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ARTICLES

OIL PRICE SHOCKS, INFLATION, AND CHINESE MONETARY POLICY

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This paper proposes a New Keynesian dynamic stochastic general equilibrium model of the Chinese economy incorporating the demand of oil to study the effects of oil price shocks on the business cycle. The model answers several questions, including how monetary policy should respond to the disturbances from such shocks, and whether monetary authorities should use core inflation or headline inflation including oil price inflation as the monetary policy rule. The contributions could be summarized as follows: First, the model reveals that the oil transmission mechanism is determined by the nominal inertia, income effect, and the portfolio allocation effect. Second, both noncore inflation monetary policy and core inflation monetary policy that are simultaneously pegged to oil prices fluctuations are inferior to the monetary policy purely pegged to core inflation. Our findings suggest that the monetary policy should focus on core inflation instead of headline inflation.

Keywords: Oil Price Shocks, DSGE Model, Monetary Policy Rules

1. INTRODUCTION

Over the past 30 years, the Chinese economy has experienced sustained rapid growth, shoring up its demand for oil. As early as 2003, China surpassed Japan to become the world's second largest oil consumer after the United States. With a sharp rise in consumption, its external dependence on crude oil is also rising. Since the year 2011, China surpassed the United States as the world's largest oil importer; in 2012, China's net oil imports accounted for 86% of the global growth increment, and China's dependence on foreign oil in 2014 reached 59.5% of its

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overall consumption. Since the beginning of this century, international oil prices have gone up and down by more than 50% at three separate occasions. Take the recent market for example, since the second half of 2014, the British Brent crude oil prices have fallen more than 60% in less than 7 months, second only to the financial crisis in 2008. Since the merger of domestic oil prices and international oil prices in 1998, China's oil benchmark price has been linked with international oil prices. Thus, the sharp volatility in international oil prices in recent years has become one of the important external sources in driving China's economic fluctuations. Oil price volatility impacts macroeconomy through a variety of channels [Kilian (2008, 2009)]. Specifically for China, oil price volatility has two effects. First, with its increase of dependence on foreign oil, oil price fluctuations can affect China's economic growth as an uncertainty shock. Second, fluctuations in oil prices may spur changes in production costs and consumer prices of many commodities, which are then transferred to inflation. In short, international oil price fluctuations have great impact on inflation and output of China, a big oil consumer and importer.

The substantial increase of crude oil prices by oil-exporting countries in 1970s caused the serious cost-push inflation in the leading industrialized countries, and the tight monetary policy to refrain inflation further led to economic stagnation in those countries. As emphasized by Eckstein (1981), in monitoring inflation level and making monetary policy, it is necessary to divide consumer price index (CPI) inflation into two parts: One is the trend determined by the total supply and demand, known as the core inflation, and the other is the noncore part determined by food or energy price, which is called the noncore inflation or temporary inflation. A noncore increase in individual commodity price could lead to a noncore rise in CPI inflation, which will fall when noncore rise ends. Such noncore fluctuations in CPI inflation should not affect the central bank's decision, and the central bank should make monetary policy based on the core inflation part.[1] Because of this argument, the traditional Taylor rule does not take into account the fluctuations in energy prices.

However, in recent years, the experience of China and other emerging market economies has been challenging to this notion: On the one hand, the impact of oil prices on inflation in China is increasingly far-reaching and permanent, with oil prices directly or indirectly propelling the consumer price; although oil price itself does not account a large share in the CPI basket, many other items such as food prices that are closely related to oil prices take large shares in the CPI basket. On the one hand, the oil price itself is significantly affected by monetary policy. During 2007–2008 and 2010–2011, China experienced a rising trend in oil prices, and high inflation occurred simultaneously with domestic high output and currency growth.

In the theoretical part, there is also growing debate in the academia on whether the monetary policy should focus more on headline inflation or core inflation. On one side, food and energy are important parts of consumer goods and can also affect the overall price level by price transmission mechanism; monetary policy adjusted with reference to headline inflation will not only help stabilize

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price fluctuations, reduce consumer welfare losses, but also keep the credibility of money policy, and stabilize inflation expectations [Neumann and Hagen (2002), Arora et al. (2013)]. But on the other side, the prices of such items are vulnerable to climate change and other nonmarket factors. Therefore, the frequent adjustment of monetary policy will have a negative impact on the economy due to its lagged effect [Bodenstein et al. (2008)]. Siviero and Veronese (2011) also noted that focusing on core inflation makes sense in a general setting, but it is still dubious whether it can be applied to monetary policy decisions.

Bernanke et al. (1997) suggested that the Fed should not take such an aggressive monetary policy when dealing with the energy prices rise in the 1970s, for the purpose of stabilizing inflation level while avoiding damage to economic growth. But research by Bernanke et al. (1997) adopted the vector autoregression (VAR) model that was criticized by Lucas as any change in monetary policy would cause changes in VAR model parameters. In light of the drawback of VAR model, a dynamic stochastic general equilibrium (DSGE) model containing oil price shocks should be constructed for analyzing optimal monetary policy rules. For instance, Leduc and Sill (2004) built a new Keynesian DSGE (NK-DSGE) model on how monetary policy deals with rising oil prices, and they concluded that the rise in headline inflation pegged to simple inflationary policy would make a radical reaction to oil prices rise, which enlarge oil price shock's impact on output and inflation, and reverse the effect of accommodative monetary policy. Dhawan and Jeske (2007) established an energy economy NK-DSGE model that contains durable goods consumption, and they showed that a Taylor rule targeted on core inflation while leaving food and energy price aside is better than a Taylor rule targeted on headline inflation. Based on the Ramsey optimal policy rules, Kormilitsina (2011) verified that the negative impact of monetary policy on the economy will be worsened by energy prices, suggesting that monetary policy needs to be targeted on core inflation. These arguments have also been echoed by several other studies such as Mishkin (2007a, b), Bodenstein et al. (2008), and Huynh (2014).

The literature on China's monetary policy with respect to oil price shock is much smaller. Both Zhang and Xu (2010) and Tang and Jiao (2012) used the VAR model to study the Chinese monetary policy to deal with the oil price shocks, and their findings show that the central bank should be refrained from excessive monetary policy reaction to oil prices volatility. This simplified VAR method, as described above, is also subject to Lucas' critique. The literature using the framework of DSGE to study China's monetary policy is even less. Liu and Song (2013) established a DSGE model for the impact of oil price volatility on macroeconomy and analyzed how monetary policy should cope with oil shocks, and suggested stabilizing output as the main objective. Wang and Zhu (2015) established a DSGE model based on the impact of energy price shocks on the macroeconomy, studied how monetary policy should be adopted to deal with rising energy prices, and showed that pegging to energy price volatility in a small and gentle way can be used in China's monetary policy. Such research works on monetary policy aim to answer the question about whether to peg to gross domestic product (GDP) or to inflation. Research on whether to peg to core inflation or to headline inflation is missing in China. Based on continuous inflation, universal inflation, and welfare losses, Hou and Gong (2013) redefined core inflation, its measurement and evaluation methods, which has laid foundation for core inflation for further research.

After the reform of China's banking system in 1984, the People's Bank of China (PBoC, China's central bank) began to exercise the functions as a central bank, which suggests that the modern Chinese central bank system has been initially established. At that time, the objective of the monetary policy was to "develop the economy and stabilize currencies," belonging to typical dual goals (dual mandate). However, it tended to promote economic growth while ignoring monetary stability and finally it might lead to inflation. In 1995, the People's Congress of China passed the "Law of the People's Bank of China" that authorized the PBoC to use monetary policy to control inflation and to help increasing production when necessary. The law also stipulated that the goal of monetary policy was to maintain currency stability so as to promote economic growth. It also made clear that inflation was the most important target of China's monetary policy. As a result, instead of economic growth, the currency stability gradually became the primary objective of China's monetary policy.

China's central bank and academics take CPI as an important indicator of the level of inflation [Basically, China does not publish an official inflation rate, and the popular inflation rate refers to the CPI compiled by the National Bureau of Statistics (NBS) in China.]. It is a reflection of the price changes of goods and services related to domestic residents, as a kind of headline inflation. CPI is a primary consideration for the PBoC to make monetary policy (such as the adjustment of the benchmark interest rate). China uses a basket of samples to compute CPI, including eight categories of consumer goods with different weight ratios. Following data show the ratio details of each category:

Category	Food	Entertainment, education, sports, and cultural products and services	Household	Transportation and communication	Health care products and services	Clothing	Household facilities maintenance	Smoking and alcohol consumption
Weights	34%	14%	13%	10%	10%	9%	6%	4%

Therefore, to account for the fact that China's CPI does not include oil price, we introduced a generalized Taylor rule, based on the work of Dhawan and Jeske (2007) and Bodenstein and Erceg (2008) that explicitly distinguishes between core and oil price inflation to study optimal monetary policy rules. In particular, this paper follows Dhawan and Jeske (2007) by introducing a New Keynesian framework with the consumption of durables and nondurables in the household utility function. A major difference from Dhawan and Jeske's specification is that on the production side, oil enters the production functions through the approach

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proposed by Finn (2000) and also used by Leduc and Sill (2004). Oil usage is tied to the intensity of capital utilization: The more is the capital used, the greater is the oil requirement. In particular, the model introduces New Keynesian features in the form of monopoly, wage rigidity, inertia prices for the durables and non-durables sectors, and monetary authorities. Previous studies such as Leduc and Sill (2004), Carlstrom and Fuerst (2006), Montoro (2012), Nakov and Pescatori (2010), Kormilitsina (2011), and Huynh (2016) provide the background and motivation for the analysis. However, the setup departs from traditional efforts in two important dimensions. In the presence of oil consumption in the household utility function, the model encompasses an income-effect channel through which oil makes its impact on the demand side of the economy. The other contribution by this paper is to explicitly analyze optimal monetary policy based on the efficient frontier method. By this method, this research further proves the superiority of purely pegging to core inflation monetary policy, thus providing a theoretical base for China's further monetary policy practice.

The remainder of this paper is organized as follows: The second part presents an NK-DSGE model on durables and nondurables consumption of oil economics, the third part describes how we calibrate our model, the fourth part performs the dynamic analysis of the model, and final part concludes.

2. MODEL

We present a closed-economy model for China, in line with Zhang (2009), Miao and Peng (2011), and Chen et al. (2012). We choose to restrict our analysis to a closed economy because of several reasons: First, capital controls are being conducted in China. There is no point to assume uncovered interest parity as domestic monetary policy is relatively independent despite the de facto US dollar peg for substantial periods of time. Particularly, China has strict capital controls, and thus Chinese currency is not convertible. The exchange rate is controlled under pegged exchange rates instead of floating exchange rates.[2] China's capital controls and pegged exchange rates weakened the effect of the Chinese monetary policy. Obviously, the Chinese currency has less influence than it should, and results in a weakened monetary policy in international transmission, even though the Chinese economy played an important role worldwide.

Second, it might not be appropriate to model China as a closed economy since China has a large export and import sector. Actually, China's export and import sector has developed rapidly because of increased investment in new urban infrastructure and transportation. Once these decisions being conducted, goods would be sold at international market prices, indicating that neither the international demand nor the exchange rate would have significant effects if price would be set to ensure available goods being sold out.

Third, in a recent work Le et al. (2014) found that a DSGE model of the closed-economy structure in China could successfully capture the key features of the Chinese macroeconomic behavior over the past two and a half decades including the financial crisis period. Hence, our choice of a closed-economy model is reasonable.[3]

2.1. Households and Wage-Setting

Households. Assume that a continuum of households i could live permanently in the economy and are uniformly distributed on [0, 1]. Every household's consumption ($C_{i,t}$) consists of durable goods ($D_{i,t}$), oil and its products ($O_{h,i,t}$, hereinafter referred to as oil), and nondurables ($N_{i,t}$), and the nested constant elasticity of substitution (CES) functional form is constituted by three elements:

$$C_{i,t} = \left(N_{i,t}\right)^{1-\alpha_c}\left[\alpha_F\left(D_{i,t-1}\right)^{-\rho_F} + (1-\alpha_F)\left(O_{h,i,t}\right)^{-\rho_F}\right]^{-\frac{\alpha_c}{\rho_F}}, \tag{1}$$

where $\alpha_c \in (0, 1)$, $\alpha_F \in (0, 1)$, $\rho_F \geq -1$, $\frac{1}{1+\rho_F}$ is the elasticity of substitution between oil and durables. It should be noted that durables are nondisposable. There is an accumulative process of consumption for durables, and the operating mode is similar to the capital ($K_{i,t}$) in the model, both act as state variables.

The representative household's utility function is as follows:

$$E_0\left\{\sum_{t=0}^{\infty}\beta^t\left[\log\left(C_{i,t}\right) - \frac{\left(L_{i,t}\right)^{1+\sigma_L}}{1+\sigma_L}\right]\right\},$$

where β denotes the discount factor, $L_{i,t}$ is the labor supply variable, and σ_L is the inverse of labor supply elasticity. The budget constraint for households is

$$\frac{B_{i,t}}{P_t} = R_t\frac{B_{i,t-1}}{P_t} + w_t L_{i,t} + r_t^k K_{i,t-1} + \mathrm{Div}_{i,t} + T_{i,t} - \left(N_{i,t} + I_{K,i,t} + I_{D,i,t} + P_{o,t} O_{h,i,t}\right).$$

Among them, households hold their financial wealth in the form of bonds $B_{i,t}$, bonds are one-period securities with price R_t, the nominal price index is represented by P_t, and $I_{K,i,t}$ and $I_{D,i,t}$ are the investments of capital and durables consumption, respectively. w_t and r_t^k denote real wages and rental price of capital services, $\mathrm{Div}_{i,t}$ is real dividends derived from the firms, $T_{i,t}$ is the lump-sum taxation, and $P_{o,t}$ is the relative price of oil, respectively. In addition, the accumulation equation of capital and durables is subjected to the following conditions:

$$I_{K,i,t} = K_{i,t} - (1-\delta_k)\,K_{i,t-1}, \tag{2}$$

$$I_{D,i,t} = D_{i,t} - (1-\delta_d)\,D_{i,t-1}, \tag{3}$$

where δ_k and δ_d are the discount factors of capital and durables, respectively.

The first-order condition in terms of $N_{i,t}$, $D_{i,t}$, $O_{h,i,t}$, $K_{i,t}$, $B_{i,t}$, $I_{K,i,t}$, and $I_{D,i,t}$ is obtained by solving the dynamic optimal choice problem of the representative household:

$$\lambda_{i,t} N_{i,t} = (1-\alpha_c) \tag{4}$$

$$\lambda_{i,t} Q_{D,i,t} = \beta \left[\alpha_c \alpha_F \left(C_{i,t+1}\right)^{\frac{\rho_F}{\alpha_F}} \left(N_{i,t+1}\right)^{(\alpha_c - 1)\frac{\rho_F}{\alpha_c}} \left(D_{i,t}\right)^{-\rho_F - 1} + (1 - \delta_d)\, \lambda_{i,t+1} Q_{D,i,t+1} \right] \tag{5}$$

$$\lambda_{i,t} P_{o,t} = \alpha_c (1 - \alpha_F) \left(C_{i,t}\right)^{\frac{\rho_F}{\alpha_c}} \left(N_{i,t}\right)^{(\alpha_c - 1)\frac{\rho_F}{\alpha_c}} \left(O_{h,i,t}\right)^{-1-\rho_F} \tag{6}$$

$$\lambda_{i,t} Q_{K,i,t} = \beta \lambda_{i,t+1} \left[r^k_{t+1} + (1 - \delta_k)\, Q_{K,i,t+1} \right] \tag{7}$$

$$\frac{\lambda_{i,t}}{P_t} = \beta \lambda_{i,t+1} \frac{R_t}{P_{t+1}} \tag{8}$$

$$Q_{K,i,t} = 1 \tag{9}$$

$$Q_{D,i,t} = 1, \tag{10}$$

where $\lambda_{i,t}$ is the Lagrange multiplier of budget constraint, and $Q_{K,i,t}$ and $Q_{D,i,t}$ are the shadow prices (i.e., the Lagrange multipliers of capital and durables accumulation equations) of capital and durables, respectively. Equations (4), (5), and (6) are Euler equations of nondurables, durables, and household oil consumption, respectively, which describe the optimal consumption choices of the household on these three goods. Equation (7) is the Euler equation of capital, equation (8) is the consumption Euler equation, equations (9) and (10) indicate the Tobin q of capital and durable goods is a unit, which depicts two types dynamic optimal behavior of two types of investment, and also indicates the optimal equilibrium equating market value to replacement cost marginally for two categories of "capital."

Wage setting. As in Erceg et al. (2000), we assume a continuum of monopolistically competitive households, each of which supplies a differentiated labor service to intermediate firms. It is assumed that the elasticity of substitution is λ_w, and then households i face labor demand curve:

$$L_{i,t} = \left(\frac{W_{i,t}}{W_t}\right)^{-\frac{1+\lambda_w}{\lambda_w}} L_t,$$

where $W_t = [\int_0^1 (W_{i,t})^{-\frac{1}{\lambda_w}} di]^{-\lambda_w}$ is the aggregate wage index, $L_t = [\int_0^1 (L_{i,t})^{\frac{1}{1+\lambda_w}} di]^{1+\lambda_w}$ is the labor index. Assume that there is wage inertia and wage adjustments according to Calvo (1983) mechanism, with the constant probability, $1 - \xi_w$, of being able to reoptimize its nominal wage, while for households with the probability ξ_w, wages could not be reoptimized. For those household that cannot reoptimize wages, we allow a partial indexation of the wages that cannot be adjusted to past inflation: $W_{i,t} = (\pi_{t-1})^{\gamma_w} W_{i,t-1}$, among which γ_w is the degree of wage indexation. Note that $\gamma_w = 0$ indicates that there is no indexation and the wages that cannot be reoptimized remain constant, and $\gamma_w = 1$ indicates that there is perfect indexation to past inflation. $\pi_t = \frac{P_t}{P_{t-1}}$ is defined as inflation. Log-linearization on the first-order conditions of the household's optimization problem

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gives the New Keyesian Philips Curve (NKWPC) as

$$\hat{\pi}_t^w - \gamma_w \hat{\pi}_{t-1}^w = \beta \left(\hat{\pi}_{t+1}^w - \gamma_w \hat{\pi}_t^w\right) + \varpi \left(\widehat{mrs}_t - \hat{w}_t\right) = \sum_{j=0}^{\infty} \beta^j \varpi \left(\widehat{mrs}_{t+j} - \hat{w}_{t+j}\right). \quad \textbf{(11)}$$

In this paper, "^" is used to denote the variables after log-linearization, wage inflation is defined as $\pi_t^w = \frac{W_t}{W_{t-1}}$, and $w_t = \frac{W_t}{P_t}$ is the real wage. Following Sbordone (2000), we define $\varpi = \frac{(1-\beta\xi_w)(1-\xi_w)}{\xi_w(1+\frac{1+\lambda_w}{\lambda_w}\sigma_L)}$ as the inertia parameter, indicating the degree and size of nominal wage rigidity. The marginal rate of substitution between consumption and leisure is represented by $\widehat{mrs}_t = \sigma_L \hat{L}_t + \hat{C}_t$, and when the wage is fully elastic, (11) reduces to $\widehat{mrs}_t = \hat{w}_t$.

2.2. Firms

There are two types of firms in the economy, one is producing the final goods and the other intermediate goods. A final good, Y_t, is produced by a perfectly competitive firm by combining a continuum of intermediate goods $Y_{j,t}$ of [0, 1] in the Dixit–Stiglitz way. The demand function of final good producer for intermediate goods is $Y_{j,t} = (\frac{P_{j,t}}{P_t})^{-\frac{1+\lambda_p}{\lambda_p}} Y_t$, where $P_{j,t}$ is the price of the intermediate good, $P_t = [\int_0^1 (P_{j,t})^{-\frac{1}{\lambda_p}} dj]^{-\lambda_p}$ is the aggregate nominal price, and λ_p is mark-up in the goods market.

Each intermediate good $Y_{j,t}$ is produced by a firm in the Cobb–Douglas form:

$$Y_{j,t} = A_t \left(z_t K_{j,t-1}\right)^{\alpha_y} \left(L_{j,t}\right)^{1-\alpha_y}, \quad \textbf{(12)}$$

where z_t denotes the capital utilization rate of firms. A_t denotes the neutral technical shock, the so-called total factor productivity whose log-linearization follows an AR (1) process, $\hat{A}_t = \rho_A \hat{A}_{t-1} + u_{A,t}$ and $u_{A,t} \sim N[0, (\sigma_A)^2]$ are white noises, $\rho_A \in (0, 1)$ is the parameter of autoregressive factor, and σ_A is the impact of the standard deviation of technology. In addition, $\alpha_y \in (0, 1)$ is the share parameter.

As in the modern industrial economy, oil is the major capital goods used in the production input. As shown in Finn (1991, 1995), the amount of oil is proportional to the size of existing capital stock, and this ratio of oil to capital is a function of capital utilization rate:

$$O_{f,j,t} = a(z_t) K_{j,t-1}. \quad \textbf{(13)}$$

This equation shows that firm's oil consumption ($O_{f,j,t}$) is not only complementary with capital, but also associated with the capital utilization rate. We assume that $a(z_t)$ is an increasing and convex function of z_t, so the specific function is

$$a(z_t) = \gamma_o \left(\frac{z_t}{z}\right)^{\upsilon},$$

where γ_o is the constant coefficients of capital utility function, z is the steady capital utilization, and υ is the elasticity coefficient. It indicates that firm's oil consumption will accelerate with increase in capital utilization and, therefore, $a(z_t)$ can be seen as the "technology" that uses oil as the input in the production of capital. Because of $z_t \in [0, 1]$, $a(z_t)$ is invertible, and we get $z_t = a^{-1}(\frac{O_{f,j,t}}{K_{j,t-1}})$. Since capital utilization rate can be expressed directly in the intermediate goods production function, and oil consumption is expressed indirectly into production function, so essentially capital, labor, and oil consumption are all input elements in intermediate goods production. Compared to simply adding oil consumption variable directly to the C-D or CES production function [Carlstrom and Fuerst (2006), Le Barbanchon (2007)], in this paper, has the following two advantages: First, it is in line with the real economy that oil influences the whole macroeconomic performance mainly through capital goods market [Kormilitsina (2011)]; second, as mentioned above, this is a generalized setting that already includes the transmission mechanism of the former oil's impact on macroeconomy, such as rise in oil prices has made the marginal productivity of intermediate goods firms decline, making capital services and labor needs change, so as to transmit it to other macroeconomic variables.

We assume intermediate good firms set prices according to a variant of the mechanism used to model the wage setting by households: A firm has the probability of $1 - \xi_p$ to reoptimize its nominal price in each period, and the other probability of ξ_p cannot optimize the price but can be adjusted according to a partial indexation: $P_{j,t} = (\pi_{t-1})^{\gamma_p} P_{j,t-1}$, among which γ_p is the degree of price indexation, $\gamma_p = 0$ shows that there is no indexation and the prices that cannot be reoptimized remain constant, $\gamma_p = 1$ indicates that there is perfect indexation to past inflation. Log-linearization on the first-order condition of the firm's optimization problem gives the following new Keynesian Philips Curve (NKPC) [4]

$$\hat{\pi}_t - \gamma_p \hat{\pi}_{t-1} = \beta \left(\hat{\pi}_{t+1} - \gamma_p \hat{\pi}_t\right) + \frac{\left(1 - \beta\xi_p\right)\left(1 - \xi_p\right)}{\xi_p} \widehat{mc}_t. \tag{14}$$

where the real marginal cost is

$$mc_t = \frac{1}{A_t} \frac{(w_t)^{1-\alpha_y} \left(r_t^k + P_{o,t} a\left(z_t\right)\right)^{\alpha_y} (z_t)^{-\alpha_y}}{\left(1 - \alpha_y\right)^{1-\alpha_y} \left(\alpha_y\right)^{\alpha_y}}.$$

2.3. Government

If the government follows a balanced budget policy, the tax the government gets from the household in each period is equal to its expenditure: $T_t = G_t$, and the actual impact of government spending is subject to AR (1) distribution, that is, $\hat{G}_t = \rho_G \hat{G}_{t-1} + u_{G,t}$ and $u_{G,t} \sim N[0, (\sigma_G)^2]$, among which $\rho_G \in (0, 1)$ is the autoregression coefficient, σ_G is the standard deviation. The main function of the government in this paper is to implement monetary policy. Xie and Luo (2002) and Li and Li (2010) applied the Chinese monetary policy to test the

Taylor rule, regarding that the deviation between interest rate rules and the actual value is precisely because policy operation lagged behind economic development. Besides, they claimed that the Taylor rule can serve as a measure of China's monetary policy. Based on this, following Clarida et al. (2000), Li et al. (2010), and Chen (2015), we set China's Taylor interest rate rule (log-linearization) as follows:

$$\hat{R}_t = \rho_R \hat{R}_{t-1} + (1 - \rho_R) \left[\rho_\pi \hat{\pi}_t + \rho_y \hat{Y}_t\right], \tag{15}$$

where ρ_R is the smoothing coefficient of interest rate, ρ_π and ρ_y are the weights on inflation and output assigned by the policy makers.

2.4. Equilibrium Conditions

So far, the optimal choices of all households and firms under constraints have been characterized: The maximization of expected utility of the households and the maximization of expected profits of firms, so the market clearing of the final good is

$$N_t + I_{D,t} + I_{K,t} + P_{o,t} \left(O_{h,t} + O_{f,t}\right) + G_t \leq Y_t. \tag{16}$$

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 exceeded the point of 55% in 2011, and surpassed the United States as the highest in the world. Thus, the oil price volatility is highly relevant to the international market of crude oil. In addition, China started late on the transactions of staple commodities, which resulted in a few problems regarding the market such as the availability of few varieties, small size, low openness, and the lack of pricing power. So the oil pricing in China depends on the international market to some extent. In order to focus on analyzing the impact of oil price on China's macroeconomy, in line with the assumptions of Rotemberg and Woodford (1996) on the US crude oil, this paper assumes that fluctuation of oil price in China depends on the international market, implying the oil price is completely exogenous and follows the ARMA (1, 1) process (see the parameter calibration part in the next chapter). The final log-linearization is

$$\hat{P}_{o,t} = \rho_o \hat{P}_{o,t-1} + \hat{u}_{o,t} + \rho_u \hat{u}_{o,t-1} \hat{u}_{o,t} \sim N\left[0, (\sigma_o)^2\right],$$

where ρ_o and ρ_u are the coefficients of the oil price ARMA (1, 1), and σ_o is the standard deviation of real oil price shocks. At the same time, a part of the economic output should be used to pay for the imported oil, so the relation is $\mathrm{VA}_t = Y_t - P_{o,t}(O_{h,t} + O_{f,t})$. The difference value is defined as the value added (VA) of production, combined with the market clearing equation of the final good:

$$\mathrm{VA}_t = N_t + I_{K,t} + I_{D,t}. \tag{17}$$

Finally, by solving the log-linearized equations, which include the first-order and equilibrium conditions of the model, optimal equilibrium path for each endogenous variable can be obtained.

3. CALIBRATION

3.1. Data

This paper uses quarterly data from CEIC (www.ceicdata.com) and Wind (http://www.wind.com.cn) databases, with a total of 73 periods, spanning from the first quarter of 1997 to the first quarter of 2015. We choose this sample period because China has officially compiled quarterly data since the 1990s, and the NBS of China began to announce monthly or quarterly data for consumer durables such as car, furniture, household appliances, sports, and entertainment goods from 1997, and moreover, durable goods data play a key role in the modeling and analysis in this paper. According to monthly CPI data month-on-month and year-on-year published by NBS, the quarterly fixed base ratio can be drawn based on the first quarter of 1997, characterizing the quarter GDP deflator, and calculating the real value of relevant economic variables.

First, the real consumption is the total quarterly retail sales of social consumer goods divided by the quarterly GDP deflator.

Second, unlike the United States, domestic China has not carried out official consumption classification for durables and nondurables. With reference to classification statistics of mainstream literature and the availability of domestic data, we take car, furniture, home appliances, sports, and entertainment supplies as four representative variables[5] of durable goods, and when divided by quarterly GDP deflator, the real consumption of durable goods is derived.

Third, in the same way, the sequence data of the society when "retail: enterprises above quota: oil and oil products" are divided by the ratio sequence in the previous footnote, and then when further divided by the quarterly GDP deflator, the real households' oil consumption is obtained.

Fourth, since there are no quarterly or monthly data of private investment in the statistics officially released, we follow Yang (2008) by assuming that investment fund sources, the total of domestic loans, self-financing, foreign investment, and other funds are taken as representative variables of private investment, and when divided by quarterly GDP deflator, real private investment is obtained, namely capital investment in this paper.

Fifth, the real output is the nominal GDP divided by the quarterly GDP deflator.

Sixth, the real government spending is the nominal one divided by the quarterly GDP deflator.

Seventh, we use spot crude oil prices in the West Texas oil price (WTI)[6] as the standard, in which monthly data will be transformed into quarterly data through a geometric average summation, and then converted to RMB (Ren Min Bi) price, and finally real oil prices will be obtained when divided by the quarterly GDP deflator.

3.2. Parameters Calibration

Oil price shocks and other shocks. The purpose of this paper is to examine the relevance of oil prices and China's economy, thus how to determine the correlation

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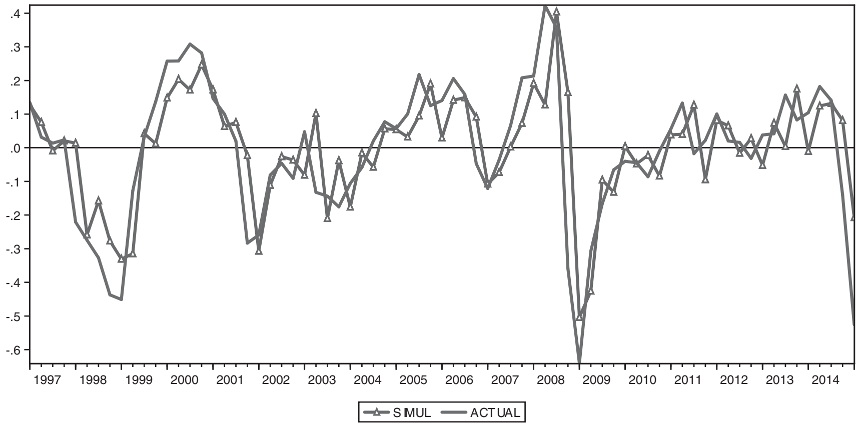

FIGURE 1. Actual value (solid line) of oil price volatility and its fitted value (dotted line + triangle) (HP filter) during 1997Q1–2014Q3; the horizontal axis presents time, and the vertical axis is fluctuating values.

TABLE 1. Estimation results of actual oil prices by the ARMA (1, 1) model

Sample: 1997Q1–2015Q1
Included observations: 73
Convergence achieved after 11 iterations
MA Backcast: 1997Q1

Variable	Coefficient	Std. error	t-Statistic	Prob.
AR(1)	0.539320	0.125419	4.300137	0.0001
MA(1)	0.592697	0.113130	5.239060	0.0000

R-squared	0.607797	Mean-dependent VAR	−0.008213
Adjusted R-squared	0.602273	S.D.-dependent VAR	0.202702
S.E. of regression	0.127835	Akaike info criterion	−1.249134
Sum squared resid	1.160272	Schwarz criterion	−1.186381
Log-likelihood	47.59338	Hannan–Quinn criter.	−1.224126
Durbin–Watson stat	1.815596		

coefficient of oil price shocks is particularly important. Through trial and error, it is found that ARMA (1, 1) model can fit the real fluctuating trend of oil prices in the sample period, as seen in Figure 1. Specific estimation results are shown in Table 1: The parameter estimation results are very significant, while tests show that residuals of the regression equation are a zero mean and the standard deviation for a smooth sequence is 0.13.[7] By its autocorrelation coefficient and partial correlation coefficient judge, it is found that no serial correlation exists and ARMA (1, 1) model can be identified. Thus, the results available are $\rho_o = 0.54$, $\rho_u = 0.59$, and $\sigma_o = 0.13$.

Based on quarterly frequency data, Wang et al. (2013) used Bayesian techniques to find that the first-order regression coefficient of China's technology shock is

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0.8, which is slightly lower than 0.95 of the United States [Kydland and Prescott (1982), Villa (2016)], and the estimated standard deviation is chosen to be 0.03, i.e., $\rho_A = 0.8$ and $\sigma_A = 0.03$.

When the fluctuation part of government spending sequence is not intercepted AR (1), $\rho_G = 0.54$ and $\sigma_G = 0.035$ can be obtained.

The discount factor β. From the first quarter of 1997 to the first quarter of 2015, the average inflation growth rate on a quarter-to-quarter basis is 1%, so the quarterly discount is set at 0.99.

Capital depreciation rate δ_k and durable goods depreciation rate δ_d. In the study of China's economic fluctuations in the literature, the average life span of China's fixed asset is mostly set at 10 years, the capital depreciation rate is 0.1, and the corresponding quarterly value is 0.025 [Gong and Xie (2004), Huang (2005)]. Previous studies have not yet estimated the depreciation rate of durable goods, but Chinese scholars also include assets of durable goods in estimating fixed assets, and therefore might assume that the depreciation rate of durable goods is identical to that of capital.

Substitution parameters ρ_F. Lee and Ni (2002) found that higher oil prices not only reduced the supply of oil-intensive output, but also reduced the demand for durable goods such as cars, and so on, which means that oil products and durable goods are complementary in the real economy. Different from Dhawan and Jeske (2007) and Huynh (2016) setting the parameter ρ_F in [0,1] to US economy, we take into account that although oil takes a large proportion in China's energy structure, more alternatives are for coal (relative to the 50% in United States, in China the ratio was as high as 80% or more), and coal as an energy source also have complementary relationship with durable goods. Hence, we set the value ρ_F of 3 larger than US economy.

Share parameter α_y. Referring to the analysis of Lv and Huang (2012), the share of labor compensation during 1979 to 2009 is 0.5, adopted in this paper. The other three share parameter values can be related through a combination of steady-state values and other parameters calculated without calibration.

The elastic parameters σ_L and υ. σ_L denotes the inverse of the elasticity of labor supply, which draws the parameter value from classic settings of Smets and Wouters (2003, 2007). Due to the utilization function of capital a(z_t) required to be increasing and the convex function of z_t, we use the most common form of quadratic functions, namely setting the elastic coefficient of the capital utility function to 2, i.e., $\upsilon = 2$.

Nominal rigidities (ξ_p, γ_p, ξ_w, γ_w, λ_w). Based on the studies by Liu (2008), ξ_p is set to be 0.75, indicating that good prices adjust once a year. ξ_w is set at 0.75,

TABLE 2. Calibration of deep parameters

β	δ_k	δ_d	α_y	ρ_F	σ_L	υ	ξ_p	γ_p	ξ_w	γ_w	λ_w	ρ_R	ρ_π
0.99	0.025	0.025	0.5	3	2	2	0.75	0.75	0.75	0.75	0.5	0.7	2.8
ρ_y	ρ_o	ρ_u	ρ_A	ρ_G	σ_o	σ_A	σ_G	$\frac{I_D}{Y}$	$\frac{O_h}{Y}$	$\frac{O_h}{N}$	$\frac{N}{Y}$	$\frac{K}{O_f}$	
0.25	0.54	0.59	0.8	0.54	0.13	0.03	0.035	0.12	0.05	0.31	0.2	300	

implying that individual wages adjust once every year, which is in accordance with China's current labor law provisions of the labor contract "signed once per year." Similar with the traditional economics literature, price and wage indexation γ_p and γ_w are set to 0.75, and λ_w is set at 0.5. In addition, λ_p is not shown in the equations after linearization and does not need calibration.

Taylor rule (ρ_R, ρ_π, ρ_y). Following Zhang (2009) and Li et al. (2010), the smoothing parameter of interest rate is set at 0.7, the weight on inflation is 2.8, and the weight on output is 0.25. The reason for the higher weight on inflation and the lower weight on GDP is that the objective of China's monetary policy is "to maintain the stability of the value of the currency and thereby promote economic growth," which means pegging to inflation is the main objective of China's monetary policy.

Steady-state value (I_D/Y, O_h/Y, O_h/N, N/Y, K/O_f). To solve the differential equations system after log-linearization, six more steady-state values needed to be determined. When utilizing mean data related to output, investment in durable goods consumption, household oil consumption, nondurable goods consumption, capital investment, and governmental spending in the sample period, it is easy to obtain I_D/Y of 0.12, O_h/Y of 0.05, O_h/N of 0.31, and N/Y of 0.2. In addition, as it is impossible to access to oil consumption data of China firms, $K/O_f = 300$ is set with reference to the estimation of the US economy by Kim and Loungani (1992). It is reasonable to assume such value, because the capital accumulation and the level of economic development of China have lagged behind the United States for nearly three decades.

In summary, all the parameters of model are included in Table 2.

4. NUMERICAL SIMULATION AND DYNAMIC ANLYSIS

4.1. Dynamic Transmission Mechanism under Oil Price Shocks

Figure 2 depicts the impulse response of major macrovariables to one standard deviation of positive oil price shock. The horizontal axis represents the quarterly period unit, whereas the vertical axis represents the deviation percentage from the steady state.

Due to the household budget constraint, rising oil prices lead to a negative income effect and therefore households reduce durable goods, nondurable goods,

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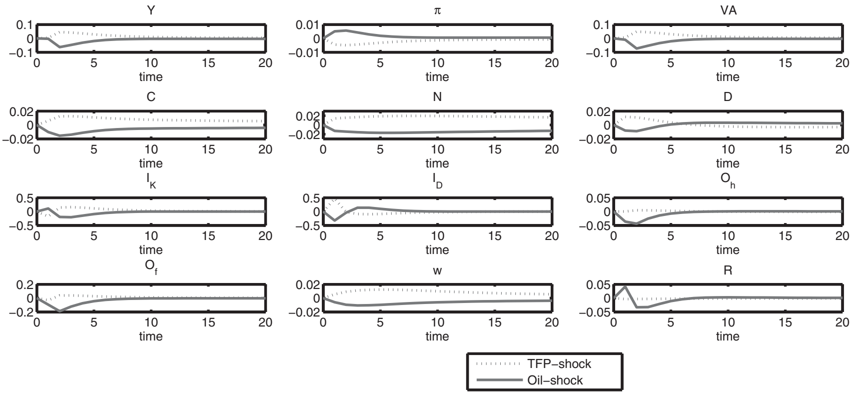

FIGURE 2. Positive reaction path of key macroeconomic variables (dashed line indicates the technology shock, and the solid line represents the oil price shock).

and household oil consumption. This further leads total consumption to fall, which in turn causes labor supply to rise and the wage level to fall. Hence, contemporarily, the rise in oil prices has triggered a running track of the capital investment "first rise and then the fall" through substitution effect, whereas durable goods investment is just the opposite. Specifically, the impact has led to increased capital investment in the first period, decline in the second period, reaches the lowest in the fourth period, which then returns to the value 0, and durable goods investment has only experienced one significant decline in the first period, turns to positive in the second period, reaches the peak in the fourth period, which then returns to the value 0. Economic logic behind this is as follows: Investment and accumulation process of durables are entirely decided by the household, whereas capital goods are jointly decided by the household and firms (the household decides capital supply, and firms determine capital requirements); therefore, it can be drawn that the household needs cross-temporal asset portfolio investment configuration for durable goods and capital goods. According to the calibration study, in the initial steady stage, the proportion between household oil and durables ($O_h/D = 0.01$) is much larger than the firm's oil capital ratio ($O_f/K = 0.003$). The marginal revenue decline of durables caused by oil price shocks is higher than the marginal revenue decline of household capital goods. In order to balance the marginal income differences, the household will immediately reconfigure the portfolio, increase capital goods while reducing durable goods, and this capital increase will sufficiently offset the decrease in firms' demand of capital investment brought by high oil prices; these have led to the initial rise (fall) of capital investment (durable goods investment). Then, the household discovers that portfolio reallocation cannot reverse the gap between high capital K in the initial period and low stock of durables D, and then a substantial increase in investment in durable goods takes place from the second period, while reducing capital investment. Finally, the decrease of consumption and investment has led to a decline in output and the VA.

In addition, it is found that higher oil prices lead to rise in inflation in two periods, and then the gradual inertia decrease that results from the nominal inertia in economy: One is price inertia, and (14) NKPC equation shows that, due to the rise in real marginal costs, and the factor of price rigidity, ($\xi_p > 0$) will lead to immediate rising inflation, then with the decline in real marginal cost, the inflation rate will gradually decrease. The other side is wage inertia, (11) NKWPC equation shows that current wage inflation depends on its past inflation plus the total sum of the expected future difference between the marginal rate of substitution between consumption and leisure and the real wage. According to the definition by Schmitt–Grohe and Uribe (2005), the marginal rate of substitution rate between consumption and leisure is equivalent to the marginal cost of labor supply, and real wages are equivalent to the marginal revenue of labor supply; monopoly in labor market has led to the labor mark-up, so the marginal substitution rate in NKWPC equation parentheses is greater than real wages. Meanwhile, wage rigidity ($0 < \xi_w < 1$) makes the inertia parameter positive, indicating that the shock has led to rise in inflation on the spot, and then similarly due to wage rigidity, despite all households have found labor marginal revenue decline after the inflation but only a part of the households are able to increase wages timely to maintain the established labor supply, the inflation rate shows an inertia decline trend. The two aspects show that higher oil prices lead to persistent, hump-shaped response in inflation.

Finally, it is found that due to the rising inflation, under the interest rates of Taylor rule, the central bank must raise the nominal interest rates to combat inflation.

Unlike oil price shocks, technological shocks have a direct impact on production function, but do not enter the utility function and then have no direct impact on investment of durables. Therefore, technological shocks do not affect the two portfolio reallocations by households, just leading to the rise in capital investment. Since our purpose is to study the impact of oil prices, and the impact mechanism of technology on the economy has been extensively studied in a large number of real business cycle (RBC) literature studies, it will not be discussed here due to limited space.

It could be found from the simulation that rise in oil prices trigger decline in output, rise in inflation, and the risk of "stagflation," and therefore does have a negative impact on the economy, and the "headwind" feature of a country's monetary policy may be required to respond to oil price shocks, which raises the question that whether it is necessary for China's monetary authorities to consider energy price volatility represented by oil when implementing monetary policy. Since former Federal Reserve Chairman Ben Bernanke and others [such as Bernanke et al. (1997)] proposed the "financial accelerator" model claiming that the change of asset prices will amplify macroeconomic fluctuations, many scholars launched quite effective studies on whether monetary policy should peg assets price volatility. By analyzing the relationship between social welfare function and loss function of monetary policy, it is discussed whether the monetary authorities will take the specified asset prices into account when implementing monetary policy. Drawing experiences from these studies, this paper will take the oil prices as asset prices [Bernanke et al. (2004)] and include the oil price inflation as a variable into the monetary policy of Taylor interest rate rule, and explore whether it is necessary for China's monetary authorities to consider oil price volatility when implementing monetary policy. In fact, it is to examine: Whether it should include the headline inflation including oil price inflation or should the core inflation be inflation target of monetary policy? The next part will answer these questions.

4.2. Which Inflation Should Monetary Policy Be Pegged to?

First, oil price inflation should be defined as $\pi_t^o = \frac{P_{o,t}}{P_{o,t-1}}$, headline inflation is defined as π_t^{HL}, and relationship with core inflation π_t is as follows:

$$\pi_t^{HL} = \pi_t + \chi_e \pi_t^o,$$

where χ_e is the relative weight in headline inflation to oil price one. Next, the Taylor rule equation (15) mentioned above is amended as follows:

$$\hat{R}_t = \rho_R \hat{R}_{t-1} + (1 - \rho_R)\left[\rho_\pi \hat{\pi}_t + \rho_e \hat{\pi}_t^o + \rho_y \hat{Y}_t\right].$$

Here, ρ_e is the reaction parameter of oil price inflation in the augmented monetary policy. When $\rho_e = 0$, the core inflation is just consistent with the headline inflation, indicating that monetary policy needs only consider the core inflation, rather than focusing on noncore inflation as determined by the fluctuations in oil prices. Leduc and Sill (2004) and Carlstrom and Fuerst (2006) studied the DSGE model of US oil economy using this rule. When $\rho_e > 0$, on one hand, monetary policy needs to consider core inflation, and on the other hand, monetary policy also considers noncore inflation, which means the monetary policy should be pegged to headline inflation. When $\rho_e < 0$, the monetary authorities accommodate the oil price inflation, rather than the traditional "headwind" regulation.

Hereafter, counterfactual simulations will be adopted to study the impact of different weights on oil price inflation (ρ_e) and on output and core inflation. Specifically, five sets of data $\rho_e \in [0, 0.1, 0.2, 0.5, -0.1]$ are selected to do the simulation: The first value is the benchmark value of the model, the following three values 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.

Figures 3 and 4 show that as ρ_e increases, oil price shocks not only increase the output losses, but also increase core inflation. Specifically, as in the benchmark model $\rho_e = 0$, the central bank follows the standard Taylor rule to select core inflation as the monetary policy target, and the decline of output in the first period is not so great, but will continue to be negative during the sample period. In addition, the rise in core inflation is less than that of the other three models

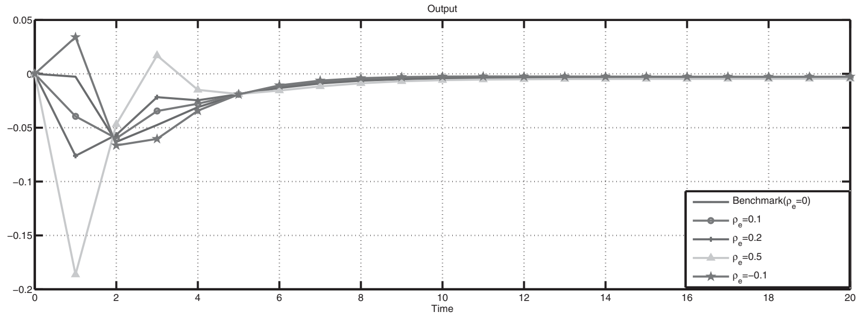

FIGURE 3. Counterfactual simulation of rising oil prices shocks (ρ_e is variable).

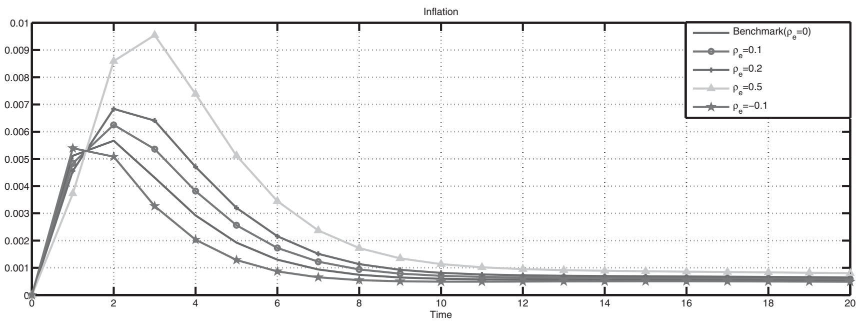

FIGURE 4. Counterfactual simulation of rising oil prices shocks (ρ_e is variable).

$\rho_e > 0$, but more than that of the accommodating model. Moreover, as in the case of the three models $\rho_e > 0$ in the augmented monetary policy, where the central bank chooses headline inflation as the monetary policy target, the output declines significantly in the first period, and then falls. Meanwhile, the core inflation rise is greater than the other two types of models. Finally, as in the case of prices for accommodating model $\rho_e < 0$, the model shows that the output will rise in the first period, and turn to negative, and then pick up again in the second period, with the core inflation rising slightly.

China's monetary policy aims to "maintain a stable value of the currency and thereby promote economic growth," indicating that steady inflation and output promotion are the core objectives in the implementation of the central bank's monetary policy. From the spot impact after the shock, the decline of output and rise of inflation are smaller and the standard Taylor rule should be the preferred choice of the central bank. In medium and long terms, although the output of the three models in the augmented Taylor rule $\rho_e > 0$ starts increasing from the second period, but the cumulative average output loss rate (L^y) in the sample

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TABLE 3. Average output loss value under different monetary policies

	Monetary policy				
	$\rho_e = 0$	$\rho_e = 0.1$	$\rho_e = 0.2$	$\rho_e = 0.5$	$\rho_e = -0.1$
Benchmark calibration	1.16	1.29	1.42	1.74	1.02
Strong nominal inertia $(\xi_p + \xi_w) + 20\%$	0.51	0.54	0.56	0.57	0.46
Weak nominal inertia$(\xi_p + \xi_w) - 30\%$	1.42	1.51	1.60	1.86	0.07
Strong interest rate rules $(\rho_\pi + \rho_y) + 30\%$	1.22	1.35	1.46	1.78	1.09
Weak interest rate rules $(\rho_\pi + \rho_y) - 30\%$	1.03	1.15	1.26	1.53	0.89
High wage markup $(\lambda_w) + 30\%$	1.15	1.28	1.41	1.74	1.00
Low wage markup $(\lambda_w) - 30\%$	1.17	1.31	1.43	1.75	1.03
No durables	0.92	1.14	1.32	1.58	0.65

Note: The values in the table is negative (i.e., output loss), in percentage.

period is calculated as follows:

$$L^y + \beta L^y + (\beta)^2 L^y + \cdots + (\beta)^{19} L^y = \sum_{t=1}^{20} \beta^{t-1} \hat{y}_t \Rightarrow L^y = \frac{1-\beta^{20}}{1-\beta} \sum_{t=1}^{20} \beta^{t-1} \hat{y}_t.$$

The results are summarized in Table 3, and by contrast, it can be found that the average output loss of 1.16% in the standard Taylor rule is still the minimum. Meanwhile, the overall price level changes (ΔP^F) in the sample period is calculated based on the core inflation rate, which is calculated as follows:

$$\Delta P^F = 1 + \exp\left(\sum_{t=1}^{20} \hat{\pi}_t\right).$$

As summarized in Table 4 and by comparing the price volatility, it is found that the change rates in the overall price level is 2.0302 in the last period compared to the first period under the standard Taylor rule, less than values of three models under the augmented Taylor rule $\rho_e > 0$.

4.3. Robustness Test

In order to make the conclusion of the model more reliable, based on different parameterizations of the model, the average loss of output and the overall price changes under oil price shocks are tested whether they are consistent with the conclusion of the benchmark model.

The nominal inertia. The nominal inertia in this paper are mainly from price and wage rigidity; ξ_p represents the price inertia and ξ_w represents wage inertia,

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TABLE 4. Overall price change values under different monetary policies

	Monetary policy				
	$\rho_e = 0$	$\rho_e = 0.1$	$\rho_e = 0.2$	$\rho_e = 0.5$	$\rho_e = -0.1$
Benchmark calibration	2.0302	2.0351	2.0399	2.0546	2.0254
Strong nominal inertia $(\xi_p + \xi_w) + 20\%$	2.0149	2.0171	2.0192	2.0257	2.0128
Weak nominal inertia $(\xi_p + \xi_w) - 30\%$	2.0360	2.0402	2.0443	2.0569	2.0005
Strong interest rate rules $(\rho_\pi + \rho_y) + 30\%$	2.0287	2.0324	2.0361	2.0471	2.0251
Weak interest rate rules $(\rho_\pi + \rho_y) - 30\%$	2.0338	2.0407	2.0476	2.0687	2.0269
High wage markup $(\lambda_w) + 30\%$	2.0299	2.0348	2.0397	2.0546	2.0251
Low wage markup $(\lambda_w) - 30\%$	2.0307	2.0355	2.0402	2.0547	2.0259
No durables	2.0245	2.0295	2.0345	2.0496	2.0196

and the closer its value is to 1, the stronger it indicates a nominal inertia. Due to the space limitation, only the results of two sets of experimental data will be reported in this paper, one group is to simultaneously increase the values of ξ_p and ξ_w by 20% and we call this set of experimental data[8] as strong nominal inertia; the other group is to simultaneously reduce the values of ξ_p and ξ_w by 30% and name the data as weak nominal inertia, keeping other deep parameter values unchanged.

The interest rate rule. The strength of Taylor interest rate rule is determined by the inflation response coefficient ρ_π and the output response coefficient ρ_y, and if the coefficient becomes larger (smaller), it means that a larger (smaller) interest rate response is needed when inflation and output are deviated. As discussed previously, only the results of two sets of data are reported, one group is the data of inflation in which output response coefficients increased by 30%, known as the strong interest rule; other group is the data of inflation in which output response coefficients reduced by 30%, known as the weak interest rate rule, keeping other deep parameter values unchanged.

Wage markup. λ_w is the parameter of wage markup. We alter its value with a 30% increase or decrease, and refer them, respectively, as high-wage markup and low-wage markup, keeping other deep parameter values unchanged.

Durable goods consumption. The benchmark model in this paper includes consumer durables. Now we put all consumer goods into a single NK-DSGE model without distinguishing between durables and nondurables, keeping other deep parameter values unchanged.

Table 3 shows that no matter what kind of structure parameters are present, the average loss value of output is the largest when the monetary policy is $\rho_e = 0.5$, and output value loss is the second largest when $\rho_e = 0.2$, $\rho_e = 0.1$, and $\rho_e = 0$, and the average loss value of output is smallest when $\rho_e = -0.1$. Therefore, it could be seen that the stronger monetary policy reacts to oil price fluctuations, the bigger the corresponding output losses. This also means that following oil price shocks, when the central bank adopts a monetary policy that is pegged to core inflation ($\rho_e = 0$), the average output loss is lower than pegged to headline inflation ($\rho_e > 0$).

As can be seen from Table 4, regardless of what kind of deep parameters are present, the overall price fluctuation is the greatest when the monetary policy is $\rho_e = 0.5$, and the overall price fluctuation is the second largest when $\rho_e = 0.2$, $\rho_e = 0.1$, and $\rho_e = 0$, and the overall price fluctuations is the smallest when $\rho_e = -0.1$, indicating that the stronger the monetary policy reacts to oil price volatility, the greater the corresponding price volatility. This means that under oil price shocks, the overall oil price volatility when the central bank's monetary policy ($\rho_e = 0$) is pegged to core inflation rate is smaller than the volatility when the monetary policy ($\rho_e > 0$) is pegged to headline inflation.

The finding shows that the adoption of a monetary policy that targets on core inflation is obviously more valuable to each country's central bank who takes price stability as the primary responsibility.

An intuitive explanation of why core targeting performs best in the model could be that the rise of oil price is a "temporary" supply shock with the "mean-reverting" feature. When rise in oil prices leads to the rise in headline inflation, the rate exceeds its trend value (i.e., core inflation), but when the price of oil drops to the initial level, headline inflation also falls below its trend value. Therefore, on average, without monetary policy pegging to the oil price inflation, inflation could return to the status quo in the future. However, if Taylor interest rate rules pegging to oil price inflation was taken aiming at the rising oil price, then the tightening of monetary policy will lead to a substantial decline in output (see Figure 3) and the core inflation rate (see Figure 4); besides, due to the long time lag between monetary policy and economic activities, even when the inflation rate has already returned to or is below its trend value, the output may still continue to decrease. Hence, the interest rate policy that is simultaneous pegged to both core inflation and oil price inflation could lead to the increased volatility of inflation and output, thereby reducing the level of social welfare, which is a departure from the central bank objectives—to promote price stability and sustained increase in output. This also suggests that the central bank only needs to be responsible for the remaining part of final consumer prices excluding all price fluctuations due to the supply-side factors (oil price shock is on supply side) since monetary policy is demand management policy.

In summary, China's monetary policy makers should take core inflation as its primary target. Otherwise "stagflation" and drastic volatility would occur, leading to social welfare loss.[9]

4.4. Efficient Frontier Curve

The above analysis discusses the choice of monetary policy under oil price shocks mainly from the impulse response in the form of "first moment," and further examines this proposition from the perspective of "second moment," which is meaningful. The objective of monetary policy is economic stability of which the most important is the stability of price and output, indicating that optimal monetary policy should minimize economic fluctuations. Following Levin et al. (1999), we explore policy decision-making and optimal monetary policy by visualizing the efficiency frontier curves to compare the merits and demerits of the monetary authorities' choice of pegging to core/headline inflation. Specifically, main steps are set as follows: (1) Assume that the central bank's loss function is a weighted sum of output and inflation variance[10]; (2) given the deep parameters of the model and the Taylor rule parameters H, the solution of the model is represented in the form of state space through solving the logarithmic linearization of rational expectations differential equations; (3) solve the minimum of the central bank's loss function subject to (2). Specific forms are expressed as follows:

$$\min_{H} \left\{ \tau \left(\sigma_y\right)^2 + (1-\tau)\left(\sigma_\pi\right)^2 \right\}$$
$$\text{s.t. } \hat{X}_t = P(H)\,\hat{X}_{t-1} + Q(H)\,\hat{\varsigma}_t, \quad \text{std}(\Delta R_t) \leq k,$$

where $(\sigma_y)^2$ and $(\sigma_\pi)^2$ represents the unconditional variance of output and inflation, respectively, $\tau \in [0, 1]$ is the weight that reflects the monetary policy authorities' preferences for stabilizing output or inflation. $\hat{X}_t$ is the endogenous variable of the model, $\hat{\varsigma}_t$ is the exogenous shocks of the model and is the white noise process with the zero average value. Taylor rule parameters are referred as vector $H = \{\rho_R, \rho_\pi, \rho_y, \rho_e\}$, and the matrices $P(H)$ and $Q(H)$ also depend on the Taylor rule parameter H. At the same time, the nominal interest rate volatility needs to be applied to with k (upper bound) as an upper optimized limit, where the nominal interest rate of 1.25 times is specifically selected as the upper bound. The calibrated value of Taylor rule is chosen as the initial value, and to use the Hill-climbing algorithm to iteratively search for the minimum target.

The horizontal axis of Figure 5 represents the standard deviation of inflation (core), the vertical axis is the standard deviation of output, and the value of $\tau = 0.04$ is selected. The figure shows two different monetary policies, one with a solid line indicates the standard interest rates rule that is pegged to core inflation rates, responding only to output and inflation in the Taylor rule; the other group with a dotted line indicates the augmented interest rates rule that is pegged to headline inflation rates, responding not only to output and inflation, but also to oil price inflation in the Taylor rule. Through careful comparison, the solid line is much closer to the origin than dotted line, but, in general, the two interest rate rules almost coincide with each other, indicating that monetary policy pegged to headline inflation rate is not in the favor of the improvement of social welfare; on the contrary, the classic one that is only pegged to the core inflation rate can be

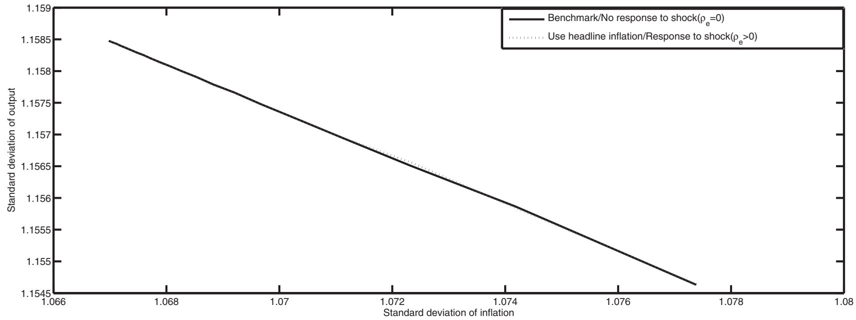

FIGURE 5. Efficiency frontier curve.

considered as the best metrics for China's monetary policy and can also verify the conclusions of "the first moment" mentioned above.

5. CONCLUSIONS

Since 1990, when New Zealand first adopted the inflation target (pegging) system, so far 11 industrialized countries including the United Kingdom, Sweden, Canada, and 11 developing or emerging market countries including Brazil, South Africa, and Thailand have explicitly implemented the policy, and even in the countries without the adoption of inflation targeting regime, price stability is usually the primary objective of their monetary policies. How to successfully implement inflation targeting regime has attracted much attentions from monetary economists, and a large number of scholars have been working to provide reference for macroeconomic regulation and control in developed countries, emerging market countries, and countries in transition. In view of this, an inflation targeting system has profound political and academic impact on China in recent years, and increasingly the implementation of inflation targeting regime is urgently required. Nevertheless, the current situation shows that because of many deficiencies in relevant environmental and institutional policies, the implementation of inflation targeting regime in China remains in discussion with few actions. However, this new inflation targeting monetary policy is undoubtedly an important direction of China's deepening monetary policy institutional reform in future. At the meantime, there are few theoretical studies on China's monetary policy taking environmental and energy policy into account. This paper attempts to fill this gap. We use Chinese quarterly data to build New Keynesian DSGE model in the oil economy. We utilize 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 the reform of China's monetary policy in the future.

By constructing a DSGE model nesting nondurable goods, durable goods, and oil in the CES consumption function, this paper examines the price transmission mechanism in the economic system and analyzes the dynamics of inflation after an oil price shocks. Following Bernanke et al. (1997), we consider oil prices as asset prices and argue that oil price inflation is important for monetary policy design. Specifically, we study whether the headline inflation including oil prices or the core inflation excluding oil prices should be pegged by the monetary policy. We have two major findings.

First, impulse responses show that rising oil prices lead to output decline, and rising inflation, with the risk of "stagflation," does have a negative impact on the economy. Our model reveals that the transmission mechanism of oil price is determined by income effect, the nominal inertia, and the asset allocation portfolio between durable goods and capital goods. When considering China's energy price reform represented by oil, one should take into account that the policy itself may impact the real economy. For example, these policies may result in the reduced degree of price inertia in the economy, and a sudden excessive relaxing of the relevant energy policies may result in a greater risk of economic fluctuations, which may eventually cause the "stagflation" risk. In this sense, its price reform must be conducted gradually, and the relationship between government regulation and market is of particular importance.

Second, by using integrated counterfactual simulation and efficient frontier curve, our model shows that monetary policy that simultaneously targets core and noncore inflation is inferior to the monetary policy that is purely pegged to core inflation, suggesting that the central bank should focus on core inflation instead of headline inflation in setting monetary policy, thus providing a theoretical support for monetary policy practice in the future.

NOTES

1. This thesis is mainly based on the previous literature, as Eckstein (1981), Neumann and Hagen (2002), and Hou and Gong (2013). Another important document supporting this view is the Fed's Board of Governors Mishkin's keynote speech on "Headline versus core inflation in the conduct of monetary policy" in the relevant international conference on October 20, 2007.

2. From 1994 to 2005, the implementation of RMB Exchange Rates Pegged to US Dollar made the exchange rate roughly constant between 8 and 8.7. After 2005, the PBoC announced a shift from US Dollar Pegged Exchange Rates to A Basket of Currencies Pegged Exchange Rates. The exchange rate of US dollar began to increase to 6.3 at the end of 2012.

3. Also, it would be interesting to build a DSGE model within an open economy in further research.

4. The derivation of (14) is shown in the Appendix.

5. In CEIC database, we found that in 1997 NBS begin to publish monthly data of relevant consumer goods classification by "retail: enterprises above quota," select the "retail: enterprises above quota: furniture," "retail: enterprises above quota: automobiles," "retail: enterprises above quota: sports and recreational goods," and "retail: enterprises above quota: household appliances and audiovisual equipment" as the data source of durable goods consumption. Since some companies in real economy that are not included in the statistics also produce durable goods of the four categories, in order to correspond to the actual economy, we have the following ratio process: first, when each period "retail: enterprises above quota: the total" is divided by the total retail sales of social consumer goods, we get the ratio of the sequence, and then when the durable goods data of the above four categories are divided by the ratio sequence separately, we get four sequence data of durable goods.

6. Data source: http://www.eia.gov/dnav/pet/pet_pri_spt_s1_m.htm

7. Table 1 shows AR (1)'s is a coefficient of 0.54, the standard deviation is 0.125, and the resulting t-test value is 4.30 with the P-value of 0.0001, indicating that at a given significance level of 5% the null hypothesis of coefficient that equals 0 could be rejected, which means that the coefficient is significant. Similarly, MA (1) is a coefficient of 0.59, the standard deviation is 0.113, and the t-test value is 5.24 with the P-value being close to 0, indicating that at a given significance level of 5% the null hypothesis of coefficient equals 0 that could be rejected, which means that the coefficient is significant.

8. If the benchmark parameters of prices and wages inertia are simultaneously increased by 30%, close to 1, then it is almost completely rigid, which strays too far from China's real economy; therefore, 20% is chosen.

9. In theory, this paper shows that the best strategy the central bank accommodates to oil price shocks, but from the practice of the national monetary policy, the monetary policy authorities do not generally make energy price shocks accommodation, so only comparative test is made in this paper.

10. Since the monetary policy objective of the PBoC is "to maintain the stability of the value of the currency and thereby promote economic growth," both output and inflation variance weighting sum is considered as a loss function that is in line with monetary policy demands to the PBoC.

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APPENDIX

This appendix provides details regarding the derivation of equation (14), i.e., NKPC.

Step one, the firm solves the following cost minimization problem and get the real marginal cost:

$$\min_{L_{j,t}, K_{j,t-1}, z_t,} \left\{ w_t L_{j,t} + r_t^k K_{j,t-1} + P_{o,t} O_{f,j,t} \right\}$$
$$\text{s.t. } Y_{j,t} = A_t \left(z_t K_{j,t-1} \right)^{\alpha_y} \left(L_{j,t} \right)^{1-\alpha_y}$$
$$O_{f,j,t} = a\left(z_t\right) K_{j,t-1}.$$

Solve the first-order conditions and obtain the expression of real marginal cost:

$$mc_t = \frac{1}{A_t} \frac{\left(w_t\right)^{1-\alpha_y} \left(r_t^k + P_{o,t} a\left(z_t\right)\right)^{\alpha_y} \left(z_t\right)^{-\alpha_y}}{\left(1-\alpha_y\right)^{1-\alpha_y} \left(\alpha_y\right)^{\alpha_y}}.$$

Step two, the firm chooses $\tilde{P}_t$ to maximize

$$E_{t-1}\sum_{l=0}^{\infty}\left(\beta\xi_p\right)^l \upsilon_{t+l}\left[\tilde{P}_t X_{tl} - mc_{t+l}P_{t+l}\right]Y_{j,t+l}$$

$$\text{s.t. } X_{tl} = \begin{cases} (\pi_t \times \pi_{t+1} \times \cdots \times \pi_{t+l-1})^{\gamma_p}, & l \geq 1 \\ 1 & l = 0 \end{cases}$$

$$Y_{j,t} = \left(\frac{P_{j,t}}{P_t}\right)^{-\frac{1+\lambda_p}{\lambda_p}} Y_t.$$

Here, υ_{t+l} is the stochastic discount factor, for the intermediate good firms, which is exogenous. Let $\tilde{P}_t$ denote the value of $P_{j,t}$ set by a firm that can reoptimize at time t. Note that here $\tilde{P}_t$ does not depend on j. Firms' best price can be obtained from the first-order condition:

$$E_{t-1}\sum_{l=0}^{\infty}\left(\beta\xi_p\right)^l \upsilon_{t+l}\left[\tilde{P}_t X_{tl} - \left(1+\lambda_p\right)mc_{t+l}P_{t+l}\right]Y_{j,t+l} = 0.$$

Obviously, when $\xi_p = 0$, price rigidity disappears, and the formula reformate to: $\tilde{P}_t = (1+\lambda_p)mc_t$, which means that the best price is the sum of the current marginal cost. When $\xi_p > 0$, the formula is still cost additive, but it turned out to be the sum of current and future periods' weighted average marginal cost. Then, the linearized equations can be obtained as follows:

$$\widehat{\tilde{p}}_t + \gamma_p\hat{\pi}_t = \left(1-\beta\xi_p\right)\sum_{l=0}^{\infty}\left(\beta\xi_p\right)^l\left(\gamma_p\hat{\pi}_{t+l} + \widehat{mc}_{t+l}\right). \qquad \textbf{(A.1)}$$

Define $\tilde{p}_t = \frac{\tilde{P}_t}{P_t}$, where "^" above a variable denotes its log deviation from the steady state. The price index has the character of $P_t = [(1-\xi_p)(\tilde{P}_t)^{-\frac{1}{\lambda_p}} + \xi_p(P_{t-1}((\pi_{t-1})^{\gamma_p}))^{-\frac{1}{\lambda_p}}]^{-\lambda_p}$. Transformation after log-linearization:

$$\widehat{\tilde{p}}_t = \frac{\xi_p}{1-\xi_p}\left(\hat{\pi}_t - \gamma_p\hat{\pi}_{t-1}\right). \qquad \textbf{(A.2)}$$

Relations (A.1) and (A.2) imply equation (14) (NKPC) in model:

$$\hat{\pi}_t - \gamma_p\hat{\pi}_{t-1} = \beta\left(\hat{\pi}_{t+1} - \gamma_p\hat{\pi}_t\right) + \frac{\left(1-\beta\xi_p\right)\left(1-\xi_p\right)}{\xi_p}\widehat{mc}_t.$$