

## Article

# The Transmission Mechanisms and Impacts of Oil Price Fluctuations: Evidence from DSGE Model

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**Abstract:** This paper constructs an open economy dynamic stochastic general equilibrium (DSGE) model with oil to investigate the transmission mechanism and impact effects of oil price fluctuations driven by different factors on China's macroeconomy using quarterly data from 1996 to 2019. The results show that the international crude oil supply-driven oil price decline promotes positive output growth in the short run through the positive cost effect of the supply channel, and the production regulation cost will dampen the incentive to invest in the new energy sector in the long run. Domestic economic development demand-driven oil price increases act on the demand channel, driving output and oil prices to fluctuate in the same direction, generating a negative real balance effect on the economy through the interest rate channel. The oil-specific demand driven by foreign nominal interest rate shocks is transmitted through the exchange rate channel, triggering imported inflation, lower aggregate demand, and lower output. Different sources of oil price fluctuations have different transmission mechanisms and thus differential effects. For this reason, based on the root causes of oil price fluctuations, policy recommendations to deal with international oil price fluctuations in the new situation are proposed at the supply level, demand level, and international level.

**Keywords:** oil DSGE model; macroeconomics; international crude oil supply shocks; economic development demand shocks; oil-specific demand shocks



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## 1. Introduction

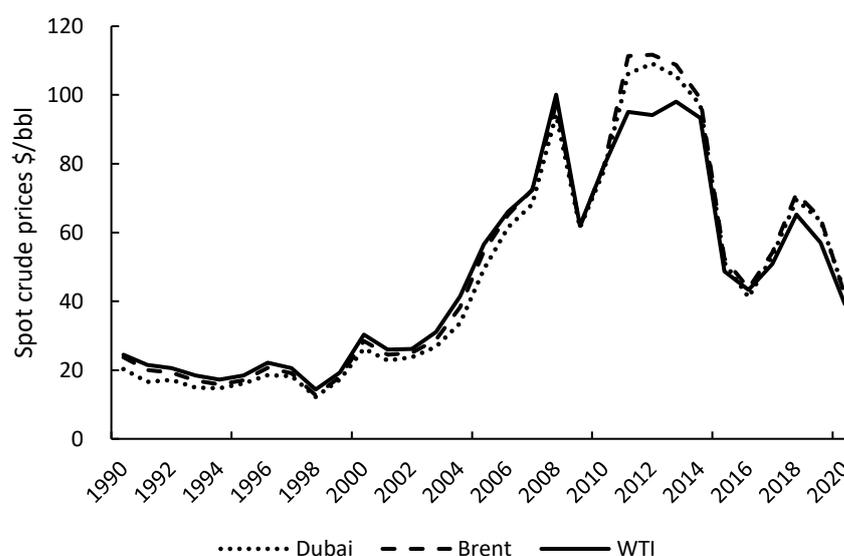
Since the 21st century, spot WTI prices surged to a record high of 145\$/bbl on 3 July 2008, and then plummeted, bottoming at 27.3\$/bbl on 11 February 2016 (Data source: International Energy Agency (IEA) (<https://www.iea.org>, accessed on 3 March 2022)), continuing to run at low levels for three years (The WTI prices remained around 50 dollars per barrel for three years, from 2015 to 2017). The dramatic fluctuations in international oil prices reflect massive changes in the global oil market from the “old triangle” to the “new triangle” (In early March 2018, at the Cambridge Energy Week conference in Houston, USA, it was suggested that “the current international oil market is moving from the era of the “old triangle” (surging Chinese consumption, globally focused energy geopolitical events, oil finance, and speculation) to the “new triangle” (global economic conditions, U.S. shale oil, production cut agreement) era of transition.). The U.S. shale oil boom triggered oil supply shocks that led to an accelerated decline in oil prices is a critical factor driving downward oil price volatility [1,2]. Meanwhile, the oil price is endogenous to global macroeconomic activity [3], and since the 1990s, high economic growth in emerging Asian economies (represented by China) has been the primary factor driving international oil prices [4,5]. In particular, the oil price spike was caused by increasing demand for oil in the 21st century [6], and the “China factor” became the main demand factor influencing oil price volatility [7].

There are nearly 100 kinds of crude oil in the world, which are distinguished by two types of indicators: (1) Density, expressed in the API degree; the greater the API, the better the

quality of crude oil; (2) Sulfur content; the higher the sulfur content of crude oil, the worse the quality of crude oil. The density and sulfur content of the three benchmarks of crude oil in the international oil market is in Table 1 (The Spot crude prices are showed in Figure 1).

**Table 1.** The API gravity and Sulfur content of three benchmark crude oil.

Benchmark Crude Oil	API Gravity	Sulfur Content
Brent crude oil	38.3	0.37%
West Texas Intermediate crude oil	39.6	0.24%
Dubai crude oil	31	2.00%



**Figure 1.** Spot crude prices of three benchmark crude oil: 1990–2020 (Data source: BP Statistical Review of World Energy).

As a common commodity, it is evident that the oil price is affected by both supply and demand shocks, and the various types of oil price fluctuations will have different impacts on economic activity [8], and that changes in the relationship between oil prices and the macroeconomy reflect the evolution of the components of oil price shocks. Therefore, distinguishing the sources of oil price fluctuations is crucial to evaluate these effects [9–11]. The traditional time-series-based econometric models lack the support of microeconomic theories, which would be unable to avoid the “Lucas critique” and explain the impact of oil price fluctuations from an endogenous perspective (Some literature uses time-varying models to analyze the time-varying relationship of oil prices with other variables (Baumeister and Peersman [12]; Hailemariam et al. [13]; Ivanovski and Hailemariam [14])). The methodology of the DSGE used in this paper belongs to structural macro-econometric research, which differs from the empirical focus and uses complete information estimation, which to some extent compensates for the shortcomings of the fixed parameter setting in terms of fitting. Fitting and forecasting are not the main intentions of this paper, and we explore more at the counterfactual and intervention levels). The new Keynesian dynamic stochastic general equilibrium theory developed on the basis of the Real Business Cycles (RBC) theory emphasizes structural analysis based on economic theory rather than statistics. It builds a competitive general equilibrium analysis framework based on the behavior optimization of microeconomic agents, which provides a theoretical analysis framework for identifying the sources of oil price shocks, analyzing its transmission mechanism, and evaluating the effects of different types of oil price shocks. It has become a critical breakthrough in the oil economy field. Therefore, in the context of the “new triangle” era of the international oil market, it is necessary to clarify the transmission channels of oil price fluctuations deriving

from sources to characterize the effects of oil price shocks from an endogenous perspective, and to formulate targeted measures to cope with international oil price fluctuations.

## 2. Literature Review

The formation mechanism of oil prices determines the trends and characteristics of oil price fluctuations, and the early attention to oil economic issues in academia originated from the research on the formation mechanism of oil prices. In the early 20th century, the early stage of global industrial economic development, Hotelling, based on the essential properties of resource goods from the perspective of resource supply, established the depletable resource pricing model, marking the birth of energy economics [15]. It was not until the outbreak of the oil crisis in the 1970s that scholars began to pay attention to the relationship between oil price fluctuations and macroeconomics. Hamilton pointed out that every recession in the U.S. economy was accompanied by a significant increase in oil prices after World War II [16].

A stable relationship between oil price fluctuations and economic activity has undergone a dynamic change. Scholars find reverse causality between macroeconomic variables and oil prices [17], suggesting that the analysis of the impact of oil price shocks on economic activity cannot ignore the endogenous response of oil prices to global economic activity; it must consider the causes of oil price volatility [3,11]. Kilian was the first to propose a structural decomposition approach based on the endogenous fluctuations in oil prices, assessing the impact of oil price fluctuations on economic activity in terms of oil supply, economic demand, and specific demand-driven oil price fluctuations [18].

Under the pioneering work of Kilian [18], scholars such as Chen et al. [19], Gong and Lin [20], and Kim and Vera [21] have studied the macroeconomic impact of oil price shocks from different sources within the framework of their decomposition approach and found that oil price shocks from diverse sources will lead to a differential impact on economic variables. Li et al. explore the dynamic relationships between the three types of oil price shocks and investor sentiment using the structural vector autoregression (SVAR) model [22]. Branger et al. identified markup shocks based on OPEC meetings, compared to the oil price shocks driven by supply and demand shocks, which create unique macroeconomic consequences [23].

The findings of the theoretical analysis framework of the DSGE model support the issue of oil price endogeneity. Unalmis et al. simulated the different sources of oil price shocks distinguished by Kilian under the DSGE theoretical framework and found the differential impact of structural shocks on oil prices [24]. Bernanke et al. examined the endogeneity of oil prices and found that different economic conditions will mitigate or amplify the impact of oil price shocks [25]. Balke et al. examined the effects of oil price volatility triggered by supply and demand shocks based on a three-country DSGE model [26]. Unalmis et al. found that by endogenously modeling oil prices within the DSGE framework, oil supply shocks and demand shocks triggered by oil price increases bring about different effects on macro-economy variables [27].

Some literature focuses on oil fluctuation, especially for oil importers. Lin Boqiang and Mou Dunguo used a computable general equilibrium CEG model to find that rising energy prices had a contractionary effect on the Chinese economy [28]. Lin Boqiang used an error correction model to analyze the negative impact of short-term fluctuations in energy prices on economic development and made corresponding recommendations [29]. Wei Weixian et al. pointed out that the energy shock is the main source of domestic economic fluctuations [30]. Wang Yunqing constructed a DSGE model that includes energy elements to study the negative impact of energy price increase shocks on the economy and the optimal monetary policy to cope with energy price fluctuations [31]. Duan et al. established the time-delay differential equation of energy prices to forecast energy prices, which can better regulate energy market allocation and maximize the economic benefits of the energy allocation cost [32]. Due to such a high import of crude oil in Poland, Manowska and Bluszcz presented a model for forecasting crude oil consumption in the Polish market [33].

The response to the decline in oil prices caused by the U.S. “shale revolution” has also become an issue of concern for scholars. Melek et al. examined the U.S. shale oil boom which led to a decline in oil and fuel prices and boosted U.S. real GDP [34]. Balke and Brown developed a medium-sized DSGE model of the U.S. economy, including the recent development in shale oil technology, to evaluate how U.S. real GDP responds to oil prices originating from global oil supply shocks [35]. Xie et al. studied China’s optimal stockpiling policy in response to oil prices and analyzed the impact of a long-term low oil price on national strategic petroleum reserve (SPR) policies in China [36].

To summarize, scholars have reached the consensus that the different effects of oil price fluctuations on the macro economy come from various sources. A branch of literature focused on the response of macroeconomic variables to crude oil price shocks has achieved some interesting results. However, there are several aspects worthy of further study: firstly, most scholars studying the impact of oil price fluctuations on China’s economy regard oil prices as an exogenous variable; secondly, some quantitative studies analyze the effects of different oil price shocks on the economy from the perspective of fitting and forecasting, lacking exploration at the counterfactual and intervention levels; thirdly, there is little literature identifying the transmission mechanisms and effects of international oil price fluctuations from different sources by constructing an actor-based structural model in the era of the “new triangle” in the global oil market during the period of profound changes in the international oil market supply and demand patterns triggered by the booming “shale revolution” in the United States.

This paper constructs an actor-based structural model using complete information estimation, which can compensate to some extent for the shortcomings of fixed parameter settings in the fitting. Under the framework of structural macro-econometric research, this paper constructs an open-ended dynamic stochastic general equilibrium (DSGE) model including oil elements to focus on the response of China’s macro-economy to global oil price shocks and the transmission mechanism of different types of oil price fluctuations, by distinguishing the diverse sources of these changes. Then, we propose policy recommendations to cope with international oil price fluctuations in the new situation.

The main findings of this paper are as follows: firstly, it is impossible to assess the effects of oil prices without distinguishing the sources of oil price shocks. Oil prices are affected by the intertwined and compounded effects of multiple variables in the macroeconomic system, thus making the transmission channels and influence paths of oil price fluctuations on the macroeconomy diverse and complex; secondly, in the framework of the DSGE model, three types of oil price shocks are effectively identified, which led to remarkably different effects of oil price shocks on economic activity through various transmission channels. The negative oil price shock driven by the international crude oil supply has a positive stimulus effect on China’s real GDP in the short run, which is consistent with the findings of Kim and Vera [21]. The domestic economic expansion-driven oil price increases show a good correlation between oil prices and output growth, which is in line with the findings of Fernald and Trehan [37]. The oil shock driven by oil-specific demand is the most powerful influence on the real GDP in China, in agreement with Zhao et al. [38].

The main contribution of this paper is to construct an open-economy DSGE model under the current historical situation of profound changes in the supply and demand pattern of the international oil market to distinguish and assess the effects of three types of oil price shocks on China’s macro-economic variables. In order to theoretically examine the effects of oil price shocks, this paper uses a dynamic stochastic general equilibrium model incorporating energy sectors to build a complete oil industry chain which includes crude oil extraction and production, import, and processing. It is an innovative attempt at the oil DSGE model. Under the framework of the open DSGE model, we can effectively identify the sources of international oil price fluctuations. Thus, we can dynamically simulate the transmission process and effects of crude oil supply shocks, domestic economic development demand shocks, and specific demand shocks on China’s macroeconomy from the perspective of the endogeneity of oil price shocks. Since few papers analyze the

transmission mechanism and effects of the different sources of oil price shocks from an endogeneity perspective, our paper will help to fill this gap.

The remainder of this paper is organized as follows: Section 2 is an analysis of the transmission mechanism of oil price shocks; Section 3 is a model construction based on the dynamic stochastic general equilibrium theory; Section 4 is a model parameter calibration and Bayesian estimation; Section 5 is an impulse response analysis of endogenous fluctuations in international oil prices; and Section 6 is an analysis of the paper's conclusions and policy recommendations.

### 3. The Transmission Mechanism of Oil Price Shock

Combined with the theory of the impact mechanism of oil price shocks, the main transmission channels of oil price shocks to the economy are summarized (as shown in Figure 2):

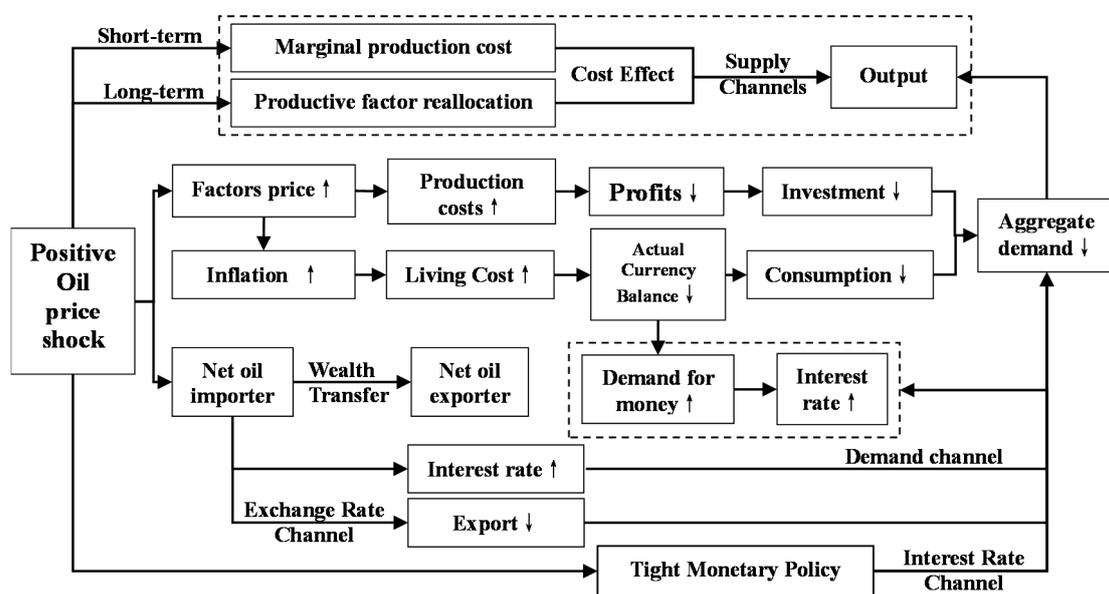


Figure 2. Transmission channel and path of action of oil price increase shock.

First, the supply channel. As the direct raw material for industrial production, oil price shocks will produce cost effects [39], the marginal cost of enterprises rise, and profit decline, leading to a decline in investment and output. In the long run, oil price fluctuations will trigger the flow and adjustment of production factors among sectors, incurring adjustment costs and triggering the inefficient or ineffective allocation of resources, thus affecting the output [40]. The supply channel also becomes one of the direct channels of oil price shocks.

Second, the demand channel. According to the market allocation theory, higher oil prices lead to higher price levels and lower real purchasing power of money, triggering the real balance effect that will lead to higher interest rates, changing household consumption demand, business investment demand, and lower output. According to income transfer theory, oil price shocks will be transmitted to net oil-importing countries through international trade, triggering imported inflation and reduced domestic consumption demand. At the same time, higher oil prices generate wealth transfer between countries, which further reduces export demand in net oil-importing countries through the exchange rate, leading to a decline in output in net oil-importing countries [41].

Third, the interest rate channel. Monetary authorities for inflation caused by rising oil prices, the increase in social demand for money, and the rise in effective interest rates will raise interest rates in response to anticipated inflation, so oil price increases have an indirect effect on macroeconomic performance through the interest rate channel [42].

### 4. Model Construction

In this paper, following the idea of the open macroeconomic DSGE model constructed by Adolfson et al. [43], we build an economic system: households, firms, government, and foreign economies, and we introduce a complete oil industry chain where crude oil extraction enterprises are responsible for extracting domestic crude oil and refineries process and refine crude oil extracted domestically and imported from abroad. According to the characteristics of China’s “productive” energy consumption structure, oil cooperates with the production function as a production factor. In the new pattern of the international oil market, China’s crude oil imports can be divided into two main channels: traditional imports (Middle East–Central Asia–Russia energy supply belt) and U.S. shale oil imports (North America–Latin America emerging energy supply belt). The refined oil produced by the energy sectors is supplied to households for domestic living consumption and to intermediate goods producers for industrial consumption as productive factors. Intermediate producers rent capital, hire laborers from households, and purchase refined oil from refined sectors to produce differentiated intermediate products, which are provided for final firms to manufacture homogeneous final goods for domestic consumption, investment, and export. The import and export sector connecting the domestic economy and foreign economies conducts differentiated (consumption or investment) goods for domestic households and foreigners and provides export goods to foreign economies. The structural relationship of the economic subject of the model is in Figure 3.

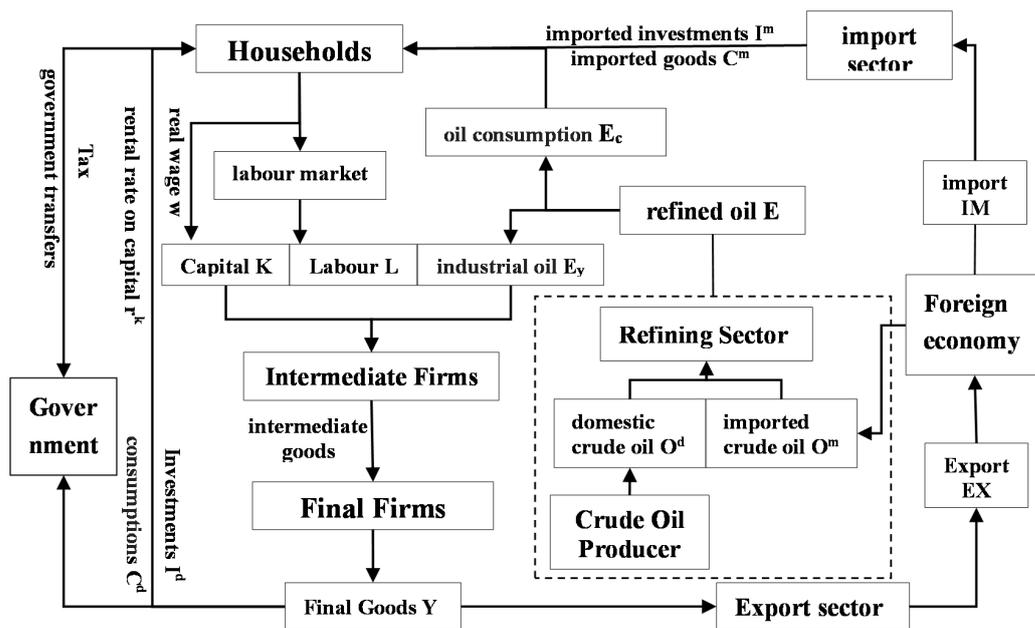


Figure 3. Basic structural relationship of the model.

#### 4.1. Firms

##### 4.1.1. Energy Firm

Crude oil is produced by a representative profit-maximizing firm, with the goal of profit maximization:  $\Pi_t^o = p_t^{od} O_t^{od} - C_t^{od}$ , where  $C_t^{od} = (O_t^{od})^{1+1/\nu^o} / (1 + 1/\nu^o)$  denotes the production costs, representing the quantity of the non-oil good, such as rigs. The domestic crude oil  $O_t^{od}$  is sold to oil refineries at a price of  $p_t^{od}$ . Profit maximization for firms implies:  $p_t^{od} = (O_t^{od})^{1/\nu^o}$ , where  $\nu^o$  is the elasticity of supply for domestic crude oil. This suggests that the higher the elasticity of the supply, the lower the marginal cost for the production.

#### 4.1.2. Refined Products Production

For the refining sector, we work with a CES production function composited of two sources of crude oil inputs:

$$E_t = \left[ (1 - w_o)^{\frac{1}{\eta_o}} (O_t^{od})^{\frac{\eta_o - 1}{\eta_o}} + w_o^{\frac{1}{\eta_o}} (O_t^m)^{\frac{\eta_o - 1}{\eta_o}} \right]^{\frac{\eta_o}{\eta_o - 1}} \quad (1)$$

where  $O_t^{od}$  and  $O_t^m$  denote domestic and imported crude oil inputs. The parameter of  $w_o$  controls the relative use of the different types of oil in the sector, and  $\eta_o$  governs the elasticity of the substitution between domestic and imported crude oil. Using a CES aggregator allows us to introduce the idea that these two sources of crude oils are imperfect substitutes for each other in a relatively parsimonious way. The real price of imported crude oil is  $F_t^{mo} \equiv S_t P_t^{mo} / P_t$ .

Using a Cobb–Douglas function to describe the imported crude oil  $O_t^m$ , it allows introducing the idea that the sources of imported oil are imperfect substitutes for each other.

$$O_t^m = (O_t^{os})^{\alpha_o} (O_t^{oo})^{1 - \alpha_o} \quad (2)$$

where  $\alpha_o$  is the elasticity of the substitution between these two sources of imported crude oil.  $O_t^{oo}$  is the imported crude oil from conventional oil producers, and  $O_t^{os}$  is the shale oil from the U.S.

#### 4.1.3. Intermediate Firms

Representative intermediate firms hire labor and rent capital from households and purchase refined products from refineries to produce differentiated intermediates of non-oil goods and sell them in a monopoly competitive market.

The production functions as follows:

$$Y_{i,t} = A_t^z [\eta K_{i,t}^v + (1 - \eta)(E_{i,t}^y)^v]^{\frac{\alpha}{v}} (L_{i,t})^{1 - \alpha} - \Phi \quad (3)$$

where  $K_{i,t}$  and  $L_{i,t}$  are the labor and capital input hired by firms  $i$ .  $E_{i,t}^y$  is Refined Oil used in the production provided by the refining sector.  $A_t^z$  represents a stationary productivity shock in the domestic goods producers and follows a log AR(1) process.  $\eta$  governs the share of capital inputs and oil inputs.  $1/(1 - v)$  is the elasticity of the substitution between capital and oil. A fixed cost  $-\Phi$  is included to ensure profits are zero in a steady state.

Given the prices of the inputs, the real wage  $w_t$ , real price of capital  $r_t^k$ , and the real price of refined oil  $pce_t$ , the cost minimization problem facing the intermediate firm  $i$  in period  $t$  can be described as the first-order condition:

$$\frac{w_t L_t}{r_t^k K_{t-1} + pce_t E_t^y} = \frac{1 - \alpha}{\alpha} \quad (4)$$

Therefore, the real marginal cost for intermediate producers is given by:

$$mc_t = \alpha^{-\alpha} (1 - \alpha)^{-(1 - \alpha)} \eta^{-\frac{\alpha}{v}} w_t^{1 - \alpha} (r_t^k)^{\alpha} \left[ 1 + \left( \frac{\eta}{1 - \eta} \right)^{\frac{1}{v - 1}} \left( \frac{pce}{r^k} \right)^{\frac{v}{v - 1}} \right]^{\alpha - \frac{\alpha}{v}} \quad (5)$$

The price-setting problem of the intermediate firms is following Calvo (1983). Each firm faces a random probability  $(1 - \theta)$  that it can reoptimize its price in any period,  $P_t^{new}$  is the newly set price.

The aggregate price index for domestic intermediate goods is:

$$P_t = \left[ (1 - \theta_d) (P_t^{new})^{1/(1 - \lambda_{d,t})} + \theta_d [(\pi_{t-1}^d)^{\kappa_d} (\bar{\pi}_t^c)^{1 - \kappa_d} P_{t-1}]^{1/(1 - \lambda_{d,t})} \right]^{1 - \lambda_{d,t}} \quad (6)$$

where,  $\pi_t^d = P_t/P_{t-1}$  denotes the domestic CPI inflation rate,  $\bar{\pi}_{t+1}^c$  is the current inflation target, and  $\kappa_d$  is a parameter that measures the degree of indexation.

#### 4.1.4. Final Firms

Final firms transform the intermediate goods at the given price of  $P_{i,t}$  into a homogenous final good, which is provided for domestic households' consumption and investment, and export. The production function of the final firms takes a CES type:  $Y_t = \left[ \int_0^1 Y_{i,t}^{1/\lambda_{d,t}} di \right]^{\lambda_{d,t}}$ , where  $\lambda_{d,t}$  is the time-varying markup in the final domestic goods market, which is subject to an exogenous stochastic process.

#### 4.1.5. Foreign Trade Sectors

The import sector is assumed to buy homogenous goods in the world market and convert them into differentiated consumption goods  $C_{i,t}^m$  and investment goods  $I_{i,t}^m$ . There is a continuum of exporting firms in the export sector, which buys final domestic goods and turns them into differentiated goods. These differential imported consumption goods, investment goods, and exported goods are summed up in CES in the final importing and exporting firms. The export and import sectors follow the Calvo pricing mechanism, and the partial indexation price movements are similar to those of domestic firms.

#### 4.2. Households

A typical household maximizes its expected lifetime utility consisting of consumption, leisure, and real cash balances, which can be characterized by:

$$E_t \sum_{t=0}^{\infty} \beta^t \left[ \frac{[C_{j,t}^\gamma (E_{j,t}^c)^{1-\gamma}]^{1-\sigma}}{\zeta_t^c} - A_L \frac{(\zeta_t^h L_{j,t})^{1+\sigma_L}}{1+\sigma_L} + \zeta_t^m \frac{(M_{j,t}/P_t)^{1+\sigma_m}}{1-\sigma_m} \right] \quad (7)$$

where the variables  $C_{j,t}$  and  $E_{j,t}^c$  are the non-oil goods and refined products, which are related via an elasticity of consumption substitution  $\gamma$ . Crude oil cannot be directly consumed by households;  $E_{j,t}^c$  provided by the refining sector is directly consumed as refined fuel for living, heating, and transportation.

However, in our open economy model, the final non-oil goods consumed by households is given as a constant elasticity of substitution (CES) aggregate of domestically produced goods  $C_t^d$  and imported goods  $C_t^m$ , which are combined with weights  $w_c$  and  $(1 - w_c)$  as follows:

$$C_t = [(1 - w_c)^{1/\eta_c} (C_t^d)^{\eta_c - 1/\eta_c} + w_c^{1/\eta_c} (C_t^m)^{\eta_c - 1/\eta_c}]^{\eta_c/\eta_c - 1} \quad (8)$$

where  $\eta_c$  denotes the substitution elasticity between  $C_t^d$  and  $C_t^m$ .

In each period all households are subject to the same budget constraint in nominal terms:

$$\begin{aligned} & M_{j,t} + S_t B_{j,t+1}^* + P_t^c C_{j,t} (1 + \tau_t^c) + P_t^I I_{j,t} + P_c E_t E_{j,t}^c + B_{j,t+1} + P_t a(u_t) \bar{K}_{j,t} \\ &= R_{t-1} B_{j,t} + W_t L_{j,t} (1 - \tau_t^n) + R_t^k u_t \bar{K}_{j,t} (1 - \tau_t^k) + R_{t-1}^* \Gamma_{B^*,t-1} S_t B_{j,t}^* + TR_t \\ & \quad + \Pi_{j,t} (1 - \tau_t^k) - \tau_t^k [(R_{t-1} - 1) B_{j,t} + (R_{t-1}^* \Gamma_{B^*,t-1} - 1) S_t B_{j,t}^*] \\ & \quad + (R_{t-1} - 1) M_{j,t} + B_{j,t}^* (S_t - S_{t-1}) \end{aligned} \quad (9)$$

It shows how the households use their resources on the left side of the terms, and what resources the households have at their disposal on the right side in period  $t$ . Where  $\beta$  is the discount factor,  $P_t^c$ ,  $P_t^I$ , and  $P_c E_t$  are the nominal prices of non-oil consumptions, investment goods, and oil, respectively; cash holdings  $M_t$ , domestic bonds  $B_t$ , and bonds abroad  $B_t^*$  are different wealth forms held by households.  $R_t$  and  $R_t^*$  are the benchmark nominal interest rates of China and the foreign economy;  $\Gamma_{B^*,t}$  is a premium on foreign bond holdings.  $R_{t-1}^* \Gamma_{B^*,t-1}$  is a risk-adjusted pre-tax gross interest rate. The households

earn income from providing labor and renting capital to firms and receive profits  $\Pi_t$  from intermediate firms.  $\tau_t^c$ ,  $\tau_t^n$ , and  $\tau_t^k$  are the tax rates on consumption, labor income, and capital income.  $\bar{K}_t$  represents the return on real capital;  $a(u_t)$  represents the function of the utilization cost and utilization rate  $u_t = K_t/\bar{K}_t$ .  $S_t$  is the exchange rate;  $TR_t$  is the transfer from the government.

Households accumulate capital according to the law of motion:

$$\bar{K}_{t+1} = (1 - \delta)\bar{K}_t + \xi_t^I [1 - S(I_t/I_{t-1})]I_t \tag{10}$$

where  $\delta$  is the capital depreciation rate,  $S(I_t/I_{t-1})$  is the adjustment cost function, and  $\xi_t^I$  is a stochastic shock to investment price.

The household decision problem is to choose final non-oil consumption  $C_t$ , oil  $E_t^c$ , investment goods  $I_t$ , working hours  $L_t$ , bonds  $B_t$  and  $B_t^*$ , and capital utilization  $a(u_t)$  to maximize the utility (Function (7)) by subjecting to its budget constraint and capital accumulation (Equation (10)).

The households can determine wages since they are the monopoly supplier of a differentiated labor service. We introduce wage stickiness following the Calvo mechanism, which is the same as the law of price movement.

#### 4.3. Government

The central bank monetary policy model follows the Taylor rule by following Smets and Wouters [44].

$$\hat{R}_t = \rho_R \hat{R}_{t-1} + (1 - \rho_R) [\hat{\pi}_t^c + r_\pi (\hat{\pi}_{t-1}^c - \hat{\pi}_t^c) + r_y \hat{Y}_{t-1} + r_{\Delta\pi} (\hat{\pi}_t^c - \hat{\pi}_{t-1}^c) + r_{\Delta y} (\hat{Y}_t - \hat{Y}_{t-1}) + \varepsilon_{R,t}] \tag{11}$$

where  $\varepsilon_{R,t}$  is the temporary nominal interest rate shock,  $\rho_R$  is the interest rate smoothing coefficient, and  $r_\pi$ ,  $r_y$ ,  $r_{\Delta\pi}$ , and  $r_{\Delta y}$  are the inflation, output, differential inflation, and differential output response coefficients, respectively.

The government budget in this model economy is:

$$P_t G_t + TR_t = \tau_t^c P_t^c C_t + \tau_t^n W_t L_t + B_t + M_t + \tau_t^k [(R_t - 1)B_t + (R_{t-1} - 1)M_t + R_t^k u_t \bar{K}_t + R_{t-1}^* \Gamma_{B^*,t-1} S_t B_t^* + \Pi_t] \tag{12}$$

The left-hand side of the equation represents government expenditure, which consists of government expenditure  $G_t$  and nominal government transfers  $TR_t$  to households. The right-hand side of the equation represents government revenue.

#### 4.4. Foreign Economy

Taking the United States as a representative of foreign economies, refer to Adolfson et al. [43], assuming foreign inflation  $\pi_t^*$ , output  $\hat{y}_t^*$ , and interest rate  $\hat{R}_t^*$  are described by an exogenous structural vector autoregressive (SVAR) model:

$$F_0 X_t^* = F(L) X_{t-1}^* + \mu_{x^*,t} \quad \varepsilon_{x^*,t} \sim N(0, \sum_{x^*}) \tag{13}$$

where  $X_t^* = [\pi_t^*, \hat{Y}_t^*, \hat{R}_t^*]'$ .

#### 4.5. Market Clearing and Exogenous Processes

Therefore, based on the household budget constraint, the profit function of the intermediate firms, the Current Account, and the government budget constraint, the equilibrium resource constraint satisfies:

$$P_t^c C_t + P_t^I I_t + P_t G_t + P_c E_t (E_t^c + E_t^y) + S_t P_t^x EX_t - S_t P_t^* IM_t = P_t Y_t - P_t a(u_t) \bar{K}_t \tag{14}$$

The exogenous shock process in the model is given as a log-linearization:  $\hat{\xi}_t = \rho_{\xi} \hat{\xi}_{t-1} + \varepsilon_{\xi,t}$ , where  $\rho_{\xi}$  is the persistence parameters of exogenous shocks,  $\varepsilon_{\xi,t}$  is distributed as i.i.d. Normal innovations:  $\varepsilon_{\xi,t} \sim (0, \sigma_{\xi})$ .

In the framework of the DSGE model, the Log-linearization and steady-state value solution of each dynamic equation in the model are required. The solving process of the DSGE model is shown in Appendix A.

### 5. Bayesian Estimation

In order to estimate this model, we use quarterly data for the period 1996:1–2019:4, a total of 100 periods, to measure the observed variables. A set of thirteen variables are chosen as the observed variables  $\tilde{X}_t^{obs}$  for Bayesian estimation: consumption, investment, GDP, exports, imports, refined oil production, employment, the GDP deflator, the consumption deflator, nominal interest rate, foreign inflation, foreign output, and foreign interest rate.

$$\tilde{X}_t^{obs} = \{\Delta \ln C_t, \Delta \ln I_t, \Delta \ln Y_t, \Delta \ln EX_t, \Delta \ln IM_t, \Delta \ln E_t, \Delta \ln EM_t, \tilde{R}_t, \tilde{\pi}_t^d, \tilde{\pi}_t^c, \tilde{\pi}_t^*, \Delta \ln Y_t^*, \tilde{R}_t^*\}$$

The parameters that need to be calibrated in the model are the static parameters of the model, which are obtained from existing research results using empirical methods and the steady-state values of the endogenous variables of the model, which need to be calibrated based on realistic data. The specific calibration data are detailed in Table 2.

**Table 2.** Calibrated Parameters.

Sectors	Parameters	Value	Source	
Households	Scaling of disutility of work	$A_L$	1.51	Chen, S. et al. [45]
	Inverse of the elasticity of Inter-term consumption	$\sigma$	1	Unalmis et al. [27]
	Steady state monetary growth rate	$\mu$	1.01	Wang J.B. [46]
	Depreciation rate of capital	$\delta$	0.025	Gong L.T. and Xie D.Y. [47]
	Inverse of the elasticity of money holdings	$\sigma_m$	1	Wang J.B. [46]
	Weights of non-oil goods for household	$\gamma$	0.70	Liu M. and Song X. [48]
	Discount factor	$\beta$	0.985	Wang J.B. and Wang W.F. [49]
	Inverse of the elasticity of labor supply	$\sigma_L$	0.818	Allegret et al. [50]
	Share of domestic consumption	$w_c$	0.194	Chen, S. et al. [45]
Firms	Share of domestic investment	$w_I$	0.595	Chen, S. et al. [45]
	Elasticity of substitution between capital and oil	$1/(1 - \nu)$	0.159	Zhao et al. [38]
	Intratemporal elasticity of substitution between the domestic and foreign consumption goods	$\eta_c$	1.5	Adolfson et al. [43]
	Intratemporal elasticity of substitution between the domestic and foreign investment goods	$\eta_I$	1.5	Adolfson et al. [43]
	Labor share in production	$\alpha$	0.60	Melek et al. [51]
	The proportion of capital inputs	$\eta$	0.996	Zhao et al. [38]
Government	Share of imported shale oil	$\alpha_o$	0.012	Calculation (The steady-state value of the Share of imported crude oil $w_o$ is calculated by the foreign dependence on crude oil (1996–2019). The weight of the imported crude oil from traditional areas and U.S. shale oil $\alpha_o$ is computed using the imported crude oil data released by the General Administration of Customs P.R. China. Referring to Liu R.C. and Ma S.Y. [52], Wang B. and Cui Z.W. [53], the annual sample means of the structural effective tax rate is measured as the data from 1996 to 2017)
	Share of imported crude oil	$w_o$	0.70	
	Consumption tax rate	$\tau^c$	0.088	
	Capital income tax rate	$\tau^k$	0.280	
	Labor income tax rate	$\tau^n$	0.097	

We should adjust the raw data: firstly, making seasonal adjustments; secondly, smoothing with first-order logarithmic differencing; thirdly, using HP filtering to obtain the cyclical factor component of the time series data. According to this data, after receiving the maxi-

imum value of the likelihood function using Algorithm No. 6 in the Matlab environment, the calibration and estimation of the model parameters were obtained by the Markov Monte Carlo simulation method (MCMC) using the Metropolis-Hastings sampling algorithm with 500,000 simulated sampling calculations in the full sample interval. Some of the parameter estimation results are reported in Table 3.

**Table 3.** Prior distribution and Bayesian estimation results.

Parameters	Prior Distribution			Posterior Distribution		
	Type	Mean	Std.Dev.	Mean	Interval [5%, 95%]	
$\theta_w$	Calvo wages	Beta	0.750	0.05	0.8002	[0.7781, 0.8212]
$\theta_d$	Calvo domestic prices	Beta	0.840	0.05	0.9330	[0.9123, 0.9546]
$\theta_{mc}$	Calvo import consumption prices	Beta	0.500	0.10	0.4602	[0.4573, 0.4638]
$\theta_{mI}$	Calvo import investment prices	Beta	0.500	0.10	0.5749	[0.5725, 0.5780]
$\theta_{mo}$	Calvo import oil prices	Beta	0.500	0.10	0.3370	[0.3322, 0.3408]
$\theta_x$	Calvo export prices	Beta	0.500	0.10	0.6712	[0.6654, 0.6757]
$\kappa_w$	Indexation wages	Beta	0.500	0.15	0.3709	[0.3658, 0.3766]
$\kappa_d$	Indexation domestic prices	Beta	0.500	0.15	0.7488	[0.7449, 0.7565]
$\kappa_{mc}$	Indexation import consumption prices	Beta	0.500	0.15	0.6579	[0.6516, 0.6680]
$\kappa_{mI}$	Indexation import investment prices	Beta	0.500	0.15	0.4255	[0.4200, 0.4291]
$\kappa_{mo}$	Indexation import oil prices	Beta	0.500	0.15	0.6409	[0.6362, 0.6487]
$\kappa_x$	Indexation export prices	Beta	0.500	0.15	0.7015	[0.6965, 0.7095]
$\theta_n$	Calvo employment	Beta	0.675	0.10	0.6765	[0.6709, 0.6817]
$\lambda^w$	Markup wages	InvGamma	2.000	2	1.7865	[1.7513, 1.8192]
$\lambda^d$	Markup domestic	InvGamma	1.200	2	1.6754	[1.0000, 2.5767]
$\lambda^{mc}$	Markup imported consumption	InvGamma	1.200	2	1.2258	[1.1244, 1.3428]
$\lambda^{mI}$	Markup imported investment	InvGamma	1.200	2	1.4451	[1.0000, 2.1591]
$\lambda^{mo}$	Markup imported oil	InvGamma	1.200	2	0.6346	[0.3066, 1.0198]
$S''$	Investment adjustment cost	Normal	4.000	2	4.6656	[3.6963, 5.9396]
$\sigma_c$	Substitution elasticity consumption	InvGamma	1.50	4	1.4344	[1.0000, 2.0926]
$\sigma_I$	Substitution elasticity investment	InvGamma	1.50	4	1.8730	[1.3091, 2.4496]
$\sigma_f$	Substitution elasticity foreign	InvGamma	1.50	4	1.3608	[0.8932, 1.8397]
$\psi_a$	Risk premium	InvGamma	0.010	2	0.0022	[0.0021, 0.0023]
$\rho_{\xi^c}$	AR for preference shock	Beta	0.85	0.10	0.9797	[0.9614, 0.9997]
$\rho_{\xi^I}$	AR for investment shock	Beta	0.85	0.10	0.8816	[0.8987, 0.9734]
$\rho_{\xi^h}$	AR for labor supply shock	Beta	0.85	0.10	0.8770	[0.8216, 0.9367]
$\rho_{\xi^m}$	AR for monetary demand of Household	Beta	0.85	0.10	0.8732	[0.8025, 0.9434]
$\rho_{z^*}$	AR for foreign productivity shock	Beta	0.85	0.10	0.9065	[0.8855, 0.9246]
$\rho_{R^*}$	AR for foreign interest rate shock	Beta	0.85	0.10	0.9523	[0.9300, 0.9794]
$\rho_{A^z}$	AR for domestic productivity shock	Beta	0.85	0.10	0.9924	[0.8541, 0.9120]
$\rho_R$	Interest rate smoothing	Beta	0.80	0.05	0.9795	[0.9739, 0.9843]
$r_\pi$	Inflation response	Normal	1.70	0.10	1.7453	[1.6862, 1.7942]
$r_{\Delta\pi}$	Diff. inflation response	Normal	0.30	0.10	0.2438	[0.1624, 0.3259]
$r_y$	Output response	Normal	0.125	0.05	0.1186	[0.1027, 0.1370]
$r_{\Delta y}$	Diff. output response	Normal	0.0625	0.05	0.0541	[0.0395, 0.0725]

Data Source: Matlab Results.

### 6. Impulse Response Analysis

Distinguishing the sources of oil price fluctuations is crucial to assessing the impact of oil shocks. This paper draws on the structural decomposition of oil prices proposed by Unalmis et al. [25] and Zhao et al. [39] to define three types of oil price shocks in the DSGE model framework: first, crude oil supply shocks driven by technological improvements in foreign economies, e.g., technological innovation breakthroughs that eventually led to the U.S. “shale revolution”, and the rapid expansion of U.S. oil supply capacity became a key factor driving the downward fluctuation of international oil prices. Second, domestic productivity improvements reflect economic activity-driven oil demand shocks, with the economic takeoff of emerging Asian economies represented by China and the world’s major developing countries stimulating a sharp increase in oil consumption as the significant

variable driving international oil price increases. Third, given the financial attributes of oil, the decline in nominal interest rates in foreign economies (the U.S.) and the enhanced liquidity driving specific demand for oil under the existing pricing system for international oil trade become the sources of oil-specific demand shocks to oil price volatility.

The three sources of oil price shocks are expressed as:

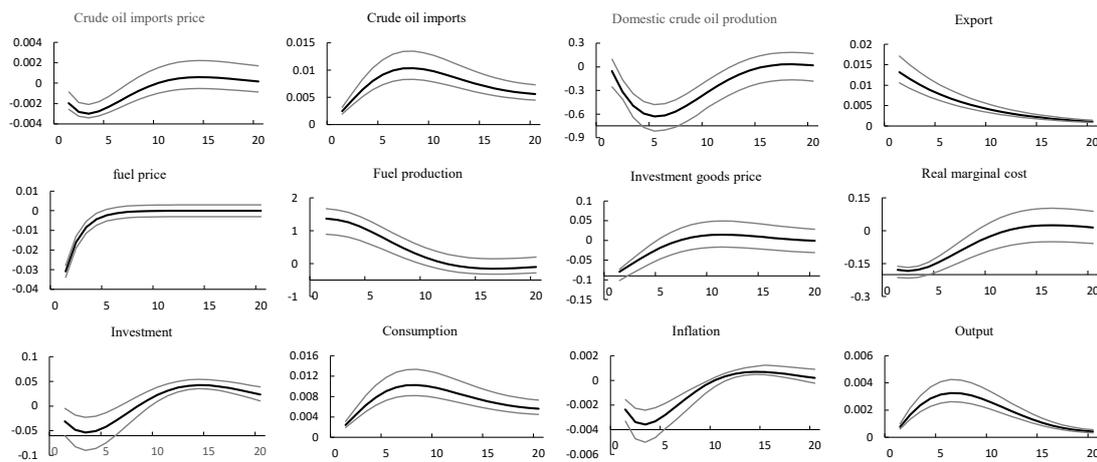
$$\hat{z}_t^* = \rho_{z^*} \hat{z}_{t-1}^* + \varepsilon_{z^*,t}, \hat{A}_t^z = \rho_{A^z} \hat{A}_{t-1}^z + \varepsilon_{A^z,t}, \hat{R}_t^* = \rho_{R^*} \hat{R}_{t-1}^* + \varepsilon_{R^*,t} \quad (15)$$

$\varepsilon_{z^*,t}$ ,  $\varepsilon_{A^z,t}$  and  $\varepsilon_{R^*,t}$  represent productivity shocks in foreign economy, productivity shocks in China, and nominal interest rate shocks in foreign economy, respectively.

The results of the simulation effects of negative oil price shocks driven by international crude oil supply, positive oil shocks driven by productivity shocks in China, and nominal interest rate shocks in the foreign economy are displayed in Figures 4–6.

### 6.1. Oil Price Shock Driven by International Crude Oil Supply

Figure 4 shows the effects of a unit standard deviation positive productivity shocks in foreign economies on the main domestic macroeconomic variables over a 20-year period. The horizontal axis denotes the period in quarters, while the vertical axis denotes the percentage deviation of the economic variables from their steady state. Positive productivity shocks increase crude oil supply driving downward fluctuations in oil prices, with import oil prices falling to a maximum of  $-0.3\%$  in the third period for negative deviations from the steady state.



**Figure 4.** Positive international oil supply shock. (Note: The black solid line represents the estimated actual mean responses, and the gray solid lines represent the 5 percent and 95 percent posterior interval).

First, the positive productivity shocks stimulate import demand in the foreign economy, and the domestic exports reach a positive deviation peak of 0.13% at the beginning of the shock. The shock-induced fall in oil prices drove down other international commodity prices and transmitted them through international trade to the domestic level, with a consequent fall in the domestic price level, but slightly, only 0.08% for a one-unit standard deviation productivity shock. Domestic investment gradually rises after a short-term decrease due to lower prices of domestic investment goods.

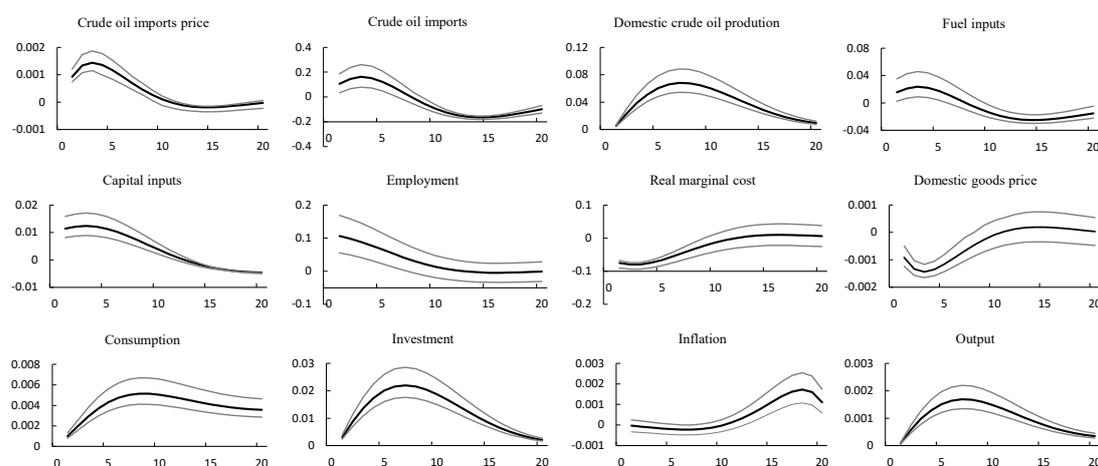
Second, the substitutability of imported crude oil is enhanced and import costs decrease as oil prices fall, so the refining sector increases imports and refined oil production growth. However, the crude oil production upstream of the domestic oil industry declines. Domestic crude oil production shows negative volatility, which decreases at the beginning of the shock to the fifth period and reaches a trough value of  $-0.63\%$ . The domestic refined oil price falls to a negative deviation from the steady-state, with a maximum of  $-0.03\%$  at the beginning of the shock occurrence. The actual marginal production costs of intermedi-

ate firms decrease as the factor input costs fall; it shows a negative fluctuation maximum of  $-1.8\%$  in the second period. At the same time, the decline in domestic price levels has an “income effect” on households, increasing real wealth and income. Consumption increases by a maximum of  $1\%$  in the eighth period. The domestic output grows, driven by the consumption and export demand, showing a maximum positive deviation of  $0.3\%$ , with an average positive shock effect of  $0.18\%$  during the period.

Therefore, the negative oil price shock driven by international supply boosts output growth in the short term. Yet, it produces a negative effect on the upstream oil industry. The new energy and clean industry are limited to a certain extent. Oil price fluctuations generate cost effects through the supply channel, reduce production and operating costs, expand profitability, relieve inflationary pressure, and bring the “income effect” for households. Therefore, consumption and investment increase, which boosts economic growth in the short term. However, in the long term, the downward fluctuation of oil prices will trigger the reconfiguration of production input factors among sectors. It will not only compress the profit margin of the upstream oil industry directly and reduce investment in the oil industry but also intensify the competition between oil and new energy. The declining investment and R and D enthusiasm are not conducive to energy-intensive industrial restructuring, and the development of the new energy and clean energy industries is constrained. At the same time, people tend to indulge in the temporary relaxed energy environment created by low oil prices and relax their awareness of the potential crisis, resulting in a weakened incentive to save and innovate. Thus, we need to realize that the low oil prices will not change the world’s energy structure and the dependence of oil-deficient countries on oil.

## 6.2. Oil Price Shock Driven by Domestic Economic Demand

Figure 5 shows the positive domestic productivity shock of one-unit standard deviation, which means the productivity growth in China increases the oil consumption demand. First, the imported crude oil prices reach a positive deviation peak of  $0.14\%$  in the fourth period under the positive economic demand shocks. At the same time, the intermediate firms add the inputs of labor, capital, and refined oil, with labor supply rising to a maximum of  $1.1\%$  at the beginning of the shock, the capital inputs and refined oil inputs reaching their maximum of positive deviation from the steady state in the third period, after which, they began to decrease since the eighth period as the oil prices continue to rise. Second, the domestic production boom increases the consumption demand for oil, and crude oil production gradually increases to reach a maximum of  $6.8\%$  in the seventh period.



**Figure 5.** Positive economic demand shock. (Note: The black solid line represents the estimated actual mean responses, and the gray solid lines represent the 5 percent and 95 percent posterior interval).

Under positive productivity shocks, the actual marginal costs of intermediate firms fall to a minimum of  $-8\%$  in the second period and then start to rebound and reach a peak

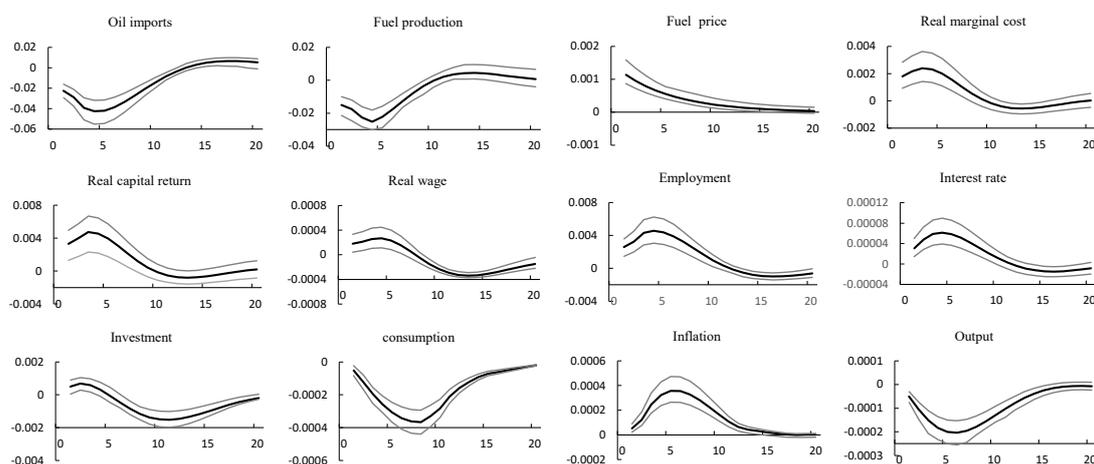
of positive deviation of 1% in the 16th period, triggering a trend of movement of domestic price levels showing a slight decline followed by a continuous rise. Domestic inflation shows a slightly negative deviation from the steady state in the short term, while the rising oil prices push inflation back up and reach a positive deviation peak of 0.23% in the 16th period. As the increasing oil price intensifies ascending inflation, the central bank will raise nominal interest rates to stabilize prices.

Furthermore, positive productivity shocks drive the growth of both consumption and investment, and an increasing oil demand positively affects the output, with a maximum of 0.17% in the seventh period.

Therefore, the positive oil demand shock driven by domestic productivity directly acts on the demand channel to increase consumption and investment, achieving simultaneous fluctuations in oil prices and output. That means the oil demand shock driven by the economic boom shows a good correlation between oil prices and output growth [38], achieving simultaneous fluctuations in oil prices and output. The output boom effectively suppresses inflation in the short run. However, the positive oil demand shock also has a negative cost effect on output through the supply channel, exacerbates domestic inflationary pressures, and induces Monetary Policy Tightening Adjustments, thus leading to an indirect influence on the economy through the interest rate channel, triggering a reduction in consumption and investment and a fall in output in the long run.

### 6.3. Oil Price Shock Driven by Oil-Specific Demand

Since the 21st century, the low interest rates under the neoliberal economic policy of the United States have led to excess dollar liquidity, dollar depreciation, and a boom in speculative trading in the financial market. Especially after the World Financial Crisis in 2008, the quantitative easing policy of the Federal Reserve injected sufficient liquidity into the market, and a large amount of liquidity flowed from the real economy to the commodity market. It increases the precautionary and speculative demand for oil. Figure 6 shows the responses of main macroeconomic variables to a one-unit standard positive oil price shock driven by oil-specific demand.



**Figure 6.** Positive Oil-specific demand shocks. (Note: The black solid line represents the estimated actual mean responses, and the gray solid lines represent the 5 percent and 95 percent posterior interval).

First, according to the Uncovered Interest Parity, the negative foreign nominal interest rate shock will trigger negative domestic nominal interest rate volatility through the exchange rate channel. At the same time, capital outflow in the foreign economy leads to a rise in the real exchange rate. Relative price fluctuations of domestic and foreign goods enhance the contemporaneous substitution effect between domestic and imported goods. With the higher degree of economic openness and export multiplier effect in China, the

decline in the relative prices of imported goods and the appreciation of the RMB exchange rate bring a significant negative impact on China's import and export trade. Therefore, under the negative foreign interest rate shocks, exports fall continuously to a minimum value of  $-1.6\%$  in the fourth period, while imports show a positive deviation, with an initial shock effect of  $2.6\%$ . The output declines amid falling net exports and lower consumer demand, with an initial negative value of  $-0.5\%$ .

Second, under the positive oil price shock driven by oil-specific demand, the imported crude oil prices reach a maximum value of  $0.5\%$  in positive deviation in the period when the shock occurs. The initial positive shock effect on crude oil imports reaches  $1.67\%$ , as the exchange rate appreciation increases the import demand for energy firms. Continued upward fluctuations in international oil prices drive up the cost of imports. Meanwhile, both the domestic output and consumption are negatively affected. The inflation reaches a maximum value of  $1.76\%$  in the fourth period.

As a result, the positive oil price shocks driven by oil-specific demand are transmitted to the domestic through the exchange rate channel, triggering negative adjustments in nominal interest rates and positive fluctuations in the local currency and reducing export demand for net oil-importing countries. Moreover, the negative cost effect of oil price rises acts on economic output through the supply channel. The positive oil-specific demand shock triggers imported inflation and a decline in the real purchasing power of the currency. The shock leads to a higher cost of living and production costs through the demand channel. Ultimately, it results in a decline in demand and a negative shock to outputs.

## 7. Conclusions and Policy Implications

### 7.1. Conclusions

First, we employ an open-economy DSGE model, taking oil as the input into the CES production function of intermediate firms building an oil industry chain that includes crude oil extraction and production, import, and processing. The transmission paths and effects of oil price shocks from different sources on the macroeconomy and oil industry are assessed from the perspective of the endogeneity of oil fluctuations.

Second, within the DSGE framework, we identify three types of oil price shocks according to [19]. The three types of oil price shocks are crude oil supply shocks driven by technological improvement in the foreign economy, oil demand shock forced by China's productivity improvements, and oil-specific demand shocks driven by increased speculative demand for oil promoted by the loose monetary policy of the foreign economy. Among them, the supply-driven oil price decline shock positively affects the net oil importer but will constrain the development of their domestic oil industry in the long run. The oil price rise driven by positive domestic economic expansion creates the same fluctuation of output and oil price in the short term, which has a positive effect on the development of the oil industry; however, the increasing inflationary will induce monetary policy tightening adjustment and thus produce an indirect negative impact on the economy. The oil-specific demand is the main factor that affects China's output and inflation.

Finally, the macroeconomic transmission paths from the different sources of oil price shocks are different. First, the crude oil supply-driven oil price shocks yield a cost effect on the production functions of intermediate firms through the supply channel in the short term. It will cause production regulation costs in the long term, lead to the inefficient allocation of resources, intensify the competition between oil and new alternative energy sources, and restrict incentives for investment in new energy fields. Second, the demand-driven oil price shocks act on consumption and investment through the demand channel to create the same direction of output and oil price fluctuations. Additionally, the shock has a negative cost effect on output directly through the supply channel. Higher inflation generates real balance effects, raising the interest rates, which will induce monetary policy adjustments. Therefore, the demand shocks result in an indirect negative effect on the macroeconomy through the interest rate channel. Third, the oil-specific demand shocks reduce the export demand through the exchange rate channel. The positive oil price shocks have a negative

cost effect on the output via the supply channel. Oil price shock raises imported inflation. Additionally, it generates the real balance effects on the cost of living and production activities through the demand channel, thus leading to a reduction in demand and output. Therefore, due to the different transmission mechanisms, the diverse sources of oil price shocks have differentiated effects (see Figure 7).

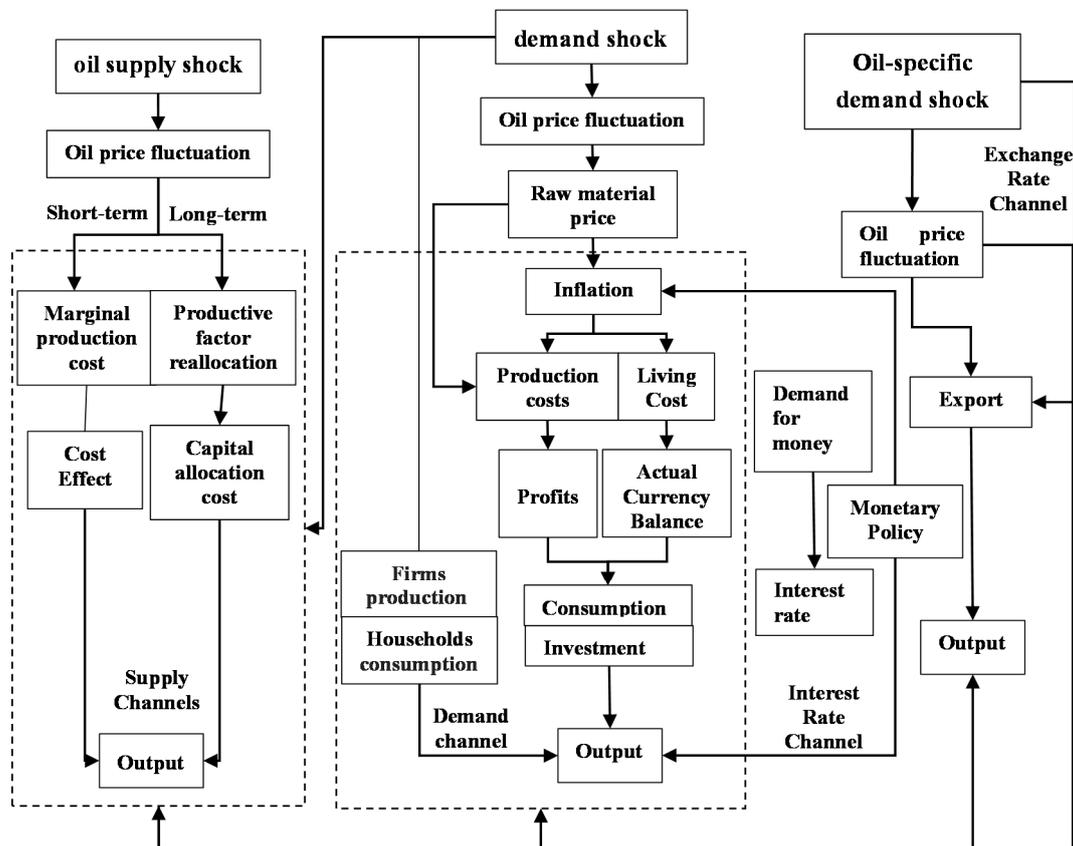


Figure 7. Transmission channels of the diverse sources of oil price shocks.

### 7.2. Policy Implications

Empirical studies show that it is impossible to assess the effects of oil prices without distinguishing the diverse sources of oil price shocks. Therefore, policy recommendations to deal with international oil price fluctuations from the supply, demand, and international aspects are as follows:

From the supply perspective, first of all, to ensure the security of the national oil supply, we should rely on ourselves, enhance the domestic oil supply capacity, and promote the exploration and development of unconventional oil resources; for instance, Shale Oil. Secondly, pay attention to the construction of the national oil reserve system, taking advantage of the “benefit window” of low oil prices to actively “stockpile oil” to build a sufficient amount of state oil reserve.

From the demand perspective, lowering the oil consumption dependence upon imports can mitigate the impact of oil price fluctuations on China’s economic growth. Firstly, this can be achieved by switching the engine of economic growth to reduce reliance on fossil energy consumption for economic growth. Secondly, it is impossible to encourage technological innovation to develop green and low-carbon new energy, promote the replacement of fossil energy, accelerate the carbon reduction process in China, and ultimately achieve the low-carbon economic development path of emission peak and carbon neutrality.

The oil-specific demand inflation, such as financial speculation demand and precautionary demand, is inevitably influenced by importing factors in an open economy. From the international perspective, with the buyer’s market right, it is a favorable time to build

the Chinese price system in the international oil market under the intensified competition on the global oil supply. Hence, the RMB pricing of the international oil trade can effectively insulate against external shocks.

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## Appendix A

The appendix gives the main solution procedure of the model.

### 1. Firms

#### 1.1 Refined Products Production

$$E_t = [(1 - w_o) \frac{1}{\eta_o} (O_t^{od})^{\frac{\eta_o-1}{\eta_o}} + w_o \frac{1}{\eta_o} (O_t^m)^{\frac{\eta_o-1}{\eta_o}}]^{\frac{\eta_o}{\eta_o-1}}$$

$$O_t^m = (O_t^{os})^{\alpha_o} (O_t^{oo})^{1-\alpha_o}$$

The first order conditions for Refined sectors are:

$$O_t^{od} = (1 - w_o)(p_t^{od} / p_{ce_t})^{-\eta_o} E_t$$

$$O_t^m = w_o(p_t^{mo} / p_{ce_t})^{-\eta_o} E_t$$

$$O_t^{os} = \alpha_o \frac{p_t^{mo}}{p_t^{os}} O_t^m$$

$$O_t^{oo} = (1 - \alpha_o) \frac{p_t^{mo}}{p_t^{oo}} O_t^m$$

#### 1.2 Intermediate firms

$$Y_{i,t} = A_t^z [\eta K_{i,t}^v + (1 - \eta)(E_{i,t}^y)^v]^{\frac{\alpha}{v}} (L_{i,t})^{1-\alpha} - \Phi$$

$$s.t. \min_{L_{i,t}, K_{i,t}, E_{i,t}^y} W_t L_{i,t} + K_{i,t} R_t^k + E_{i,t}^y P_{ce_t}$$

Representative intermediate firms' Lagrangian function for optimal production decisions:

$$\Gamma_t = W_t L_{i,t} + K_{i,t} R_t^k + E_{i,t}^y P_{ce_t} + MC_{i,t} [Y_{i,t} - A_t^z [\eta K_{i,t}^v + (1 - \eta) A_t^z (E_{i,t}^y)^v]^{\frac{\alpha}{v}} (L_{i,t})^{1-\alpha} + \Phi]$$

The first order conditions for Intermediate firms' cost minimization are:

$$\partial L_t : w_t = (1 - \alpha) \frac{Y_t}{L_t}$$

$$\partial K_t : r_t^k = \frac{\alpha \eta Y_t}{\eta (K_t)^v + (1 - \eta) A_t^z (E_{y,t} / K_t)^{v-1} E_{y,t}}$$

$$\partial E_{y,t} : p_{ce_t} = \frac{\alpha (1 - \eta) A_t^z Y_t}{\eta (K_t / E_{y,t})^{v-1} K_t + (1 - \eta) A_t^z E_{y,t}}$$

2. Households Representative Households' Lagrangian function for optimal behavioral decisions:

$$L_t = E_0^j \sum_{t=0}^{\infty} \beta^t \left[ \zeta_t^c \frac{[C_{j,t}^c (E_t^c)^{1-\gamma}]^{1-\sigma}}{1-\sigma} - A_L \frac{(\zeta_t^h L_{j,t})^{1+\sigma_L}}{1+\sigma_L} + \zeta_t^m \frac{(M_{j,t}/P_t)^{1+\sigma_m}}{1-\sigma_m} \right] + \lambda_t \left[ \begin{aligned} &R_{t-1} B_{j,t} + W_t L_{j,t} (1 - \tau_t^n) + R_t^k u_t \bar{K}_{j,t} (1 - \tau_t^k) + R_{t-1}^* \Gamma_{B^*,t-1} S_t B_{j,t}^* \\ &\quad + TR_t + \Pi_{j,t} (1 - \tau_t^k) - \tau_t^k [(R_{t-1} - 1) B_{j,t} \\ &\quad + (R_{t-1}^* \Gamma_{B^*,t-1} - 1) S_t B_{j,t}^* + (R_{t-1} - 1) M_{j,t} + B_{j,t}^* (S_t - S_{t-1}) \\ &\quad - [M_{j,t} + S_t B_{j,t+1}^* + P_t^c C_{j,t} (1 + \tau_t^c) + P_t^i I_{j,t} + Pc E_t E_{j,t}^c \\ &\quad \quad + B_{j,t+1} + P_t a(u_t) \bar{K}_{j,t}] \\ &\quad + p_{k',t} [(1 - \delta) \bar{K}_t + \zeta_t^I [1 - S(\frac{I_t}{I_{t-1}})] I_t - \bar{K}_{t+1}] \end{aligned} \right]$$

The first order conditions for utility maximization of the representative household are:

$$\begin{aligned} \partial C_t : \lambda_t &= \frac{\zeta_t^c C_t^{\gamma(1-\sigma)-1} (E_t^c)^{(1-\gamma)(1-\sigma)}}{p_t^c (1 + \tau_t^c)} \\ \partial B_{t+1} : \lambda_t &= \beta E_t \lambda_{t+1} \pi_{t+1}^{-1} [R_t - \tau_{t+1}^k (R_t - 1)] \\ \partial E_t^c : p c e_t &= \frac{\zeta_t^c C_t^{\gamma(1-\sigma)} (E_t^c)^{(1-\gamma)(1-\sigma)-1}}{\lambda_t} \\ \partial m_t : \lambda_t &= \frac{\beta \zeta_t^m (m_t)^{-\sigma_m}}{(1 - \tau_t^k) (R_t - 1)} \\ \partial L_t : \beta A_L \zeta_t^h L_t^{\sigma_L} &= \lambda_t w_t (1 - \tau_t^n) \\ \partial \bar{K}_{t+1} : \lambda_t p_{k',t} &= \beta E_t [p_{k',t+1} \lambda_{t+1} (1 - \delta) + r_{t+1}^k u_{t+1} (1 - \tau_{t+1}^k) - a(u_{t+1})] \\ \partial I_t : p_{k',t} \zeta_t^I [1 - S(\frac{I_t}{I_{t-1}}) - S'(\frac{I_t}{I_{t-1}}) \frac{I_t}{I_{t-1}}] &+ \beta E_t \frac{\lambda_{t+1}}{\lambda_t} p_{k',t+1} \zeta_{t+1}^I S'(\frac{I_{t+1}}{I_t}) (\frac{I_{t+1}}{I_t})^2 = F_t^I \\ \partial u_t : r_t^k (1 - \tau_t^k) &= a'(u_t) \\ \partial B_{t+1}^* : \lambda_t S_t &= \beta E_t [\frac{\lambda_{t+1}}{\pi_{t+1}} (S_{t+1} R_{t+1}^* \Gamma_{B^*,t} - \tau_{t+1}^k S_{t+1} (R_{t+1}^* \Gamma_{B^*,t} - 1) - \tau_{t+1}^k (S_{t+1} - S_t))] \end{aligned}$$

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