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The macroeconomic effect of petroleum product price regulation in alleviating the crude oil price volatility

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Abstract
China adopted a market-based pricing mechanism for petroleum products to improve the economic efficiency of resource allocation, thereby exposing its macroeconomy to higher shocks in world crude oil price volatility. To address the WCOP volatility, the price of petroleum products is subject to government regulations. However, the macroeconomic effects of PPP regulations are yet to be studied thoroughly. Accordingly, this study first quantifies the degree of PPP regulation using a "profit + cost" model, followed by the filtration of the macroeconomic impacts of fiscal and monetary policies and then analyzes the economic effects of PPP using an SVAR model. Furthermore, a counterfactual analysis is conducted to verify the results. It was found that PPP regulation could alleviate the shock of WCOP volatility on industrial value-added, finished fixed asset investment, and the producer price index. These findings provide a deeper understanding of the macroeconomic effects of PPP regulations and provide policymakers with new information on the necessity of PPP regulations.

Keywords Oil price volatility · Petroleum product price regulation · Degree of price regulation · Macroeconomic impacts

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1 Introduction

The volatility of world crude oil prices (WCOP) has received worldwide attention because it is a major external shock that negatively affects macroeconomic growth (Hamilton 1983; Ramey and Ramey 1995). Fluctuations in the WCOP may affect macroeconomic activities by changing the prices of oil products and the relative prices of other products and increasing future price uncertainty, resulting in delayed investment or inefficient resource reallocation (Pindyck 1991; Guo 2005). Eventually, WCOP volatility can negatively affect investments, foreign trade, production, and consumption (Rafiq and Salim 2014; Dong et al. 2020; De Oliveira et al. 2021; Wang et al. 2022).

China has adopted uniform, dual-track, and market-based pricing mechanisms to regulate its petroleum product price (PPP) since 1949 (Ju et al. 2017). A market-based pricing mechanism is applied to improve China's economic efficiency in resource allocation; however, this exposes China to a market situation with a high level of risk. To deal with WCOP volatility, the market determines PPPs but is subject to government regulations in China (IEA 2015).

China started its first PPP regulation in 1998, according to which PPPs were initially anchored to the Singapore market; subsequently, a national benchmark price was set by referring to the market prices of crude oil in Singapore, New York, and London and considering taxes, distribution costs, and reasonable profit margins. The two major oil companies, the China National Petroleum Corporation and China Petrochemical Corporation, can adjust their retail PPP within a specified range above the benchmark price. If the weighted price estimated according to prices in the three markets fluctuated beyond 5%–8%, the National Development and Reform Commission (NDRC) made corresponding adjustments to the benchmark price. However, the prices of crude oil and petroleum products vary asynchronously because of the delayed adjustment of benchmark prices.

In 2006, the State Council made a further pricing reform plan for petroleum products, specifying that PPPs would be determined according to the WCOP that were calculated to be the weighted prices of the Brent, Dubai, and Minas markets, along with domestic average processing costs, taxes, and appropriate profits (referred to as the "crude oil pricing method"). In 2009, the NDRC released the "Petroleum Price Management Measures (Trial)," according to which the PPP was adjusted when the moving average price of crude oil in the international market changed more than four percent for 22 consecutive working days. When the WCOP fell below $80 per barrel, the national benchmark price for domestic petroleum products would gradually decrease until the processing profits became zero. Conversely, if the WCOP exceeds $130 per barrel, the government employs proactive fiscal policies to maintain the stability of the PPPs. The adjustment period was changed from 22 to 10 working days, according to the "Circular on further improving the oil and fuel pricing mechanism" issued by the NDRC in 2013.

Furthermore, when gasoline and diesel prices are below CNY 50 per tonne, no immediate adjustment is made; instead, the changes are accumulated or offset in the next adjustment period. In 2016, the NDRC released a policy document titled "Notice on Further Improving Issues Related to the Pricing Mechanism for Petroleum Products" to highlight that PPP is no longer lowered when the WCOP falls below $40 per barrel. Despite ongoing market-oriented reforms in China's petroleum product pricing mechanism, a relatively high level of regulation is still maintained. However, their effects have not been thoroughly investigated.

This study makes three major contributions to existing literature. This study aims to understand how PPP regulations alleviate the WCOP shocks to China's macroeconomy. This study answers this question by quantifying the degree of PPP regulation, which is usually ignored in existing literature because it is limited by data and quantification methods. There are a few studies on the economic effects of PPP regulations, including those by Zhang and Xie (2016), Ju et al. (2017), and Shi and Sun (2017); however, none have quantified the degree of PPP regulation. Instead, these studies assessed the macroeconomic effects of PPP regulation by identifying the difference between the macroeconomic effects of the WCOP and PPP (Zhang and Xie 2016) or by estimating the distortions of PPP using the US gasoline price as a benchmark price (Ju et al. 2017; Shi and Sun 2017).

The degree of PPP regulation is the difference between unregulated PPP and observed PPP; however, its quantification is difficult because unregulated PPP data are unavailable. Although Zhang et al. (2023) constructed an indicator to measure the degree of PPP regulation in terms of the difference between the domestic market price and the price with price control (the latter is calculated using the international market price plus transport insurance and related taxes), the indicator is not appropriate because it does not reflect the reality that China is a major importer of crude oil and the volume of imported petroleum products is negligible. For example, from 2016 to 2020, the average annual import volume of crude oil was 46.2 million tonnes, and those of gasoline and diesel were 0.3 million tonnes and 0.95 million tonnes, respectively, in China.

For this reason, Jia and Lin (2023) highlighted the role of energy processing sectors in analyzing the effect of price regulation in China. However, Jia and Lin (2023) did not quantify the degree of price regulation based on factual data but assumed different regulations in scenarios. The first contribution of this study is the estimation of the unregulated PPP using a "cost + profit" pricing model based on the production process of petroleum products and then quantifying the degree of PPP regulation.

Second, we assess the macroeconomic impact of the WCOP volatility by eliminating the effects of monetary and fiscal policies. Because the volatility of the WCOP has negative economic consequences, many countries have attempted to address this issue by implementing fiscal and monetary policies (Gimeno and Ortega 2016; Morana 2017; Delpachitra et al. 2020; Amiri et al. 2021). To assess the macroeconomic impacts of the WCOP, the economic indicators studied included M1 (Zhang and Xie 2016; Cheng et al. 2019; Wei and Guo 2016; Wen et al. 2019), M2 (Wei and Guo 2016; Wen et al. 2019), government expenditure (Iwayemi and Fowowe 2011; Emami and Adibpour 2012), interest rate (Zhang et al. 2023), and a combination of these, as in Cheng et al. (2019).

However, the observed values of these indicators were partially the result of macroeconomic policies. For example, a change in the observed values of macroeconomic indicators may be the cumulative result of crude oil price shocks and macroeconomic policies. Thus, the macroeconomic impacts of PPP regulations should be assessed by disaggregating and filtering the effects of macroeconomic policies; however, no existing study has been found to do so.

The third contribution is providing an alternative explanation for the role of PPP regulations in alleviating the WCOP shocks to the macroeconomy. Many studies have concluded that the macroeconomic impacts of PPP regulations are limited in China (Zhang and Xie 2016), which could be positive or negative in terms of different types of price distortions (Ju et al. 2017), supporting the argument of energy price deregulation in China (Shi and Sun 2017). The study concludes that PPP regulation plays a significant role in alleviating WCOP shocks to the macroeconomy and, thus, should be sustained for macroeconomic stability.

Figure 1 illustrates the steps involved in the research methodology. First, it identifies the research question: Does the macroeconomic effect of PPP regulation play a role in alleviating crude oil price volatility? Second, the transmission mechanism of oil volatility is analyzed, and the data used to answer this question are collected and processed. Third, a "cost + profit" pricing model is constructed to quantify the degree of PPP regulation. Fourth, ordinary least squares regression was employed to filter the impact of fiscal and monetary policies. Finally, an SVAR model is constructed to estimate the macroeconomic effects of PPP regulations, and a counterfactual analysis is conducted to verify the estimated results.

The remainder of this paper is organized as follows. Section 2 presents a literature review. Section 3 describes the transmission of oil price volatility to the macroeconomy. Section 4 presents the data and methods. Section 5 introduces the results and discussion. Finally, Sect. 6 concludes the paper and provides policy implications.

2 Literature review

Sharp price increases in oil and other energy products are typical examples of negative supply shocks (Hamilton 2005). The justification is that an increase in oil price implies an increase in production cost, and consequently, economic vitality decreases, and higher inflation occurs (Bernanke 1997). Policymakers may

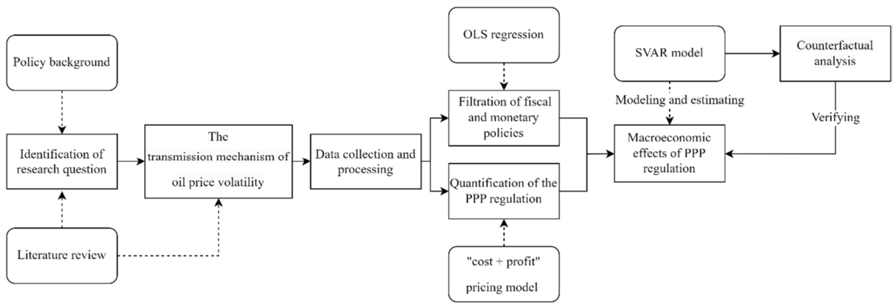

Fig. 1 The steps of the research methodology

implement energy price regulation policies to alleviate shocks to a certain extent (Delpachitra et al. 2020). This study reviews the literature on the effects of oil price shocks and energy price regulations on the macroeconomy.

2.1 Effect of oil price shocks on the macroeconomy

Since the first oil crisis in the 1970s, oil price shocks and their macroeconomic impacts have attracted worldwide attention. Since Hamilton (1983) initially proposed the nexus between oil price shocks and economic growth in the US market and systematically reviewed major oil price shocks after World War II, many studies have investigated the impact of oil price shocks on different economies. Numerous empirical studies have documented the negative effects of energy price increases on output and employment (Hille and Möbius 2019; Huntington and Liddle 2022; Calì et al. 2023).

Many studies have revealed that oil price fluctuations negatively affect output and domestic price levels, resulting in lower demand and output (Gong et al. 2021; Dong et al. 2020; Wang et al. 2022). Other studies found that the impacts of oil price decline and increase on the macroeconomy were asymmetric: (1) the impact of the positive oil price shocks was not significant, while the negative oil price shocks reduced economic growth significantly (Du et al. 2010); (2) real GDP responded to unexpected increases in the real price of oil, but did not respond to unexpected declines (Kilian and Vigfusson 2011); (3) the impact of a positive oil revenue shock on output growth was positive, while a negative one decreased output, and the effects of negative oil shock were greater than those of positive ones (Emami and Adibpour 2012); and (4) the effects of rising oil prices were greater than those of falling oil prices (Aimer and Lusta 2022).

However, some researchers question the relationship between oil price shocks and the macroeconomy. Empirical evidence supports this hypothesis. Some researchers claimed that the oil price shocks did not have a significant impact on most macroeconomic variables in Nigeria (Iwayemi and Fowowe 2011), had no distinct effect on output growth in Brazil (Cavalcanti and Jalles 2013), and had a limited impact on the four oil-consuming Asian economies, including Japan, South Korea, India and Indonesia (Cunado and Gracia 2015). Some studies have concluded that oil price shocks promote economic expansion because a positive oil price shock is usually associated with an economic boom in developed economies, leading to the expansion of the export sector and, consequently, investment and output (Du et al. 2010; Nusair 2016).

2.2 Effects of energy price regulation on the macroeconomy

Policymakers generally believe that oil price shocks play a negative role in the domestic economy, and many countries have implemented price regulation policies such as price capping and subsidies to deal with shocks (IEA 2015; Delpachitra et al. 2020; Jin and Xiong 2021). The macroeconomic impacts of energy price regulations have been studied extensively. Dewenter and Heimeshoff (2012) analyzed the effects of the first

Austrian fuel price regulation in 2009 on price levels from 2005 to 2012 and found that the regulation reduced price volatility in the macroeconomy. Suvankulov et al. (2012) found that since the regulation was implemented in 2006, the prices of nine cities in New Brunswick converged to the national mean, and the volatility of the macroeconomy reduced significantly. Similarly, Anyars and Adabor (2023) found that oil price changes statistically affect the transport sector. They argued that policies should be implemented to contain oil price shocks to stabilize inflation. However, some researchers have found that oil price regulation is ineffective compared to the non-regulated market, resulting in welfare losses (Berninghaus et al. 2012) and is not likely to have the anticipated results (Polemis 2012).

Considering the importance of energy in economic growth and social development, energy prices are regulated and often underpriced in China (Ouyang and Sun 2015; Jia and Lin 2023). This has inspired Chinese researchers to explore the effect of China's energy price regulation on the macroeconomy. Some studies have found that China's PPP regulations have a limited impact on the macroeconomy (Zhang and Xie 2016) and distort prices, thus negatively affecting output growth (Shi and Sun 2017). Moreover, Ju et al. (2017) found that relative and moving distortions in energy prices could contribute to China's economy but that absolute distortions negatively affected economic growth. These studies suggest that the energy prices in China should be deregulated. These studies attempted to assess the economic effects of China's PPP regulations but did not quantify the degree of PPP regulation.

Although Wang et al. (2019) and Zhang et al. (2023) constructed measures to quantify the degree of PPP regulation, the former did not analyze the effect of PPP regulation on indicators other than gross domestic product, such as the producer price index (PPI) and finished fixed asset investment (INV), while the latter used a measure based on PPP in the international market, which is not consistent with the fact that the import volumes of petroleum products are negligible. Thus, a measure consistent with factual transmission from the WCOP to domestic PPP is required to estimate the economic effects of PPP regulations more objectively.

In summary, most studies indicate that oil price shocks are detrimental to economic growth; thus, many countries implement energy price regulation policies to maintain their economic vitality. However, there is no consensus on the macroeconomic effects of energy price regulations because different methods have been applied (Kaufmann 2011). To estimate the macroeconomic impact appropriately, a theoretically sound method should focus on quantifying the degree of regulation and assessing its macroeconomic effects. Furthermore, no existing study has disaggregated and filtered the effects of macroeconomic policies, although a change in the observed values of macroeconomic indicators may be the cumulative result of PPP regulations and macroeconomic policies. Studies estimating the economic effects of PPP regulations by quantifying the degree of regulation and filtering the effects of macroeconomic policies are expected to bridge these gaps in the literature.

3 The transmission mechanism of oil price volatility

The WCOP usually experiences frequent fluctuations because it is easily affected by geopolitical conflicts such as the Russia-Ukraine War, financial issues, and other events such as COVID-19. Although China's PPP is regulated in response to fluctuations in the WCOP, it is necessary to understand the transmission mechanism of oil price volatility.

According to the theoretical framework of the impact mechanism of oil price shocks, WCOP shocks can affect the macroeconomy through supply, demand, and interest rate channels. WCOP shocks impact enterprises' marginal cost and profit, influencing investment and output (Nordhaus et al. 1980). They further induce the flow and adjustment of production factors among sectors, incurring adjustment costs and inefficient resource allocation, thereby affecting output (Loungani 1986). From a demand perspective, based on the market demand allocation theory, an increase in crude oil prices leads to a rise in price levels and a decrease in the real purchasing power of money, triggering the real balance effect and causing an increase in interest rates. This, in turn, alters household consumption and business investment demand, leading to a decline in output. In terms of interest rates, an increase in crude oil prices leads to inflation, increasing demand for money, and real interest rates. Monetary authorities raise interest rates to curb anticipated inflation, indirectly affecting the macroeconomy (Segal 2007).

To summarize, the transmission mechanism of WCOP volatility is shown in Fig. 2.

Crude oil is imported as a raw material and processed domestically to produce petroleum products. The WCOP is a major component of the cost of petroleum products and is embedded in the prices of petroleum products when petroleum products are priced with a "cost + profit" method. Thus, oil price volatility is transmitted to the petroleum product prices.

Second, according to PPP regulation policies, the prices of petroleum products are subject to adjustment, as the WCOP volatility meets the regulation requirements before petroleum products enter the market. As petroleum products are sold in the market, they are used as fuels in transportation, production, or as raw materials for chemicals. Thus, WCOP volatility is transmitted to the rest of the national economy.

Third, to maintain macroeconomic stability, the central government usually implements monetary or fiscal policies to deal with shocks resulting from WCOP volatility, which impacts economic indicators along with PPP regulation.

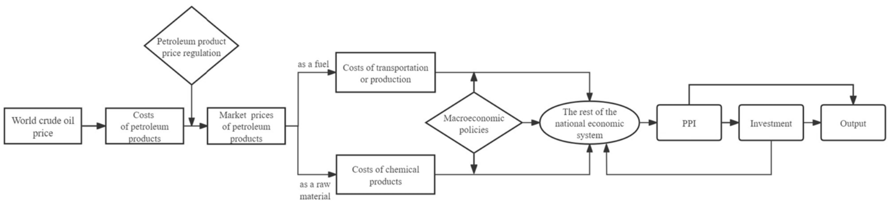

Fig. 2 The transmission mechanism of world crude oil price volatility

In other words, the economic indicators are the cumulative effects of PPP regulations and monetary and/or fiscal policies. Therefore, it is necessary to disaggregate and filter the effects of monetary and fiscal policies to estimate the macroeconomic impact of PPP regulations.

Fourth, the WCOP volatility directly affects PPP, which further affects investments and output. While PPP volatility is an important indicator of risk because it affects investors' expectations, investment is indirectly affected by WCOP volatility and has a further effect on economic output in subsequent years.

4 Methodology and data

4.1 Data sources

The study was conducted from January 1998 to October 2023. Following Du et al. (2010), we analyze six variables in the system: P_o(WCOP), V_c (PPP regulation), P_t(PPP), PPI (producer Price Index), INV (finished fixed asset investment), and IVA (industrial value added). The CPI is omitted because it is not directly affected by WCOP volatility, and its impact is negligible (Jia and Lin 2023; Zhang et al. 2023). We use the Brent crude oil price (unit: dollar/barrel) to represent P_o because China imports crude oil mainly from Middle Eastern countries, and the Brent crude oil market is the core global market (Wei and Lin 2007; Zhang and Cao 2014). The monthly exchange rate was used to convert the WCOP data to yuan/tonne. We used the #93 gasoline price (yuan/tonne) to represent P_t, considering that the prices of the two major oil products, gasoline and diesel, fluctuate in similar patterns. Fiscal expenditure and M1 are selected as proxy variables for fiscal and monetary policies, respectively.

The data on Brent crude oil prices are from the Energy Information Administration (EIA), and those on #93 gasoline prices are from the National Development and Reform Commission (NDRC). The data on PPI, INV, IVA, and fiscal expenditure are from the National Bureau of Statistics of China (NBSC), whereas those on M1 and the exchange rate are from the People's Bank of China (PBOC).

The profit-cost ratio in the oil processing sector is estimated as the ratio of the total net taxes on production and operating surplus to the sum of direct consumption, depreciation, wages, and compensation using data from the 1997 to 2017 input–output tables. The share of oil products is derived from Sinopec's annual reports. The density data used to convert the measurement units of oil products were obtained from Cheng and Liang (2003).

We deduce inflation from the GDP deflator index based on nominal variables. The data were processed using the GDP deflator index based on January 1998.

The data for all variables were found to be nonstationary and were thus analyzed in a logarithmic form. In addition to stationarity, the INV and IVA data have strong seasonal features and were seasonally adjusted using the X12 method.

4.2 Methodology

4.2.1 Quantification of the PPP regulation degree

To calculate the unregulated PPP (P_g) and quantify the PPP regulation degree (V_c), we follow the model of "cost + profit" in Wang et al. (2019), in which the studied time horizon is divided into $N(n \in N)$ intervals, the relationship between petroleum product (in the case of #93 gasoline P_g) price and the world crude oil price (P_o) is presented in Eq. (1) based on a "production cost + profit" model:

$$\begin{aligned} P_{gt} &= \frac{\overline{P_g^n}}{\alpha\overline{P_g^n} + \gamma\overline{P^n}}\left(P_{ot} + R\right) + C_t + \beta_t\frac{\overline{P_g^n}}{\alpha\overline{P_g^n} + \gamma\bar{c}}\left(P_{ot} + R\right) + C_t \\ &= (1 + \beta_t)\frac{\overline{P_g^n}}{\alpha\overline{P_g^n} + \gamma\overline{P^n}}\left(P_{ot} + R\right) + C_t \end{aligned} \tag{1}$$

where P_{gt} is the gasoline price at time t; $\overline{P_g^n}$ is the average price of gasoline in the nth period, R is the import tariff rate; $\overline{P^n}$ is a vector of the average prices of other products, including diesel, heavy oil, kerosene, and naphtha, in the nth period; β_t is the profit-cost ratio of gasoline; $\frac{\overline{P_g^n}}{\alpha\overline{P_g^n}+\gamma\overline{P^n}}$ is the percentage of gasoline cost attributed to crude oil; P_{ot} is the crude oil price at time t; α is the unit of gasoline, and γ (a vector 1×4) are the units of other oil products, which can be produced from one unit of crude oil; C_t is the cost of capital and tax associated with per unit of gasoline.

The government can regulate gasoline prices by changing the profit-cost ratio, β_t. P_{gt} is free of regulation as β_t equals the normal industrial profit-cost ratio; otherwise, it is considered a regulated price. Note that β_t is negative when the government subsidizes the producers of petroleum products.

The regulatory effect of the PPP is quantified as follows: First, the price of petroleum products without regulation, P_{gt} is calculated according to Eq. (1) by adopting the average sectoral profit-cost rates at different time intervals. Second, the observed data on gasoline price P_t, which contains PPP regulation effects, were obtained from the NDRC. The degree of PPP regulation was quantified as follows:

$$V_{ct} = P_t - P_{gt} \tag{2}$$

Therefore, the PPP regulation was effective as long as $V_{ct} \neq 0$. If $V_{ct} < 0$, the regulation lowers the price of petroleum products. In contrast, regulations increase prices.

4.2.2 Filtration of fiscal and monetary policies

External shocks in international oil markets inevitably trigger many government reactions through monetary and fiscal policies (Dong et al. 2019) because monetary policy aims to maintain price stability to promote economic growth, maximize employment, and achieve a balance of payments equilibrium (Zhang 2009).

Macroeconomic variables, particularly fiscal and monetary variables, are inevitably affected by macroeconomic policies (Dong et al. 2019). Government expenditure and revenue are the most critical fiscal policy instruments, whereas money supply and interest rates are common means of monetary policy. Empirical studies typically use government expenditure and money supply ($M1$) to represent fiscal and monetary policies, respectively (Iwayemi and Fowowe 2011; Du et al. 2010; Dong et al. 2019).

The effects of fiscal and monetary policies are filtered out when the impact of other policies on a given indicator are analyzed. For this purpose, the variables INV, IVA, and PPI are regressed over the explanatory variable $M1$ and fiscal expenditure using the ordinary least squares method, according to Wooldridge (2009). In the context of the Chinese economy, the time lag of fiscal policy is about 4 months, and that of monetary policy is about 3 months (Hao 2004; Bai and Li 2010). Moreover, because INV, IVA, and expenditures have a common trend, time t was added to the model to avoid a "spurious regression.” Thus, this study formulates Eqs. (3) and (4) to identify the effects of fiscal and monetary policies, respectively.

$$\mathrm{INV}_t = \alpha_0 + \alpha_1 \mathrm{Expenditure}_{(t-4)} + \alpha_2 M1_{t-3} + \alpha_3 t + \mu_t (t = 1, 2, \ldots, T) \tag{3}$$

$$\mathrm{IVA}_t = \beta_0 + \beta_1 \mathrm{Expenditure}_{(t-4)} + \beta_2 M1_{t-3} + \beta_3 t + \vartheta_t (t = 1, 2, \ldots, T) \tag{4}$$

where INV_t and IVA_t are the completed fixed asset investment (representing investment activity) and industrial value added (representing industrial output), respectively. $\mathrm{Expenditure}_{(t-4)}$, $M1_{t-3}$ and t are the four-lag term of Expenditure, the three-lag term of $M1$, and the time, respectively; α_i and β_i are the corresponding coefficients. Moreover, μ_t and ϑ_t are the residuals representing the macroeconomic indicators free of fiscal and monetary effects.

For the PPI, the time lag for fiscal policy is approximately 4 months, and the time lag for monetary policy is approximately 10 months (Bai and Li 2010; Hao 2004). Thus, PPI is regressed over Expenditure and $M1$, according to Eq. (5).

$$\mathrm{PPI}_t = \gamma_0 + \gamma_1 \mathrm{Expenditure}_{t-4} + \gamma_2 M1_{t-10} + \gamma_3 t + \varepsilon_t (t = 1, 2, \ldots, T) \tag{5}$$

where PPI is producer price index (representing inflation) and the current value of $M1$(money supply); $\mathrm{Expenditure}_{(t-4)}$, $M1_{t-10}$ and t and are the four-lags term of Expenditure, the 10-lags term of $M1$ and the time, respectively; γ_i are the corresponding coefficients; ε_t is the residual representing the PPI free of $M1$.

Thus, Eqs. (3)–(5) can be used to filter the fiscal and monetary policy effects on macroeconomic indicators (INV, IVA, and PPI).

4.2.3 SVAR model

The SVAR model can capture the contemporaneous causal relationships between the economic variables in the system and test the impact of the degree of PPP regulation (V_c) on the macroeconomic indicators of the six variables.

Specifically, the SVAR model is expressed as:

$$B_0 Y_t = \Gamma_0 + \sum_{i=1}^{p} \Gamma_i Y_{t-i} + \varepsilon_t (t = 1, \ldots, T) \tag{6}$$

where B_0 is an $N \times N$ coefficient matrix representing the contemporaneous causal relationships among the economic variables. Y_t is a column vector containing N economic variables, expressed as $Y_t = [y_{1t}, y_{2t}, \ldots, y_{Nt}]'$. Γ_0 and Γ_i represent an N-dimensional constant column vector and a coefficient matrix of $N \times N$, respectively. ε_t is an N-dimensional column vector representing the perturbations of the economic variables, which are independent of each other (Kilian 2011).

Multiplying B_0^{-1} to the both hand sides of Eq. (6) yields:

$$Y_t = B_0^{-1}\Gamma_0 + \sum_{i=1}^{p} B_0^{-1}\Gamma_i Y_{t-i} + B_0^{-1}\varepsilon_t \tag{7}$$

Letting $B_0^{-1}\Gamma_0 = A_0$, $B_0^{-1}\Gamma_i = A_i$, and $B_0^{-1}\varepsilon_t = u_t$, Eq. (7) is modified as:

$$Y_t = A_0 + \sum_{i=1}^{p} A_i Y_{t-i} + u_t \tag{8}$$

The SVAR model is obtained using constraints, including the identification of the disturbance of each variable. Once the SVAR is identified, the impulse response functions (IRFs) can be obtained in terms of structural parameters. The IRF indicates how each variable in the system responds to shocks from another variable. This results in a better way of summarizing the dynamic causal relationships among the variables. Moreover, IRF is appropriate for studying the role of PPP regulation when the macroeconomy is impacted by WCOP shocks.

The impulse response functions (IRFs) are specified as Eq. (9):

$$\begin{bmatrix} y_{1,t} \\ y_{2,t} \\ y_{3,t} \\ y_{4,t} \\ y_{5,t} \\ y_{6,t} \end{bmatrix} = \begin{bmatrix} c_{01} \\ c_{02} \\ c_{03} \\ c_{04} \\ c_{05} \\ c_{06} \end{bmatrix} \sum_{i=0}^{\infty} \begin{bmatrix} \pi_{11}(i) & \pi_{12}(i) & \pi_{13}(i) & \pi_{14}(i) & \pi_{15}(i) & \pi_{16}(i) \\ \pi_{21}(i) & \pi_{22}(i) & \pi_{23}(i) & \pi_{24}(i) & \pi_{25}(i) & \pi_{26}(i) \\ \pi_{31}(i) & \pi_{32}(i) & \pi_{33}(i) & \pi_{34}(i) & \pi_{35}(i) & \pi_{36}(i) \\ \pi_{41}(i) & \pi_{42}(i) & \pi_{43}(i) & \pi_{44}(i) & \pi_{45}(i) & \pi_{46}(i) \\ \pi_{51}(i) & \pi_{52}(i) & \pi_{53}(i) & \pi_{54}(i) & \pi_{55}(i) & \pi_{56}(i) \\ \pi_{61}(i) & \pi_{62}(i) & \pi_{63}(i) & \pi_{64}(i) & \pi_{65}(i) & \pi_{66}(i) \end{bmatrix} \cdot \begin{bmatrix} \varepsilon_{1,t-i} \\ \varepsilon_{2,t-i} \\ \varepsilon_{3,t-i} \\ \varepsilon_{4,t-i} \\ \varepsilon_{5,t-i} \\ \varepsilon_{6,t-i} \end{bmatrix} \tag{9}$$

where $\pi_{12}(i)$, for example, represents the marginal effect of shock ε_2 of i periods ago (or contemporaneous if $i=0$) on y_1. When plotted over periods i, $\pi_{12}(i)$ represents the total marginal effect of y_2 on y_1 over time in the IRF.

5 Results and discussion

5.1 Stationarity test of data

The Dickey-Fuller generalized least squares (DF-GLS) method was applied to test stationarity, a prerequisite for building an SVAR model. It is an updated alternative to the DF test proposed by Elliott et al. (1996), and its power is significantly higher than that of other versions of the DF test (Zhang and Bai 2005). Moreover, compared to the Bayesian information criterion (BIC), the modified Akaike information criterion (MAIC) used in this study tends to choose more lagged terms, which can significantly improve the stationarity test (Ng and Perron 2001).

Table 1 shows that, first, all nine variables are nonstationary. Second, the first-order differences of INV and $M1$ reject the null hypothesis that there exists a unit root at the 5% significance level, while those of the other variables reject the null hypothesis that there is a unit root at the 1% significance level; that is, they are all $I(1)$ variables. Because all variables are single first-order integrals, conducting a cointegration test before estimating the SVAR model is unnecessary.

5.2 Empirical results

The empirical analysis comprises three steps: quantification of the degree of PPP regulation, filtration of the effects of fiscal and monetary policies on INV, IVA, and

Table 1 Results of the stationarity test

Variables	Differential times	Lag order	DF-GLS test statistic	1%critical value	5%critical value	10%critical value
P_o	0	1	− 1.915	− 2.953	− 2.800	− 2.663
	1	1	− 5.354	− 3.494	− 2.953	− 2.644
P_t	0	1	− 0.951	− 3.495	− 2.959	− 2.669
	1	0	− 10.547	− 3.495	− 2.959	− 2.669
P_{gt}	0	1	− 1.478	− 3.495	− 2.959	− 2.669
	1	0	− 8.245	− 3.495	− 2.959	− 2.669
V_c	0	1	− 2.247	− 3.492	− 2.953	− 2.663
	1	1	− 7.551	− 3.494	− 2.953	− 2.664
INV	0	12	2.124	− 3.492	− 2.816	− 2.538
	1	13	− 3.145	− 3.512	− 2.973	− 2.638
IVA	0	12	− 0.758	− 3.508	− 2.970	− 2.680
	1	2	− 5.357	− 3.497	− 2.961	− 2.671
PPI	0	3	− 1.875	− 3.497	− 2.961	− 2.671
	1	1	− 4.854	− 3.496	− 2.960	− 2.670
M1	0	12	1.485	− 2.577	− 1.9425	− 1.6156
	1	12	− 2.374	− 2.576	− 1.9424	− 1.6157
Expenditure	0	11	− 0.614	− 3.507	− 2.969	− 2.679
	1	11	− 3.842	− 3.496	− 2.830	− 2.551

PPI; and estimation of the degree of PPP regulation on macroeconomic variables when encountering WCOP shocks.

5.2.1 Quantification of PPP regulation degree

In Fig. 3, P_o is the WCOP in yuan/tonne, P_{gt} is the unregulated PPP estimated according to Eq. (1) and P_t is the observed PPP. The degree of PPP regulation V_{ct}, was calculated as the difference between P_t and the P_{gt}.

As shown in Fig. 3, P_{gt}, P_t, and P_o exhibit similar trends. Unregulated PPPs tend to have volatilities identical to those of WCOP. The observed PPP (P_t) followed a trend of lower similarity to that of P_o and P_{gt}. It is clear that the volatility of P_t is much smaller than those of P_o and P_{gt} in terms of amplitude. In other words, the volatility of P_t is much lower than those of P_o and P_{gt}.

Moreover, the Pt curve of P_t revealed that P_t occasionally remained unchanged for two or more periods, especially before 2012, indicating that V_{ct} (PPP regulation degree) remained unchanged during this period. This phenomenon is the result of differences in regulation. From January 2001 to May 2009, the prices of petroleum products were subject to regulations under the condition that P_o changed at a rate of greater than 8%. The P_t was allowed to fluctuate within a fixed range; otherwise, it was considered moderately regulated. On May 7, 2009, the National Development and Reform Commission (NDRC) promulgated the "Oil Price Management Measures," which illustrated that the plant gate prices and retail benchmark prices of petroleum products were subject to regulation when the average oil price of the Brent, Dubai, and Minas markets changed by a rate greater than 4% for 22 consecutive working days. From March 26, 2013, the regulation period was shortened to 10 days, and the threshold for a 4% price change, as required for regulation, was removed. In particular, P_t is free of regulation, as P_t is less than 50 yuan/tonne, but the change in P_t is accumulatively accounted for in the subsequent price regulation. Thus, P_t remained constant for some time.

PPP regulation V_{ct} is calculated according to Eq. (2): As shown in Fig. 3, the PPP regulation takes effect most of the time ($V_{ct} \neq 0$).

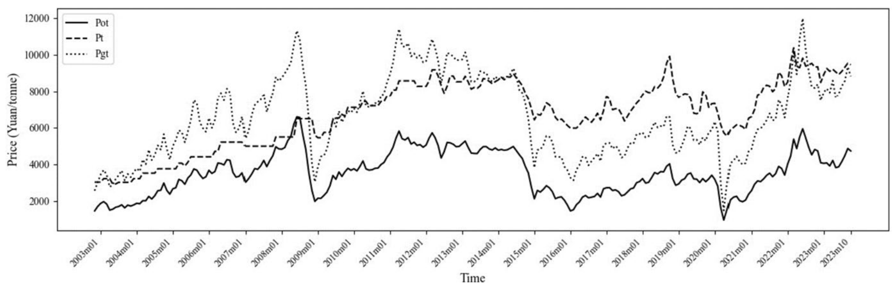

Fig. 3 The volatilities of fuel prices. Source: US Energy Information Administration (P_o), NBSC P_t

Table 2 Estimated results

Variable	INV	IVA	PPI
$Expenditure_{(t-4)}$	8.14^{***}	0.57^{***}	3.63E−06
	(2.91)	(0.21)	(1.97−05)
$M1_{t-3}$	0.76^{***}	8.07^{***}	
	(0.04)	(0.59)	
$M1_{t-10}$			0.38^{*}
			(0.21)
t	0.01^{***}	3.52^{***}	-0.02^{***}
	(0.0012)	(1.38)	(0.0021)
Constant term	− 85.60	− 76.12	0.38^{***}
	(771.48)	(95.08)	(0.14)

Values in parentheses are standard errors. INV, IVA, and PPI are the macroeconomic variables representing investment activity, output, and inflation, respectively. $Expenditure_{(t-4)}$, $M1_{t-3}$, $M1_{t-10}$ and t represents the lag terms of Expenditure, $M1$ and time, respectively. Data were obtained from NBSC and PBOC. *, **, and *** indicate 10%, 5%, and 1% significance levels, respectively

5.2.2 Filtration of the macroeconomic effects of fiscal and monetary policies

To filter the macroeconomic effects of fiscal and monetary policies, Eqs. (3)–(5) are estimated and the results are presented in Table 2. The coefficients of $Expenditure_{(t-4)}$ and $M1_{t-3}$ on INV and IVA are statistically significant at the 1% level. An approximately 1% increase in the $Expenditure_{(t-4)}$ resulted in a corresponding increase of 8.14% in INV, 0.57% in IVA, and 3.63E-06% in PPI. A 1% increase in the $M1_{t-3}$ led to a rise of 0.76% in INV and 8.07% in IVA. Similarly, the coefficient of $M1_{t\text{-}10}$ on PPI is significant at the 10% level, indicating that a 1% increase in $M1_{t\text{-}10}$ leads to a PPI increase of 0.38%. Additionally, variable t has a positive relationship with INV and IVA and a negative relationship with PPI, and their estimated coefficients are statistically significant at the 1% level.

The findings of this study are consistent with Keynesian economic theory, showing that fiscal expenditure is a vital component of fiscal policy. Incremental fiscal spending stimulates economic activity and fosters growth in investment and output, with a relatively lower impact on PPI. As a key reference for monetary policy, PPI is directly influenced by changes in money supply. Expansionary monetary policies, characterized by an increase in money supply, guide capital allocation and impact businesses and households' financing and investment decisions. This, in turn, stimulates investment and output growth.

The estimated results indicate that variations in INV, IVA, and PPI contain the impacts of fiscal and monetary policies and should be filtered. Based on the regression results, the macroeconomic variables without policy effects were estimated in terms of residuals.

5.2.3 Macroeconomic effects of PPP regulation

In the SVAR model, the optimal lag order of each variable was identified using the Akaike Information Criterion (AIC) and Schwarz Information Criterion (SIC). According to the AIC and SC, the optimal lag order of the SVAR is two. Furthermore, the absolute reciprocal of the eigenvalue of the characteristic equation of the estimated SVAR model lies within the unit circle, indicating that the model is stable.

The impulse response function (IRF) analysis method was used to describe the response of an endogenous variable to the impact of a standard error, as revealed by the effects of a shock equal to the standard deviation of the random error term on the current and future values of the endogenous variable. We consider an active role of PPP regulation in the system, i.e., PPP regulation degree (V_c) responds in contemporaneous time to WCOP (P_o). Then the unregulated PPP (P_t) appears, followed by macroeconomic variables: PPI, INV, and IVA, resulting in a Cholesky ordering of $P_o \rightarrow V_c \rightarrow P_t \rightarrow$ PPI $\rightarrow$ INV $\rightarrow$ IVA. The economic rationale behind this identification scheme is that the P_t is regulated by considering the state of the Chinese economy and the variations in P_o.

In Fig. 4, the horizontal axis represents the period of the impulse response and the vertical axis represents the reaction degree of the response. The solid line represents the impulse response function, while the dashed line represents the standard deviation band (±2S. E).

In Panel a of Fig. 4, for a given shock of P_o, V_c falls sharply and reaches a negative maximum (−297.8775 yuan/tonne) in contemporaneous time but rises sharply to axis 0 one period later and dies out within two periods. This response was statistically significant during the contemporaneous periods. China's PPP regulation responds positively and quickly to the shock of P_o fluctuations, attenuating to zero within two periods.

Panel b of Fig. 4 shows the response of P_t to P_o, which is positive and statistically significant over the first three periods. After a positive standard innovation shock of P_o to P_t, the response of P_t reached its maximum value (195.2532 yuan/tonne) at the contemporaneous time. Subsequently, the influence of each period declined rapidly and approached the 0-axis from the fourth period, indicating that China's PPP regulation on PPP was a positive and effective effect on PPP.

Figure 4c shows the response of P_t to V_c, which was positive and reached its maximum value (178.3725 yuan/tonne) during the 1st period. This response falls sharply to a negative maximum (−54.4571 yuan/tonne) in the second month and rises to axis 0 from the sixth period onward. This response is statistically significant during the first three periods. The results show that price regulation has a considerable impact on the prices of petroleum products in the first two periods, and that this impact on petroleum products dies out within several periods. It can be said that the role of price regulation policy in regulating the PPP is exceptionally rapid, and the time lag of the price regulation policy is relatively short.

Panels d–f in Fig. 4 reveal how P_t shock affects the three variables, PPI, INV, and IVA, whose effects on fiscal and monetary policies have been removed. The response of PPI to P_t shock was not statistically significant, as the IRF fluctuated around the zero axis, except that it reached its maximum value (−0.3473%) in

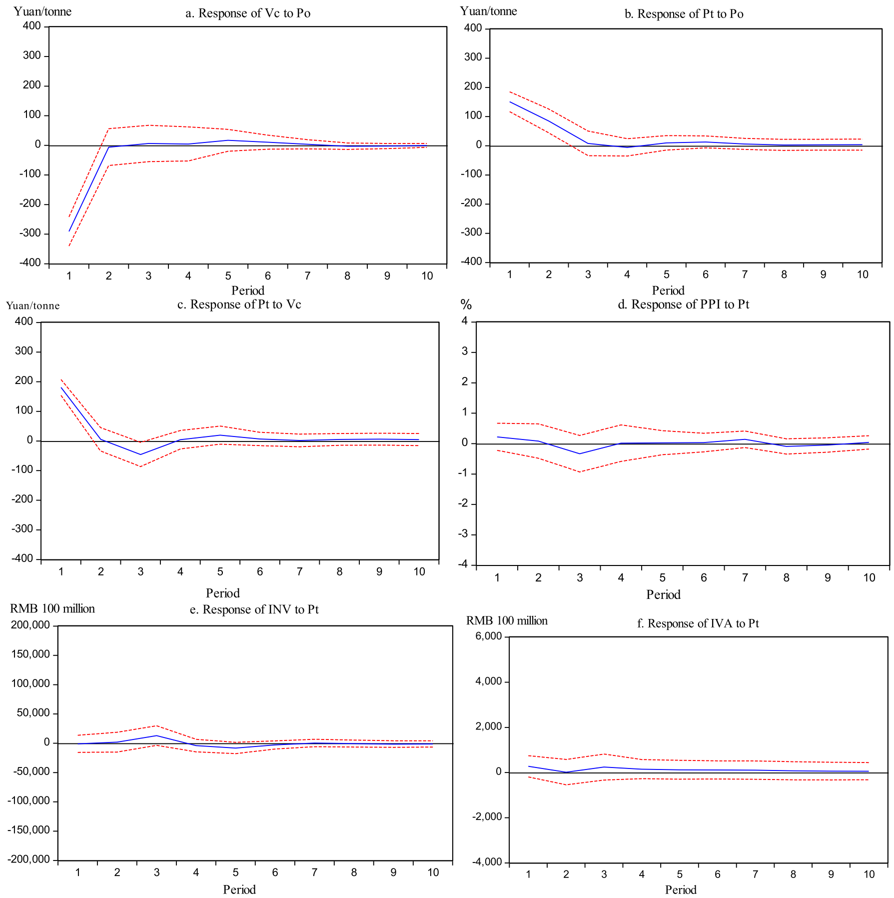

Fig. 4 Impulse response function curves. P_o, V_c, P_t are the world crude oil prices, price regulations, and observed PPP, respectively. INV, IVA, and PPI are the residuals of Eqs. (3)–(5) represent the investment, industrial value-added, and producer price indices, respectively, free of fiscal and monetary effects. Source: author's compilation

the third period. The response of INV to P_t shock was not statistically significant. After the positive standard innovation shock of P_t on INV, the IRF curve of INV almost coincides with the zero axis, indicating that P_t has little effect on INV. The response of the IVA to P_t shock is positive within two periods, but not statistically significant, reaching the maximum value (only 54.1544 RMB 100 million) in the third period and approaching the horizontal axis from the fifth period, indicating that the effect of China's PPP regulation on PPP is positive and effective.

In summary, the response of V_c to P_o was statistically significant contemporaneously, the response of P_t to P_o and the response of P_t to V_c were statistically significant within the three periods, whereas the responses of PPI, INV, and IVA to P_t shock were not statistically significant at all times.

The empirical results of this study differ significantly from those of Zhang and Xie (2016). Zhang and Xie (2016) used the domestic oil product price (DOP) to represent the results of China's oil product pricing mechanism, while the degree of PPP regulation was not quantified. Furthermore, in their counterfactual analysis, the scenario of no PPP regulations was treated by deleting domestic petroleum product prices. Consequently, the responses of PPI, INV, and IVA to WCOP shocks are reported to be positive and statistically significant by Zhang and Xie (2016). In contrast, the responses of PPI, INV, and IVA to P_t shocks were not statistically significant in this study because PPP regulation plays a vital role in alleviating WCOP volatility.

Next, we assess the robustness of the established SVAR model. Considering that the Cholesky decomposition is closely related to the sequence of variables, the results may vary significantly if the variables are sequenced differently. The robustness of the SVAR model can be tested by assuming other possible sequences of variables. Specifically, it is assumed that the mechanism follows the logic that since crude oil and its products have a large weight in PPI among the 186 investigated products covering 39 industries, PPP regulation may have a direct and significant effect on PPI and then on IVA. Fluctuations in oil prices are expected to influence investment decisions (INV) through their effects on PPI and IVA (Dong et al. 2019). In the robustness test, we adjusted the variable sequence, estimating and testing a model with the order of $P_o \rightarrow V_c \rightarrow P_t \rightarrow \text{PPI} \rightarrow \text{IVA} \rightarrow \text{INV}$. The robustness test results revealed that compared to the findings presented in Sect. 5.2.3, the impulse response curves are closely consistent with those illustrated in Fig. 4. Given this consistency, the test outcomes have not been repeatedly reported. These results further reveal that the model established in this study is robust.

5.2.4 Counterfactual analysis

Based on the above analysis, we further examine the following question: What is the effect of the government deregulating such prices? A counterfactual analysis was conducted to answer the following question: What happens to the system if the PPP regulation (V_c) is removed in a counterfactual setting? In this model, P_t is replaced by P_{gt} because there is no regulation. Thus, a model with the sequence of $P_o \rightarrow P_{gt} \rightarrow \text{PPI} \rightarrow \text{INV} \rightarrow \text{IVA}$ was estimated and tested.

Figure 5 shows, in the counterfactual scenario, how P_{gt} responds to P_o shock and how P_{gt} shocks affect PPI, INV, and IVA in the system. In Panel a of Fig. 5, the response of P_{gt} to P_o is positive and significant over a three-period horizon with the positive maximum value in the first period (402.4232 yuan/tonne), and it does not approach zero until the fourth period. In Panel b of Fig. 5, the response of PPI to P_{gt} shock is positive and significant within the 4 periods. It reaches the positive maximum value (0.0037%) in the second period and gradually approaches zero, lagging seven periods. This result reveals that the fluctuations of unregulated PPP could cause lasting impacts on domestic inflation; that is, if there is no price regulation policy, the shock of P_o will cause domestic PPI to rise and thus increase inflation. In Panel c, the response of INV to P_{gt} shock is statistically significant during Periods 2 to 3, indicating that P_{gt} has a significant impact on INV. Panel d shows that

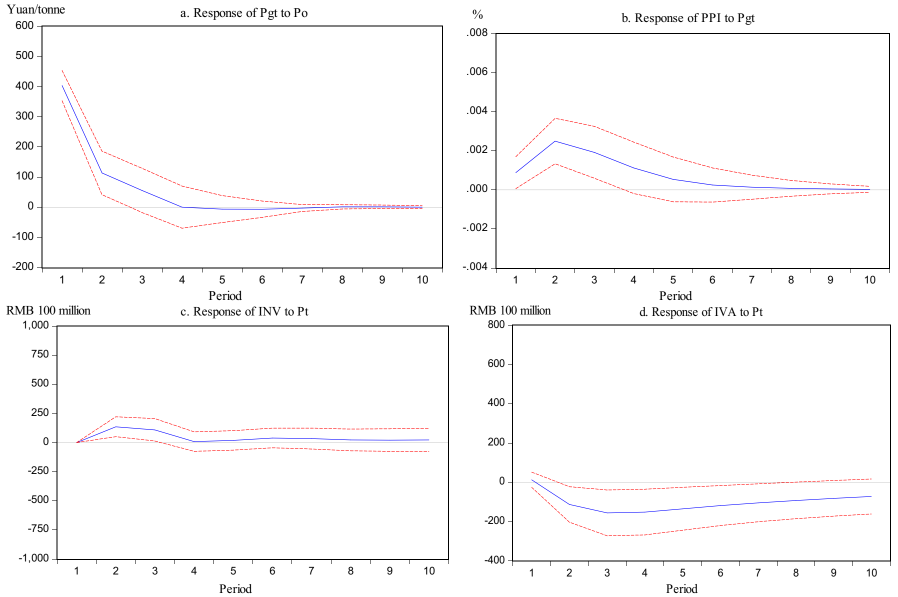

Fig. 5 Impulse response function curves in counterfactual analysis. P_o, P_{gt}, PPI, INV, and IVA represent the international oil price, unregulated refined oil price, producer price index, investment, and industrial value added, respectively. INV, IVA, and PPI are the residuals of Eqs. (3)–(5), representing investment, industrial value added, and the producer price index free of fiscal and monetary effects. Source: author's compilation

the response of IVA to P_{gt} shock is statistically significant during period 2 to 8. It reaches the maximum value (−186.2515 RMB 100 million) in the third period and gradually approaches the horizontal axis from the 8th period.

In summary, the response of P_{gt} to P_o was statistically significant for all three periods, and the responses of PPI and IVA to P_{gt} shocks were substantial in several periods.

By comparing Figs. 4 and 5, it can be seen that the response of P_t to P_o was smaller (195.2532 yuan/tonne) than that of P_{gt} to P_o (402.4232 yuan/tonne) because PPP regulation alleviated the shock of P_o contemporaneously to a great extent. This result indicates that PPP under regulation is less affected by WCOP shocks. Meanwhile, the responses of the macroeconomic indicators to P_{gt} shock are more perceptible according to the counterfactual analysis. The findings of the counterfactual analysis show that PPP regulation can effectively alleviate WCOP volatility and thus contribute to economic stability. Unlike the findings of some studies that energy price regulation plays a limited role in stabilizing the macroeconomy (e.g., Lin and Jiang 2011; Zhang and Xie 2016; Shi and Sun 2017), the findings obtained in this study are consistent with those of Dewenter and Heimeshoff (2012), Suvankulov et al. (2012), Jia and Lin (2023), and Zhang et al. (2023). In other words, PPP regulations can significantly reduce the effect of WCOP volatility on the macroeconomy.

6 Conclusion and policy implications

The market determines the prices of petroleum products but is subject to governmental regulation in China. To understand the macroeconomic effects of PPP regulation, this study first quantifies the degree of PPP regulation, which is usually absent in the existing literature. Second, we examine the role of PPP regulation in stabilizing China's macroeconomy in terms of its effects on inflation, investment, and output. Third, we analyze the impact of adopting a deregulation policy in a counterfactual scenario.

The results show the responses of V_c to P_o, P_t to P_o, and P_t to V_c are statistically significant, whereas those of the producer price index (PPI), finished fixed asset investment (INV), and industrial value added (IVA) to P_t shocks are not. Furthermore, the counterfactual analysis results show that, compared with the unregulated price P_{gt}, the regulated PPP, P_t, is less affected by shocks to P_o. In conclusion, PPP in China's market is significantly affected by the world crude oil price (WCOP), and PPP regulations effectively stabilize the macroeconomy.

The results of the study have the following policy implications. First, as a scarce and exhaustible natural resource, oil is an essential input for economic growth, but its price is affected by many uncertain events, such as political and military conflicts and economic sanctions. PPP regulation is an effective measure for managing external shocks to an economy. The role of PPP regulations in alleviating oil-induced shocks should be highlighted in the course of petroleum product pricing reform. PPP regulations can be used as policy instruments for macroeconomic stability, particularly in countries whose economies have a high degree of openness. However, the degree of regulation should be adjusted in response to the WCOP volatility. In particular, PPP regulations are better executed if combined with an early warning analysis of the international oil market and a simulation analysis of the economic impacts of the WCOP. Moreover, PPP regulations should be synchronized to respond to fluctuations in the WCOP.

Second, in addition to widely adopted fiscal and monetary policies, PPP regulation is expected to be an alternative option for controlling inflation, especially when inflation results from energy price hikes. When implemented before petroleum products are sold on the market, PPP regulations can effectively control energy-related inflation. From this perspective, it may be more effective than fiscal policies for managing energy-related inflation, although it has not been officially used as an instrument for inflation control. While currency oversupply is the direct cause of inflation, the execution of PPP regulations alone may not meet the inflation control target. Still, it can be used as a supplement to monetary policy.

Finally, one limitation of this study is that it analyzes the macroeconomic effects of PPP regulation in alleviating shocks to WCOP volatility. In terms of economic efficiency, an economic policy should be justified by assessing its effects on social welfare, particularly the external effects associated with carbon emissions from fossil fuel consumption. Thus, future studies are recommended to estimate the impact of PPP regulation on carbon emissions and social welfare and identify the optimal PPP regulation to maximize social welfare or minimize economic loss resulting from WCOP shocks.

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Declarations

Conflict of interest The authors have no relevant financial or non-financial interests to disclose.

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