China's calvo prices	BETA [0.75, 0.05]	0.4339	[0.3872,0.4716]
ξ^*	World's calvo prices	BETA [0.75, 0.05]	0.6550	[0.5827,0.7272]
ρ_r	Coeff. on lagged Interest rate of China	BETA [0.50, 0.1]	0.5486	[0.4318,0.6744]
ϕ_π	Weight on inflation in China's Taylor rule	NORMAL [1.75, 0.1]	1.6805	[1.5121,1.8426]
ϕ_x	Weight on output gap in China's Taylor rule	NORMAL [0.70, 0.1]	0.6746	[0.5125,0.8382]
ρ_r^*	Coeff. on lagged Interest rate of world	BETA [0.80, 0.1]	0.7170	[0.6175,0.8202]
ϕ_π^*	Weight on inflation in world's Taylor rule	NORMAL [1.5, 0.1]	1.5067	[1.3442,1.6768]
ϕ_x^*	Weight on output gap in world's Taylor rule	NORMAL [0.50, 0.1]	0.5342	[0.3710,0.7034]
ρ_a	China's productivity shock	BETA [0.85, 0.075]	0.8170	[0.7573,0.8836]
ρ_{a*}	World's productivity shock	BETA [0.85, 0.075]	0.8397	[0.7317,0.9506]
ρ_g	China's gov. expenditure shock	BETA [0.85, 0.1]	0.9148	[0.8903,0.9395]
ρ_{g*}	World's gov. expenditure shock	BETA [0.85, 0.1]	0.3768	[0.2465,0.5031]
ρ_υ	China's interest rate shock	BETA [0.85, 0.1]	0.1032	[0.0829,0.1242]
$\rho_{\upsilon*}$	World's interest rate shock	BETA [0.85, 0.1]	0.7683	[0.6314,0.9149]
ρ_o	International oil supply shock	BETA [0.85, 0.1]	0.7080	[0.5494,0.8722]

compares the real oil prices model for the period 1979–1986 with that of the sample period in this paper. In measuring real oil prices for the period 1979–1986, it is necessary to use the quarterly GDP deflator for the period. As the CPI index is annual until 1987, the quadratic interpolation method is used to estimate the quarterly year-on-year series from 1979 to 1986. From the quarterly year-on-year series for this period, the quarterly chain series can be converted to obtain a quarterly fixed base based on the first quarter of 1996 to characterise the quarterly GDP deflator. Finally, following the procedure in Section 3.2.1, real oil prices can be calculated from 1979 onwards.

We use the Bayesian method to fit the AR(1) process to real oil prices, assuming that the parameter ρ_o follows the Beta distribution with a mean of 0.85 and a standard deviation of 0.1, and the obtained results are given in Table 3.

As seen in Table 3, the parameter estimation result of AR(1) for the sample period selected in this paper (0.7091) is very close to that of the parameter estimation result for the period 1979–1986 (0.7208), and the estimation results for all three sample periods are around 0.70. Also, the parameter estimates in Table 3 are close to those in the DSGE structural model (Posterior mean of 0.7080 in Table 2). The above conclusions illustrate that it is reasonable and robust to assume that real oil prices follow the AR(1) process.

4. Dynamic Responses to Shocks

4.1. Impulse Response Analysis

Figure 2 depicts the impulse responses of the main macro variables for both countries to a negative international oil supply shock of one standard deviation. The horizontal axis represents the period in quarters, and the vertical axis represents the percentage

Table 3. The Bayesian Estimation results of real oil prices by AR(1) model.

Period	Posterior mean	5%–95% Posterior Interval
1979Q1–1986Q4	0.7208	[0.5406, 0.8861]
1996Q1–2015Q3	0.7091	[0.5889, 0.8252]
1979Q1–2015Q3	0.6870	[0.5961, 0.7772]

deviation from steady state. Note that although a reduction in international oil supply (a negative shock) leads directly to a rise in oil prices in both China and the ROW, this type of increase in oil prices has endogenous properties, which contrasts with a traditional exogenous increase in oil prices. The oil markets clearing condition $o_t^{d*} = o_t^s$, which

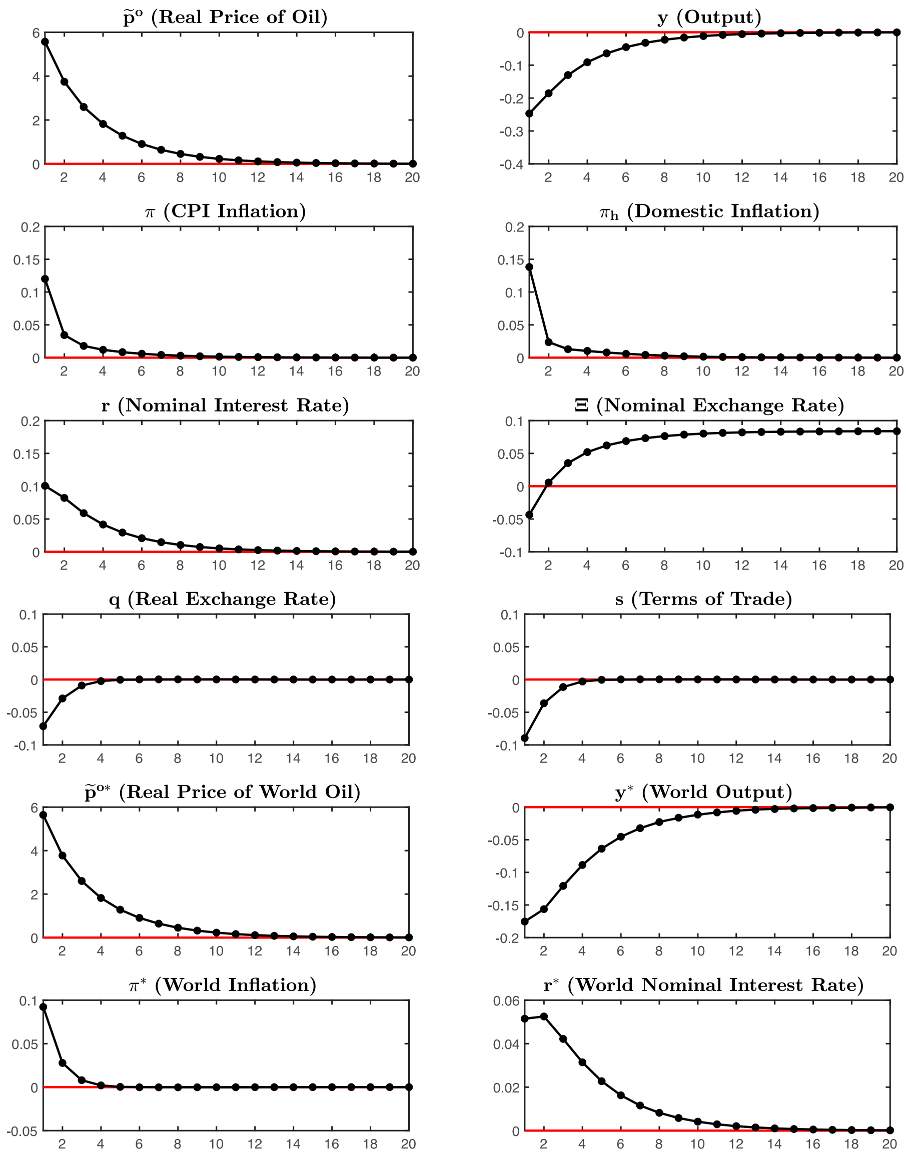

Figure 2. Impulse response of a negative standard deviation International oil supply shock.

was used in the model mentioned earlier, indicates that exogenous shocks of international oil supply are first delivered to the ROW; therefore, let us start by analysing the situation in the ROW (or world). According to the production function, a reduction in the international oil supply would cause a decrease in oil input, which in turn causes a decline in production. At the same time, under the marginal cost function, a negative shock causes the marginal costs of firms to rise, resulting in higher inflation. According to the Taylor rule, central banks would then raise the nominal interest rate to combat inflation. As for China, due to the exchange rate pass-through effect, rising real oil prices of the ROW results in an increase in domestic real oil prices. On the one hand, this would cause a decrease in firms' demand for oil input, which in turn would lead to a decline in output. On the other hand, this would cause an increase in marginal cost, resulting in higher inflation and then causing the central bank to raise the nominal interest rate. Note that according to the Taylor rule for both China and the ROW, the increase in the domestic interest rate triggered by these shocks would be higher than that ROW because the response coefficients of domestic inflation and output gap are larger than the ROW ones. Coupled with uncovered interest rate parity, this scenario would appear an initial appreciation in the nominal exchange rate followed by depreciation, which in turn would lead directly to a similar trend in real exchange rate and terms of trade.

4.2. Variance Decomposition

Table 4 depicts the variance decomposition of the volatility of each variable, where the first row is the exogenous shock. As Table 4 shows, international oil supply shock mainly affects real oil prices, but has little effect on the output and inflation, namely, no more than 10%, which is similar to Zhao et al. (2016). Monetary policy shocks account for the most important sources of inflation fluctuations, while labour productivity shocks have a big contribution to output fluctuations in China, which is consistent with most of the literature on RBC. Government spending shocks account for 20.37% of the output variance, which is in line with China's recent dependence on increased government expenditure to boost the economy.[10]

4.3. Historical Decomposition

From Figures 3–5, histograms of various colours represent each type of shock, and the black solid line represents the historical data. First, Figure 3 shows that real oil prices

Table 4. Variance decomposition (Unit: %).

	International oil supply shock	China's interest rate shock	World's interest rate shock	China's Gov. spending shock	World's gov. spending shock	China's productivity shock	World's productivity shock
Real Oil Prices	69.83	0.13	9.40	7.31	9.51	3.69	0.13
Output	3.05	2.50	0.27	20.37	0.27	73.51	0.02
CPI-Inflation	0.64	90.50	0.07	3.67	0.73	4.34	0.04
Inflation	0.79	81.76	0.42	5.98	0.33	10.69	0.03
Output of the ROW	8.60	0.00	24.87	18.46	28.74	0.00	19.34
Inflation of the ROW	0.75	0.00	91.99	2.75	3.73	0.00	0.77

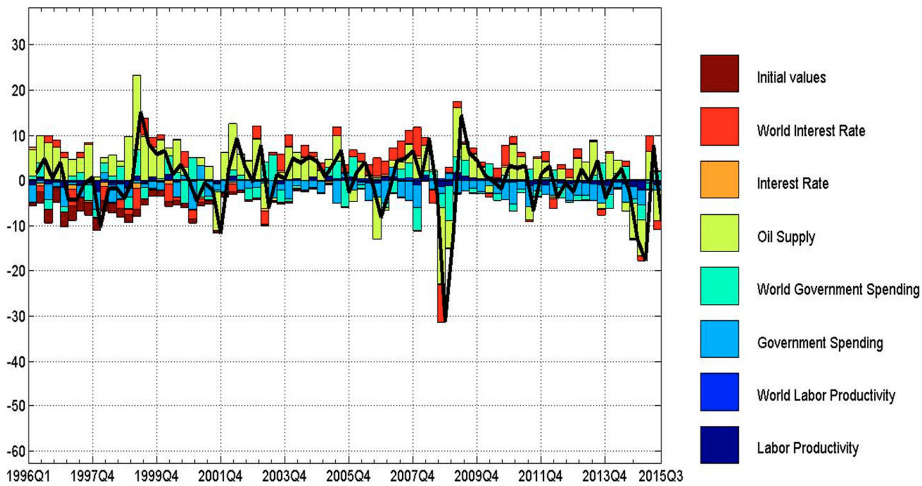

Figure 3. Historical variance decomposition of China's real oil price.

in China have a strong positive correlation with international oil supply. For the two sample periods of 2008Q2–2009Q2 and 2014Q3–2015Q3, the international oil supply and world interest rate shocks play a major role in accounting for volatility in real oil price. Second, Figure 4 shows that China's output fluctuation is mostly driven by government spending. During the global financial crisis from the second half of 2007 to the first half of 2009, the sharp decline in output was due mainly to the shocks of interest rate policy and labour productivity. Finally, Figure 5 shows that most of the variation in CPI inflation seems to be due to interest rate and government spending shocks. In addition, Figures 4 and 5 indicate that international oil supply shock does not contribute significantly to fluctuations in China's output and inflation over time, which is consistent with the above results from variance decomposition.

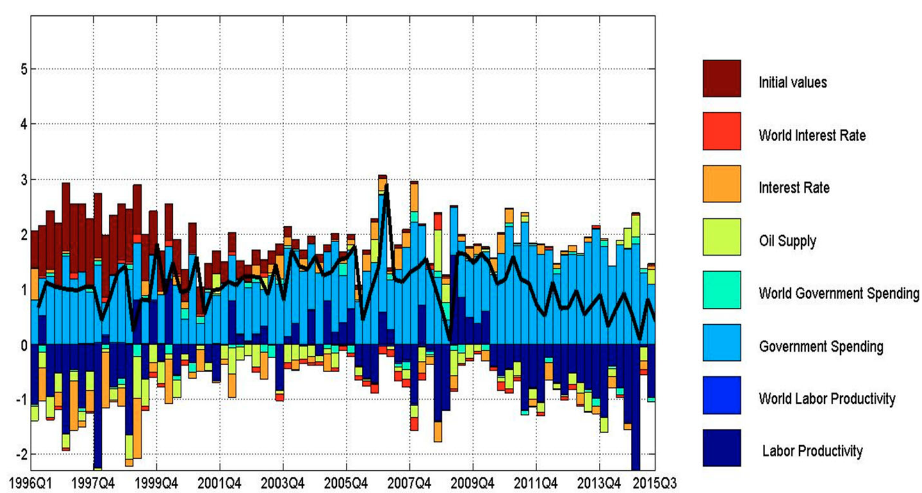

Figure 4. Historical variance decomposition of China's output.

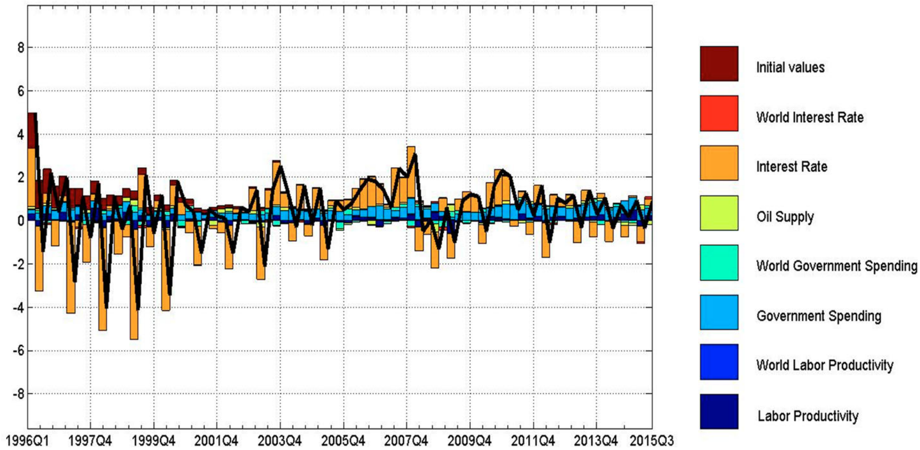

Figure 5. Historical variance decomposition of China's CPI inflation.

5. What Inflation Indicator to Target: Core or Headline Inflation?

The simulation results show that rising oil prices trigger a loss in output and an increase in inflation, which raise the risk of stagflation and therefore do have an adverse effect on the economy. The 'leans into the wind' feature of monetary policy may be required to respond to oil price shocks, which raises the question that whether the PBoC should take into account energy prices volatility represented by oil when executing monetary policy. Since the financial accelerator theory on how changes in asset prices can amplify macroeconomic fluctuations is proposed by Ben Bernanke, former chairman of the Fed, and others, numerous academics have conducted successful research into the issue of whether monetary policy must pay closer attention to fluctuations in asset prices. By analysing the relationship between the social welfare function and loss function of monetary policy, it is discussed whether monetary authorities will take the specified asset prices into account when executing monetary policy. Learning from their ideas, we will take the oil prices as asset prices (Bernanke et al. 1997), introducing inflation in oil prices as a variable in the Taylor rule to explore whether the PBoC must consider oil price volatility when executing monetary policy. In summary, it is to examine: what measure of inflation should the PBoC target, headline inflation including oil prices or core inflation? The next part will answer these questions.

5.1. A Numerical Analysis of First Moments

As mentioned above, the headline inflation can be decomposed into core inflation (trend component) and oil prices inflation (temporary component). Similar to the setting of Dhawan and Jeske (2007), intuitively, we use a simple linear equation, $\Pi_t^{HL} = \Pi_t + \chi_e \Pi_t^o$, to visualise, where Π_t^{HL}, Π_t and Π_t^o are headline inflation, core inflation and oil prices inflation, respectively, and χ_e denotes the relative weight in headline inflation to oil price inflation.

Due to the fact that oil price inflation (log-linearised) is defined as $\pi_t^o \equiv p_t^o - p_{t-1}^o$, we can modify the standard Taylor rule (equation (20)) as follows:

$$r_t = \rho_r r_{t-1} + (1-\rho_r)[\phi_\pi \pi_t + \phi_\pi^o \pi_t^o + \phi_x x_t] + \upsilon_t \tag{31}$$

where ϕ_π^o is the oil price inflation reaction parameter in the extended Taylor rule. When $\phi_\pi^o = 0$, core inflation collapses to headline inflation, that is $\Pi_t^{HL} = \Pi_t$, indicating that monetary policy needs only target core inflation, rather than focusing on non-core inflation determined by oil prices volatility. Leduc and Sill (2004) and Carlstrom and Fuerst (2006) study the DSGE model of US oil economy in terms of this rule. When $\phi_\pi^o > 0$, the monetary policy must take both core and non-core inflation into account, which means monetary policy should target headline inflation. When $\phi_\pi^o < 0$, the monetary authorities accommodate the oil price inflation, rather than the traditional 'headwind' regulation.

Hereafter, we adopt the counterfactual simulations to study the effects of different weights on oil price inflation (ϕ_π^o)[11] on output and core inflation in the event of an increase in oil prices. Specifically, similar to the setting of Wang and Zhu (2015), five sets of values $\phi_\pi^o \in [0, 0.1, 0.2, 0.5, -0.1]$ are selected to do the simulation, the first is the benchmark value for the model; the following three are chosen in ascending principles, a negative value is chosen as the last value to investigate the accommodating simulation analog to oil price inflation (hereinafter referred to as the accommodating model), and other deep parameters are assumed to be the same.

Figure 6 shows the counterfactual simulation of the output response to oil price increases for different ϕ_π^o settings. Figure 6 shows that as ϕ_π^o increases, rising oil prices cause a loss in output in the first period progressively. In particular, for the benchmark model of $\phi_\pi^o = 0$, if the central bank follows the standard Taylor rule by selecting core inflation as the monetary policy objective, then the loss in output in the first period would be less than that of the other three model of $\phi_\pi^o > 0$, but more than that of accommodating model of $\phi_\pi^o < 0$. Though there is a slight reversal from the beginning of the second period, the output values of all models in sample periods are negative. Furthermore, the cumulative average output loss during the sample period (L^y) satisfies:

$$L^y + \beta L^y + \beta^2 L^y + \cdots + \beta^{19} L^y = \sum_{t=1}^{20} \beta^{t-1} y_t \Rightarrow \quad L^y = \frac{1-\beta^{20}}{1-\beta} \sum_{t=1}^{20} \beta^{t-1} y_t$$

and by contrast, it can be found the average output loss of 4.34% under the standard Taylor rule is lower than three models' value of the augmented Taylor rule $\phi_\pi^o > 0$, but greater than that of the accommodating model.

Figure 7 shows the counterfactual simulation of the inflation response to oil price increases for different ϕ_π^o settings. Figure 7 shows that as ϕ_π^o increases, although rising oil price causes the decline in inflation in the first period progressively, inflation starts to be increased in the second period. Moreover, the overall price level changes (Δp^F) in the sample period are calculated based on the core inflation rate, which is calculated

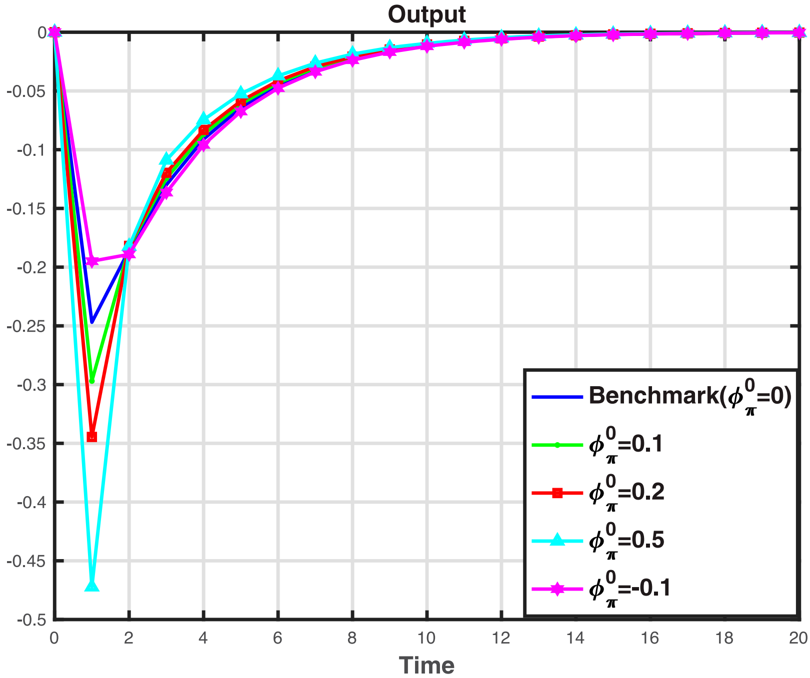

Figure 6. Counterfactual simulation of output response in rising oil prices (ϕ_π^o is variable).

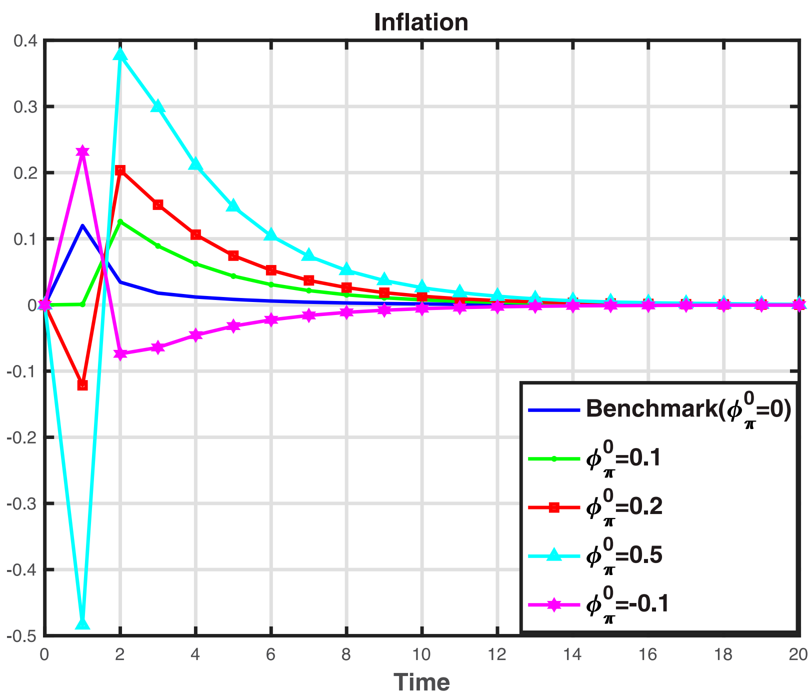

Figure 7. Counterfactual simulation of inflation response in rising oil prices (ϕ_π^o is variable).

as follows:

$$\Delta p^F = 1 + exp\left(\sum_{t=1}^{20} \pi_t\right)$$

By comparison with price volatility, the change rates in overall price level are 2.24 in the last period with respect to the first period under the standard Taylor rule, which is less than three models' value of the augmented Taylor rule with $\phi_\pi^o > 0$, but higher than that of the accommodating model.[12]

The objective of China's monetary policy is to 'maintain the stability of the value of the currency and thereby promote economic growth', indicating that stable inflation and output promotion are core objectives in the implementation of its monetary policy. In medium to long terms, the standard Taylor rule, which results in a smaller decline in output and a smaller increase in price levels after shock, is the preferred choice for the PBoC. It also suggests that the PBoC to target core inflation rather than headline inflation.

5.2. Numerical Analysis of Second Moment

We follow Woodford (2003) and Galí (2008) by taking the second-order approximation of the utility losses of the domestic consumer resulting from shocks that hit the economy. Thus, as $\beta \to 1$, the expected welfare losses of shocks can be written in terms of variances of domestic inflation and output gap[13]:

$$V_t = -\frac{(1-\alpha)}{2}\left[\frac{\varepsilon}{\lambda} var(\pi_{H,t}) + \frac{1+\psi}{\eta} var(x_t)\right]$$

Compared with the GM model, the most prominent difference is the parameter of the output gap volatility. Take the share of oil in the production equals to $0(\eta = 1)$, which indicates only labour input in the production function, thus the welfare loss function collapses to that of GM. The existence of oil input, $\eta(0 < \eta < 1)$, increases the output gap volatility.

Making use of the above expression, we calculate the welfare loss in terms of different interest rate rules for the robustness test, and summarise the results in Table 5. Regardless of what kind of deep parameters, the stronger the monetary policy response to oil price fluctuations, the greater the corresponding welfare loss. This result indicates that monetary policy pegged to the headline inflation rate is not in favour of the improvement of social welfare, on the contrary, the classic one that is only pegged to core inflation rate could be considered as the best metrics for China's monetary policy, and can also verify the conclusions of 'the first moment' mentioned above.

6. Conclusion

Aggregate supply shocks, as represented by oil prices, present a challenging issue for most countries. In the event of a severe shock that affects the economy, a monetary policy response that targets a corresponding inflation indicator must be implemented.

Table 5. Contributions to welfare losses (international Oil supply shock with one standard deviation).

	Monetary policy			
	$\phi_\pi^o = 0$	$\phi_\pi^o = 0.1$	$\phi_\pi^o = 0.2$	$\phi_\pi^o = 0.5$
Benchmark model				
Var (Domestic Inflation)	0.0201	0.0258	0.0773	0.4343
Var (Output Gap)	0.0010	0.0005	0.0047	0.0388
Total Welfare Loss	0.0671	0.0842	0.2600	1.4912
Strong nominal inertia $\xi + 20\%$				
Var (Domestic Inflation)	0.0158	0.0240	0.0648	0.3304
Var (Output Gap)	0.0019	0.0009	0.0087	0.0720
Total Welfare Loss	0.0554	0.0794	0.2296	1.2383
Weak nominal inertia $\xi - 20\%$				
Var (Domestic Inflation)	0.0239	0.0273	0.0895	0.5369
Var (Output Gap)	0.0005	0.0002	0.0023	0.0190
Total Welfare Loss	0.0781	0.0883	0.2934	0.5369
Strong interest rules $(\phi_\pi + \phi_x) + 20\%$				
Var (Domestic Inflation)	0.0137	0.0157	0.0566	0.3546
Var (Output Gap)	0.0007	0.0004	0.0042	0.0332
Total Welfare Loss	0.0458	0.0515	0.1922	1.2213
Weak interest rules $(\phi_\pi + \phi_x) - 20\%$				
Var (Domestic Inflation)	0.0332	0.0514	0.1209	0.5534
Var (Output Gap)	0.0015	0.0004	0.0050	0.0448
Total Welfare Loss	0.1104	0.1662	0.4009	1.8888
High degree of openness $\alpha + 20\%$				
Var (Domestic Inflation)	0.0201	0.0253	0.0759	0.4292
Var (Output Gap)	0.0010	0.0004	0.0046	0.0381
Total Welfare Loss	0.0671	0.0823	0.2553	1.4731
Low degree of openness $\alpha - 20\%$				
Var (Domestic Inflation)	0.0200	0.0264	0.0788	0.4394
Var (Output Gap)	0.0010	0.0005	0.0049	0.0395
Total Welfare Loss	0.0667	0.0861	0.2653	1.5093

Otherwise, inflation may exceed its target value, leading to costly losses in output and employment. Therefore, both academic researchers and central banks give a rising concern on the issue of whether to stabilise the headline or core inflation, also including China. Being downturn brought about by economic restructuring, it is inappropriate for China to select the money supply as the regulatory objective of its monetary policy. Learning from the international experience, inflation targeting is undoubtedly an important direction of China's deepening monetary policy institutional reform in the future. We use Chinese quarterly data to build New Keynesian DSGE model in the oil economy. We utilise the state-of-the-art welfare evaluation method in modern monetary economics to study the pros and cons of two types of monetary policies, namely headline inflation targeting and core inflation targeting. Our purpose is to provide theoretical support for future reforms to China's monetary policy system.

(1) Based on the calibrated model associated with seven structural shocks, the impulse response function, variance decomposition and historical variance decomposition are calculated. Some conclusions are worth noting. First, International oil supply shock plays a direct role in China's oil price, whereas has a very limited impact on China's output and inflation. For the wide fluctuations of China's real oil price during the sample periods of 2008Q2–2009Q2 and 2014Q3–2015Q3, the international oil supply shocks and the World's interest rate shocks play leading roles. Second, the interest rate policy shocks are the main driving force to push China's CPI Inflation, followed by government spending. Third, the government spending

shocks are the main strength that undertakes China's output fluctuations. However, during the global financial crisis starting from the second half of 2007 to the first half of 2009, the dramatic decline of output growth rate was mainly due to the combined shocks of China's interest rate policy and labour productivity.

(2) By integrated using counterfactual policies and welfare evaluations, our model shows a monetary policy that simultaneously targeting on core and non-core inflations are inferior to the monetary policy that is purely pegged to core inflation, suggesting the central bank should focus on core inflation instead of headline inflation in setting monetary policy, thus providing theoretical support for monetary policy practice in the future.

In future work, it will also relax the implied assumption that the central bank has a significant amount of credibility, to the point that temporary oil shocks do not spill over to a permanent increase in prices and hence higher inflation over time.[14] The PBoC and modern central banking are still in its infancy in China and will likely evolve considerably in the coming years. To this end, as the institutions evolve and the economy matures and becomes more open, such considerations of credibility in maintaining its inflation target will become more important. As a result, it may be the case that to establish its credibility, the PBoC may for some time need to target headline inflation to anchor expectations permanently and establish credibility before transitioning to a core targeting framework. Another extension would be to include China's prevailing policy regime such as capital control, exchange rate targets, sticky wages, and many additional frictions in the model.

Notes

1. Credit constraint and even financial constraints seem to be an obvious, unquestionable proposition for a relatively less-developed countries and regions and intuitively people think that this conclusion is remarkable. But in fact, for China, credit restraint itself is lacking of adequate theoretical and empirical evidence. On the one hand, according to the survey and empirical research on Chinese farmers' borrowing behaviour Zhong, Sun, and Xu (2010) found, the majority of households credit demand can be met. On the other hand, since the late 1990s, the Chinese government has been expanding domestic demand and consumption, as one of the "Troika" for boosting economic growth, is highly expected during the process of expanding domestic demand. In this context, consumer credit for improving consumer environment and expanding consumer is developing rapidly in support of the government. Since the new century, the scale of Chinese consumer credit is developing at an average annual growth rate of 29%. By 2014, China's consumer credit reached 15.4 trillion. China has become the largest country in Asia excluding Japan in the size of consumer credit, while consumer credit would weaken consumer precautionary savings or myopic consumer motivation (Berg 2013), which is the premise of motivation for consumer credit constraints.
2. Galí and Monacelli (2005) lay out a small open economy version of the Calvo sticky price model. Based on Galí and Monacelli (2005), this paper developes a small open economy DSGE-based New Keynesian model incorporating the demand of oil, to focus on whether Chinese central bank targets core inflation or headline inflation including oil price inflation.
3. Unalmis, Unalmis, and Unsal (2009)'s aim is to model macroeconomic consequences of these shocks within a new Keynesian DSGE framework. It models a small open economy and the rest of the world together to discover both accompanying effects of oil price changes and their international transmission mechanisms. Based on Unalmis, Unalmis,

and Unsal (2009), this paper discusses the operational objectives and economic implications of China's monetary policy.

4. For instance, certain unforeseen political events (e.g. Iran–Iraq War, Gulf war) in OPEC countries cause dramatic changes in the world oil supply. This scenario supports for the exogenous assumptions about the world oil supply. We assume that all the consumers equally share the profits of international oil supply in the world, same as Campolmi (2008), Unalmis, Unalmis, and Unsal (2009).
5. Equations (27) and (28) show that government spending has a negative impact on international real oil prices and affects domestic real oil prices through exchange rates. The oil prices mentioned here are real world oil prices, which are equal to world oil prices divided by the price index. An increase in world government spending leads to higher prices and an increase in the price index leads to lower real world oil prices.
6. Sourcing: http://edu.macrochina.com.cn/login.html.
7. Sourcing: http://www.eia.gov/dnav/pet/pet_pri_spt_s1_m.htm.
8. Since in general, two curves are too close implies the data does not provide much information, while too far means the worse choices of prior distributions.
9. Using DYNARE, our estimation has passed the Iskrev's test (2010), implying that there is no identification problem of the processed model, which can be used in Bayesian estimation.
10. A typical example is the global financial crisis in 2008, which was triggered by the subprime mortgage crisis in the U.S.A. To stimulate economic growth, the Chinese government rolled out fiscal expansion plans worth 4 trillion and implemented an expansionary monetary policy.
11. Note that there is no direct relation between the weight parameters χ_e and ϕ_π^o. The former helps the reader to visualize, whereas the latter introduces oil price inflation into the reaction coefficient of the Taylor rule equation under the monetary policy.
12. We also make the robustness test, which can be requested from the author.
13. Specific steps can be obtained from the author.
14. If the central bank had no credibility, headline and core inflation would essentially move in the same manner as we saw in the 1970s in the U.S.A., implying virtually no difference in welfare between the two approaches.

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