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Article

A Study of the Macroeconomic Impact of Electricity Price Volatility Based on Regression Analysis

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Abstract: As a basic energy source, the price fluctuation of electricity has an important impact on macroeconomic operation. This paper adopts the DSGE model combined with regression analysis to excavate the mechanism of electricity price fluctuations on the macroeconomy. The extended DSGE model is constructed to quantify the relative contribution of electricity price shocks to macroeconomic variables. Based on the VAR model, reveal the dynamic impact path of electricity price volatility on core macroeconomic indicators. The findings show that the impact of electricity price shocks on total output ranks third, accounting for 25.91%. Increasing the electricity markup from 0.2 to 0.6, the numerical simulation finds that it will lead to an increase in electricity prices. Electricity price volatility has a significant and heterogeneous impact on the macroeconomy through the channels of cost transmission and demand adjustment.

Keywords: electricity price; macroeconomy; regression analysis; DSGE model; VAR model

1. Introduction

Electricity plays an important role in the development of the national economy, not only related to the daily life of residents, but also as a necessary factor of production into agriculture, industry and commerce and other production activities [1-4]. Although the output of China's electric power industry only accounts for 3% to 4% of the gross domestic product of electricity, but the fluctuation of electric power prices can have a huge impact on the macroeconomy, including economic impact on economic growth, inflation, international trade, etc. [5-7]. First of all, electricity price fluctuations have a direct impact on economic growth, when the price of electricity increases, the production costs of enterprises increase, resulting in a decline in corporate profits, which in turn inhibits corporate investment and expansion [8], which will further affect the growth rate of the economy. On the other hand, electricity price volatility also affects the purchasing power of consumers, when the price of electricity increases, the consumer's expenditure on electricity consumption increases, weakening their ability to consume in other areas, which in turn negatively affects economic growth [9-11].

Literature [12] analyzed the relationship between electricity prices and economic growth based on a multivariate analytical framework, and using the results of autoregressive distributional lag model, it was concluded that there is a correlation between electricity supply, economic growth, and electricity prices, and that electricity prices have a negative impact on economic growth. Literature [13] examines the impact that electricity prices have on the output of various industries and conducts an econometric analysis of the impact of electricity prices on output at the level of each industry over the same period of time and concludes with policy recommendations. Literature [14] assessed the relationship between electricity consumption, economic performance, and electricity prices in four sectors: industry, commerce, mining, and agriculture, with the aim of developing effective energy and pricing policies to encourage consumers to use energy more efficiently. Literature [15] analyzed the relationship between residential electricity demand and household disposable real gross domestic product (GDP), electricity prices, and degree of urbanization. Literature [16] discussed the causal relationship between energy prices, energy consumption and economic growth in Turkey based on a VAR model and quarterly data, and the results pointed out that there is a bi-directional causality between electricity consumption and GDP, and that there is a causality from real GDP to electricity prices.

The second is that electricity price volatility has an important impact on inflation. An increase in the price of electricity leads to an increase in the cost of production, which in turn drives up producer prices [17]. This rise is gradually passed on to consumer prices, triggering inflation, which reduces people's purchasing power and leads to a decrease in consumption, thus negatively affecting the economy [18-20]. In addition, inflation leads to currency depreciation, which further aggravates the instability of the economy, so the impact of electricity price volatility on inflation needs to attract our great attention [21-22]. Literature [23] suggests that electricity prices may be an important factor in triggering inflation, and explores the impact of wholesale electricity price shocks on inflation dynamics by analyzing the transmission after the introduction of real-time pricing (RTP) in the retail electricity market, and the results show that the transmission of electricity price shocks to inflation is faster after the introduction of RTP. Literature [24] examined the impact of electricity price fluctuations on consumer spending and inflation and came up with econometrically grounded recommendations that enable dynamic analysis to effectively regulate the economic process. Literature [25] aimed at assessing the impact of electricity prices on the overall economic price level, revealing serious inefficiencies in the market mechanism, and found that the expected correlation between electricity prices and inflation indicators is statistically insignificant. Literature [26] discusses the relationship between the exchange rate, economic growth, and the impact of inflation-induced consumption of electricity on the unemployment rate, and the results of the analysis point out that the interaction between inflation and the price of electricity exhibits a negative and statistically significant impact on the unemployment rate. Literature [27] assesses the role of supply shocks in driving inflation in the euro area, particularly energy price shocks, and the results show that energy price shocks have both direct and indirect effects on inflation.

Finally, electricity price volatility will also have an impact on international trade. Electricity is an important part of international trade, the fluctuation of electricity prices will directly affect the scale and structure of international trade [28-29]. When the price of electricity increases, the cost of imported electricity increases, which leads to the expansion of the trade deficit; on the contrary, a decrease in the price of electricity will reduce the cost of imported electricity and promote the increase of trade surplus [30-32]. Literature [33] analyzed the impact of changes in electricity prices on net FDI inflows to EU countries, and the results of the study pointed out that electricity prices are not yet harmonized between the southern and northern regions of the EU, and that labor costs, tax rates, and higher electricity prices reduce the countries' ability to attract FDI. Literature [34] analyzed the impact of renewable energy consumption, energy prices and trade on emissions in the G7 countries, and the results showed that renewable energy and prices negatively affected CO_2 emissions, while trade volumes had a significant positive impact. Literature [35] analyzed the impact of international trade, government policies, and market development on the price of solar PV modules, and the results of the study help to provide references for academic research and are also important for policy analysis.

This paper first analyzes the causes of electricity price volatility at both micro and macro levels. Price stickiness and wage stickiness are introduced to establish a DSGE model, and key parameters are calibrated through Bayesian estimation. Combining variance decomposition and impulse response analysis, the contribution of electricity price shocks relative to other exogenous factors is quantified. Obtain data on the volatile components of economic variables with the help of HP filter decomposition. Construct a VAR model to exclude seasonal factors. Smoothness test is performed on the variable data to determine the optimal lag order of the model. The model is solved using MCMC to verify the mechanism of power price fluctuations on the macroeconomy.

2. Modeling the impact of electricity price volatility on macroeconomic shocks

As an important part of China's "energy-economy-environment" system, electric power has made outstanding contributions to the sustainable development of the national economy, among which electric power price is an important economic variable concerning the national economy and people's livelihood, which affects the effective allocation of resources. In this paper, a stochastic dynamic general equilibrium model is developed to analyze the impact of electricity price shocks on China's macroeconomic effects, taking into account the realities of China.

2.1. Causes of electricity price volatility

2.1.1. Micro-level

(1) Coal-based fuel prices

At present, the main body of China's power structure is still thermal power, thermal power composition of coal power and accounted for the vast majority of the coal resources become the main supply of thermal power, so the thermal power prices are very sensitive to fluctuations in coal prices.

(2) The management level and technology of the power industry

The equipment cost, equipment utilization rate, technical ability and management level of power enterprises will be passed on to the price of electricity. Higher costs will ultimately affect the level of electricity prices, and technological advances in the power industry can reduce the input-output ratio of enterprises, which in turn reduces the level of electricity prices.

(3) Monopoly of the power industry

The power industry is a secondary energy industry with significant scale effect, and the high concentration brought by the implementation of monopoly operation can reduce the unnecessary welfare and efficiency loss, and at the same time, facilitate the regulation. However, the monopoly of the power industry also affects the level of electricity prices to a certain extent, so that the price does not reflect the real market supply and demand situation.

2.1.2. Macro-level

(1) Electricity price policy

Electric power industry as a pillar industry of the national economy, the formulation of electricity price policy has long been subject to state control. Utilizing the electricity price, the state can cooperate with the implementation of other policies and carry out the corresponding industrial structure adjustment.

(2) Economic level and residents' income

Economic development is often accompanied by an increase in power consumption, and the marginal cost of electricity production will continue to increase, thus affecting the price of electricity. Changes in residents' income will directly affect the residents' consumption habits, further affecting the demand for electricity, and ultimately lead to the price of electricity.

(3) Low-carbon policy

China's power supply type can be simply divided into thermal power and clean energy power, with the implementation of the national low-carbon policy and the people's awareness of energy saving and emission reduction, the power supply structure will also be adjusted.

2.2. Dynamic Stochastic General Equilibrium Modeling

The basic framework of the dynamic stochastic general equilibrium model constructed in this paper stems from an extended form of the Ireland model. Since the level of detail in the model portrayal is proportional to the complexity of the model, only price stickiness and wage stickiness are considered in this paper, and financial frictions are not taken into account.

There are two main ways to introduce stickiness, one is the Calvo pricing method, which assumes that a certain percentage of intermediate goods producers can optimally decide on the new price level only when they receive a “signal” of price adjustment. The second is the quadratic cost adjustment method, which reflects price stickiness by assuming that there is a penalty function, i.e. an adjustment cost, when manufacturers adjust their prices. Compared with the first method, the method of introducing price adjustment cost is relatively easy to understand. Therefore, the latter is chosen in this paper to introduce price rigidity through price adjustment costs, while drawing on the idea of Calvo pricing to introduce wage stickiness to the labor market to better simulate the stickiness in the real economic environment.

Meanwhile, since the focus of this paper is not to analyze the impact of fiscal and monetary policies on the macroeconomy, the model assumes that fiscal policy is Ricardian neutral and ignores the role of fiscal policy, while monetary policy is set as a Taylor rule that only considers the level of the interest rate, the level of output and the level of inflation.

2.2.1. Representative families

Assuming that the economy has a large and homogeneous number of households with infinite lifespans, the representative household can derive a corresponding increase in utility from higher consumption (in the presence of inertial consumption) and cash holdings, while the representative household can derive a positive utility from the enjoyment of leisure, and therefore, a negative utility from participation in labor. The decision required of the representative household is to maximize the expected value of its utility by adjusting its consumption (including electricity consumption), the amount of labor, and the amount of cash it holds, subject to the corresponding budget constraints.

$$\max_{c_t, m_t, h_t} \tilde{U} = E_0 \sum_{t=0}^{\infty} \beta^t U\left(c_t^f, \frac{m_t}{p_t}, h_t\right) \tag{1}$$

where $\tilde{U}$ denotes the utility received by the representative household, U denotes the representative household's immediate utility, E is the mathematical expectation, β is the discount factor, $0 < \beta < 1$, c_t^f denote the consumption of the final good (excluding the electricity good) by the representative household in period t, m_t is the nominal money held by the representative household in period t, $\frac{m_t}{p_t}$ is the real money held by the representative household in period t, and h_t is the supply of labor provided by the representative household in period t. The specific form of the household's immediate utility U is assumed as follows:

$$U\left(c_t^f, \frac{m_t}{p_t}, h_t\right) = \ln\left(c_t^f - bc_{t-1}^f\right) + \ln\frac{m_t}{p_t} - \frac{h_t^\xi}{\xi} \tag{2}$$

where p_t is the final product price, which reflects the price level in period t, while $\xi \geq 1$, $1/(\xi - 1)$ is the Frisch elasticity of labor supply. Thus, the effect of maximizing the requirements of representative households is finally represented by equation (3).

$$\max_{c_t, m_t, h_t} \tilde{U} = E_0 \sum_{t=0}^{\infty} \beta^t \left\{ \ln\left(c_t^f - bc_{t-1}^f\right) + \ln\frac{m_t}{p_t} - \frac{h_t^\xi}{\xi} \right\} \tag{3}$$

Incorporating the habit-forming utility function into the utility function makes the low real interest rate reflect a higher growth rate of consumption in the current period relative to the future, which also carves out a hump-like response curve for consumption that can better fit the autocorrelation of the variables and the exogenous shocks to which they are subjected in the real economic environment.

Since the representative household's current period choice is constrained by the level of wealth at the end of the previous period, which consists mainly of: money balances, bonds, wage income, corporate dividends, and one-time transfers from the government, the household's budget constraint is shown in (4):

$$c_t^f + i_t + \frac{\frac{1}{\xi} q_t e_t + \frac{b}{r_t^f} + m_t}{p_t} \leq \frac{m_{t-1} + b_{t-1} + w_t h_t + r_t^k k_t + \tau_t + d_t}{p_t} \tag{4}$$

$$i_t = k_{t+1} - (1-\delta) k_t \tag{5}$$

$$c_t = c_t^f + \frac{1-\xi}{\xi} q_t e_t \tag{6}$$

where i_t is the investment of the representative household in period t, k_t is the capital stock of the representative household in period t, with capital accumulation in the form of perpetual inventories, r_t^k the nominal capital rent rate in period t, q_t is the average price of electricity for the whole society in period t, $\frac{1}{\xi} e_t$ is the total electricity consumption of the whole society, where e_t denotes the electricity consumption of the industry, and the share of the total electricity consumption of the whole society is ξ, b_t is the number of bonds owned by the representative household at the end of period t, the market interest rate at bond maturity is r_t^f, the nominal compensation received by the representative household for providing labor is denoted by w_t, and the household also receives a lump-sum transfer τ_t from the monetary authority, and this representative household's total consumption is c_t, which consists of two components: household electricity cost expenditures and other consumption. In addition to this, the model implicitly assumes a non-Ponzi game, i.e., the present value of the household's assets (after discounting the market interest rate) must be greater than or equal to zero at infinity.

At the same time, in order to examine the macroeconomic impact of electricity price volatility, the real price of electricity is thus assumed to obey the following autoregressive process:

$$\ln\left(\frac{q_t}{p_t}\right)=\rho_q \ln\left(\frac{q_{t-1}}{p_{t-1}}\right)+(1-\rho_q)\ln(\overline{q})+\varepsilon_{qt} \tag{7}$$

where $\overline{q}$ represents the real price of electricity resources at steady state, ρ_q is the autoregressive coefficient, and $\rho_q \in [0,1)$, ε_{qt} denotes exogenous shocks to electricity prices, which follow a normal distribution with mean 0 and standard deviation σ_q, i.e., $\varepsilon_{qt} \sim N\left(0,\sigma_q^2\right)$.

The corresponding first order conditions are solved as follows:

$$\frac{1}{c_t^f - bc_{t-1}^f} - E_t \frac{b\beta}{c_{t+1}^f - bc_t^f} - \lambda_t = 0 \tag{8}$$

$$-\frac{\lambda_t}{p_t r_t^f} + \beta E_t \frac{\lambda_{t+1}}{p_{t+1}} = 0 \tag{9}$$

$$\frac{1}{p_t}\left(\frac{m_t}{p_t}\right)^{-1} + \beta E_t \frac{\lambda_{t+1}}{p_{t+1}} - \frac{\lambda_t}{p_t} = 0 \tag{10}$$

$$\beta E_t \lambda_{t+1}\left(\frac{r_{t+1}^k}{p_{t+1}} + (1-\delta)\right) - \lambda_t = 0 \tag{11}$$

where λ_t is the Lagrange multiplier whose internal meaning reflects the marginal utility of the population.

2.2.2. Labor market

Since all labor in the labor market is supplied by households, and thus households have a monopoly in the labor market, this paper assumes that there are numerous "packaged" firms in the economic environment that package all differentiated labor into a single type of labor and provide it to the intermediate goods producers in a Dixit-Stiglitz-type of aggregation. producers for the production of goods.

$$h_t = \left(\int_0^1 h_{it}^{\frac{1}{1+\lambda_h}} di\right)^{1+\lambda_h} \tag{12}$$

where λ_h is the wage markup elasticity to measure the degree of monopoly in the labor market, the larger λ_h is, the smaller the elasticity of substitution between different labors is, the smaller the wage markup is, and the higher the degree of monopoly in the labor market is. In this paper, we assume that these packaged firms (the labor intermediation market) are perfectly competitive, then their profit maximization objective is:

$$\max_{h_{it}} w_t h_t - \int_0^1 w_{it} h_{it} di \tag{13}$$

where w_t, as above, is the nominal wage level. Maximizing its profit according to equation (13) yields the nominal wage and labor demand curve:

$$w_t = \left(\int_0^1 w_{it}^{-\frac{1}{\lambda_h}} di\right)^{-\lambda_h} \tag{14}$$

$$h_{it} = \left(\frac{w_{it}}{w_t} \right)^{-\frac{\lambda_h + 1}{\lambda_h}} h_t \tag{15}$$

Referring to Calvo's setup of introducing a lagged wage contract mechanism to achieve wage stickiness, in each period, a proportion $(1-\kappa)$ of households can optimize their wage levels, leaving a proportion κ of households that cannot adjust their wage levels based on utility maximization, and these households that cannot maximize utility can only adjust their wages based on the level of inflation, $\pi_{t-1}\left(\pi_{t-1} = p_{t-1} / p_{t-2}\right)$:

$$w_{it}^{\kappa} = \left(\pi_{t-1}\right)^{\psi_h} w_{it-1}^{\kappa} \tag{16}$$

where ψ_h denotes the degree of wage indexation; when $\psi_h = 0$, the nominal wage remains constant, and when $\psi_h = 1$, the wage is fully indexed to the level of prior inflation.

Those households that can optimize the level of wages maximize their utility, and the objective function and the constraints faced by the Ω -th household that picks the optimal nominal wage w_{it}^{Ω} , for example, are as follows:

$$\max_{w_{it}^{\Omega}} E_t \sum_{s=0}^{\infty} (\beta\kappa)^s \left[\ln\left(c_{t+s}^{\Omega} - bc_{t+s-1}^{\Omega}\right) + \ln \frac{m_{t+s}^{\Omega}}{p_{t+s}} - \frac{1}{\xi} \left(\left(\frac{w_{it}^{\Omega}}{w_{t+s}} \right)^{\frac{1+\lambda_h}{\lambda_h}} h_{t+s} \right)^{\xi} \right] \tag{17}$$

$$c_{t+s}^{\Omega} + i_{t+s}^{\Omega} + \frac{\frac{1}{\xi} q_{t+s} e_{t+s}^{\Omega} + \frac{b_{t+s}^{\Omega}}{1+r^f} + m_{t+s}^{\Omega}}{p_{t+s}} \leq \frac{m_{t+s-1}^{\Omega} + b_{t+s-1}^{\Omega} + w_{it}^{\Omega} \left(\frac{w_{it}^{\Omega}}{w_{t+s}} \right)^{-\frac{1+\lambda_h}{\lambda_h}} h_{t+s} + r_{t+s}^{k} k_{t+s}^{\Omega} + \tau_{t+s}^{\Omega} + d_{t+s}^{\Omega}}{p_{t+s}} \tag{18}$$

The corresponding first order conditions are shown below:

$$\frac{w_{it}^{\Omega}}{p_t} = (1+\lambda_h) \frac{E_t \left[\sum_{s=0}^{\infty} (\beta\kappa)^s h_{it+s}^{\xi} \right]}{E_t \left[\sum_{s=0}^{\infty} (\beta\kappa)^s \left(\frac{p_{t+s-1}}{p_{t-1}} \right)^{\psi_h} \left(\frac{p_t}{p_{t+s}} \right) (h_{t+s} \lambda_{t+s}) \right]} \tag{19}$$

where λ_t is consistent with the above, let $w_{it}^{*} = w_{it}^{\Omega}$, according to Eq. (14), can be derived:

$$w_t = \left[(1-\kappa)\left(w_t^{*}\right)^{-\frac{1}{\lambda_h}} + \kappa \left(\frac{p_{t-1}}{p_{t-2}} \right)^{\psi_h} w_{t-1}^{-\frac{1}{\lambda_h}} \right]^{-\lambda_h} \tag{20}$$

2.2.3. Manufacturers

The New Keynesian DSGE model introduces the assumptions of “nominal price” and “monopolistic competition” on the basis of the dynamic stochastic general equilibrium model, and this assumption is mainly modified by modifying the setting of the original model's manufacturers' sector, which has been subdivided into the sectors of final product manufacturers and intermediate product manufacturers. This assumption enriches and refines the actors by modifying the setting of the original model's vendor sector and subdividing it into final goods producers and intermediate goods producers. Among them, final product manufacturers in a perfectly competitive market process intermediate products into final products and provide them to other economic agents; intermediate product manufacturers in a monopolistically competitive market make use of factors of production such as labor, physical capital, and electric power resources provided by representative households to produce and sell intermediate products to final product manufacturers, and in a monopolistically competitive environment, intermediate product manufacturers have a certain pricing power over intermediate products, but they do not have the right to sell them to other economic agents. intermediate goods have some pricing power, but changing prices requires payment of certain adjustment costs.

(1) Manufacturers of final products

Assume that the final product producer uses intermediate goods $y_{it}\left(i \in [0,1]\right)$ on $\left[0,1\right]$ to produce into final product y_t in a Dixit-Stiglitz type of summation, see equation (21):

$$y_t = \left\{ \int_0^1 y_{it}^{\frac{\theta-1}{\theta}} di \right\}^{\frac{\theta}{\theta-1}} \tag{21}$$

where θ is the elasticity of substitution between intermediate goods, reflecting the price markup over marginal cost.

The final product producer operates in a perfectly competitive environment with the business objective of maximizing profits subject to the constraints of (21), as shown by (22):

$$\max_{y_{it}} \Pi_t^F = p_t y_t - \int_0^1 p_{it} y_{it} di \tag{22}$$

where the final good y_t is sold at price p_t and the intermediate good y_{it} produced by the i -th intermediate good producer is sold at price p_{it} .

The corresponding first order conditions are shown below:

$$y_{it} = y_t \left\{ \frac{p_{it}}{p_t} \right\}^{-\theta} \tag{23}$$

$$p_t = \left\{ \int_0^1 p_{it}^{1-\theta} di \right\}^{\frac{1}{1-\theta}} \tag{24}$$

(2) Intermediate Goods Producers

The intermediate goods producers are monopolistically competitive, and since the products produced by each intermediate goods producer are symmetrically entered into the production function of the final goods producer, only the representative intermediate goods producer needs to be analyzed. Its production activities are carried out through capital accumulation, hiring of labor, and use of electricity resources, and it is assumed that it follows a production function of the following form:

$$y_{it} = z_t \left[\eta k_{it}^v + (1-\eta) e_{it}^v \right]^{\frac{\alpha}{v}} h_{it}^{1-\alpha} \tag{25}$$

The production function of the intermediate goods producer is a nested CES production function, where y_{it} is the output of intermediate goods and k_{it}, e_{it}, h_{it} are capital, electricity resources, and labor, respectively. The elasticity of substitution between capital and electricity is a constant $1/(1-v)$, as is the elasticity of substitution between capital, electricity, and labor. z_t reflects technological progress, and its natural logarithm obeys a stochastic process of the form AR (1):

$$\ln(z_t) = \rho_z \ln(z_{t-1}) + \varepsilon_{zt} \tag{26}$$

where ρ_z is the autoregressive coefficient and ε_{zt} is the exogenous shock to productivity, which is assumed to follow a normal distribution with mean 0 and standard deviation σ_z , i.e., $\varepsilon_{zt} \sim N(0, \sigma_z^2)$.

The intermediate goods producer, which is owned by the household, has the same production objective as the representative household, which is mainly to maximize its profit by altering the price of intermediate goods.

$$\max_{p_{it}} \Pi_t^I = E_0 \sum_{t=0}^{\infty} \beta^t \left(\frac{d_{it}}{p_t} \right) \tag{27}$$

where $\frac{d_{it}}{p_t}$ reflects the real profit received by intermediate goods producer i in period t, in the form shown in equation (28):

$$\frac{d_{it}}{p_t} = \left\{ \frac{p_{it} y_{it} - w_t h_{it} - p_t i_{it} - q_t e_{it}}{p_t} - \chi(p_{it}, p_{it-1}) \right\} \tag{28}$$

where w_t is the nominal wage, q_t is the nominal price of electricity resources, and p_t is the price level. p_{it} is the pricing of the intermediate good produced by intermediate good producer i in period t, and p_{it-1} is the pricing of the intermediate good produced by intermediate good producer i in period $t-1$.

The intermediate goods producer is subject to a quadratic adjustment cost constraint of the following form:

$$\chi(p_{it}, p_{it-1}) = \frac{\phi}{2} \left[\frac{p_{it}}{\bar{\pi} p_{it-1}} - 1 \right]^2 y_t \tag{29}$$

Where ϕ is the parameter controlling the magnitude of price adjustment, $\phi > 0$, with larger values indicating larger price adjustment costs, reflecting the existence of more pronounced price stickiness in the economic environment. $\bar{\pi}$ is the rate of inflation at steady state, which can generally be thought of as the target level of inflation set by the monetary authority (government).

The corresponding first-order conditions are shown below:

$$\begin{aligned} (1-\theta)\left(\frac{p_{it}}{p_t}\right)^{-\theta} y_t = \phi \left[\frac{p_{it}}{\bar{\pi} p_{it-1}} - 1 \right] \frac{y_t p_t}{\bar{\pi} p_{it-1}} \\ -\beta\phi E_t \left[\left(\frac{p_{it+1}}{\bar{\pi} p_{it}} - 1 \right) \frac{y_{t+1} p_t p_{it+1}}{\bar{\pi} p_{it}^2} \right] - \Xi_t \theta y_t \left(\frac{p_{it}}{p_t} \right)^{-\theta-1} \end{aligned} \tag{30}$$

$$\frac{w_t h_{it}}{p_t} = (1-\alpha)\Xi_t y_{it} \tag{31}$$

$$1 = (1-\delta)\beta + \alpha\eta\beta E_t \left\{ \Xi_{t+1} \left[\frac{y_{it+1} k_{it+1}^{v-1}}{\left(\eta k_{it+1}^v + (1-\eta) e_{it+1}^v\right)} \right] \right\} \tag{32}$$

$$\frac{q_t e_{it}^{1-v}}{p_t} = \alpha(1-\eta)\Xi_t \frac{y_{it}}{\eta k_{it}^v + (1-\eta) e_{it}^v} \tag{33}$$

where Ξ_t is the Lagrange multiplier of the constraint. Whereas equation (30) hides the New Keynesian Phillips (NKPC) curve, equation (31) reflects the marginal productivity of labor.

2.2.4. Central Bank of the Republic of China (Taiwan)

Taking into account the central bank to obtain economic information to the formulation of monetary policy and the implementation of the process of time lag, as well as the viscous economic environment, so that the implementation of monetary policy on the economy has a certain lag, in order to ensure the effectiveness of the monetary policy objectives, the central bank is required to formulate monetary policy with a certain degree of forward-looking vision.

In this paper, on the basis of the general interest rate rule, consider the Taylor rule of the last period interest rate, output growth rate, inflation rate as a monetary policy tool, the specific form is as follows:

$$\ln\left(\frac{r_t^f}{\overline{r}^f}\right) = \rho_r \ln\left(\frac{r_{t-1}^f}{\overline{r}^f}\right) + (1-\rho_r)\left[\rho_y \ln\left(\frac{y_t}{y_{t-1}}\right) + \rho_\pi \ln\left(\frac{\pi_{t+1}}{\overline{\pi}}\right) + \rho_u \ln\left(\frac{\hat{r}_t^k}{\overline{r}^k}\right)\right] + \chi_t \tag{34}$$

$$\chi_t = \rho_\chi \chi_{t-1} + \varepsilon_{rt} \tag{35}$$

The r_{t-1}^f is included in the Taylor rule, taking into account that monetary policy is adjusted incrementally in response to demand and technology adjustment shocks. where $\overline{r}^f$ is the risk-free rate at steady state and $\overline{\pi}$ is the level of inflation in the economy at steady state. This monetary policy reflects both the gradual adjustment of interest rates and forward-looking considerations of the current rate of output growth and the expected level of inflation, as well as the inclusion of the current price of capital in the examination of the current price of capital to avoid distortions in the price of capital due to monetary policy biases. The Taylor rule for interest rates also contains some other parameters, $\rho_r, \rho_y, \rho_\pi, \rho_u$ are the interest rate smoothing coefficient, the output growth rate response coefficient, the response coefficient of the inflation rate deviation from the steady state and the capital price response coefficient.

Where χ_t is the residual, which obeys the autoregressive form of AR(1), ρ_χ is the autoregressive coefficient, and ε_{rt} is the monetary policy shock, which obeys an independent normal distribution with mean 0 and standard deviation σ_r, i.e., $\varepsilon_{rt} \sim N\left(0, \sigma_r^2\right)$.

2.2.5. Equilibrium condition

(1) Symmetrical equilibrium

After the main body of the New Keynesian DSGE model is constructed, the model needs to be simplified accordingly, i.e., it is assumed that there is no information asymmetry in the model and that the decisions of all intermediate goods producers are consistent. In other words, the number of intermediate goods producers is set to be standardized to 1, and the symmetric equilibrium condition has:

$$y_{it} = y_t,\ k_{it} = k_t,\ e_{it} = e_t,\ p_{it} = p_t,\ w_{it}^* = w_t^* \tag{36}$$

(2) Currency and bond market clearing

Secondly, it is required that the currency and bond market clearing, i.e:

$$m_t = m_{t-1} + \tau_t \tag{37}$$

$$b_t = b_{t-1} = 0 \tag{38}$$

2.2.6. Market clearing

Based on symmetric equilibrium and money and bond market clearing, the constraint equation for aggregate resources can be obtained from the household budget constraint equation (4).

$$y_t = c_t + i_t + \frac{q_t}{\xi p_t} e_t + \frac{\phi}{2}\left[\frac{p_t}{\overline{\pi} p_{t-1}} - 1\right]^2 y_t \tag{39}$$

At this point, the DSGE modeling framework constructed above will have been demonstrated.

2.3. Bayesian estimation

The advantage of Bayesian estimation is that it can make the estimates of the parameters more relevant to the real economic significance of the model. In this paper, the MCMC method is used in the estimation process, based on the M algorithm with 10,000 random samples. Before estimation, the type of prior distribution of the parameters to be estimated needs to be determined. The Bayesian estimation results for each parameter are shown in Table 1. The autoregressive coefficients of exogenous shocks are all based on the Beta distribution setting a priori mean of 0.8, but all coefficients in the posterior estimation, except the coefficient of the response of the residual term of the monetary policy, are lower than the a priori mean, which suggests that some of the shocks in the real economy are weakly persistent.

Table 1. Bayesian estimation results of the DSGE model.

Parameters	Prior distribution			Posterior distribution		
	Distribution type	Mean value	Standard deviation	Mean value	Standard deviation	Posterior interval
ρ_z	Beta	0.800	0.15	0.2062	0.0897	[0.0512,0.3521]
ρ_q	Beta	0.800	0.15	0.6084	0.0723	[0.4523,0.7412]
ρ_r	Beta	0.800	0.15	0.6517	0.0689	[0.5124,0.7789]
ρ_y	Beta	0.800	0.15	0.6114	0.0752	[0.4531,0.7523]
ρ_π	Beta	0.800	0.15	0.6022	0.0718	[0.4456,0.7345]
ρ_u	Beta	0.800	0.15	0.5926	0.0734	[0.4312,0.7298]
ρ_x	Beta	0.800	0.15	0.8137	0.0521	[0.7012,0.9023]
ε_z	Inv-Gamma	0.010	0.02	0.0511	0.0089	[0.0352,0.0689]
ε_q	Inv-Gamma	0.010	0.02	0.0202	0.0034	[0.0152,0.0261]
ε_r	Inv-Gamma	0.010	0.02	0.3772	0.0421	[0.2812,0.4623]
ψ_h	Beta	0.700	0.11	0.6944	0.0652	[0.5523,0.8124]
κ	Beta	0.700	0.11	0.8936	0.0412	[0.8012,0.9523]
φ	Normal	40.000	4.25	32.4863	3.2145	[26.1234,38.9876]

2.4. Variance decomposition

Macro policy makers often focus on the impact of individual shocks on economic variables. In the following, we analyze the impulse response plots and variance decomposition results of electricity price shocks, production technology shocks, subsidy rate shocks, and sewage rate shocks on the economic variables that will independently cause the economy to fluctuate. The key economic variables considered are gross output, consumption, employment, investment, and capital stock.

Because the variables in the economic system receive shocks from various types of factors, and the results of the variance decomposition show the share of each shock in the combined variance, the impact of each shock on that economic variable can be assessed. The variance decomposition data for the impact of each shock response on the economic variables when subsidy rates and sewage rates are applied in period t are shown in Table 2. Where e_c, e_p, e_t, e_pe, e_b, and e_r represent, in order, the clean manufacturer technology shock, the polluter technology shock, the tax rate shock, the electricity price shock, the subsidized rate shock, and the interest rate shock. Clean vendor technology shocks and pollution vendor technology shocks have a greater impact on total output and are the main reasons for making output change, accounting for 58.67%, while electricity price shocks come in third place, accounting for 25.91%. Electricity price shocks are the main factor in the change in electricity use by intermediate manufacturers. The impact of electricity price shock on wages is more significant at 79.53%. This indicates that when electricity price fluctuates, it has a significant impact on the employment of workers, which is why wages fluctuate more significantly.

Table 2. Variance results of DSGE model(%).

	Economic significance	e_c	e_p	e_t	e_pe	e_b	e_r	Total
y	Output	32.48	26.19	3.45	25.91	4.22	7.75	100

c	Consumption	52.91	30.86	2.04	6.25	4.79	3.15	100
q	Environmental quality	27.83	22.48	37.12	9.45	0.15	2.97	100
k	Capital stock	62.33	22.51	3.23	1.12	2.36	8.45	100
i	Investment	50.03	24.04	2.16	20.03	3.45	0.29	100
p	General price level	49.38	28.77	4.62	5.19	3.22	8.82	100
w	Salary	9.22	6.19	0.72	79.53	0.55	3.79	100
r_k	Capital rental rate	19.02	5.24	0.76	70.18	0.43	4.37	100
y_c	Output volume of intermediate products by cleaning manufacturers	60.28	29.15	1.24	6.23	0.09	3.01	100
y_p	Output volume of intermediate products of polluting enterprises	35.33	26.75	4.12	25.77	6.84	1.19	100
E_c	Electricity consumption of cleaning contractors	9.02	0.41	0.26	60.25	23.27	6.79	100
E_p	Pollution-causing enterprises' electricity consumption	0.98	14.15	0.83	72.37	0.81	10.86	100

3. Analysis of the macroeconomic impact of electricity price volatility

In this paper, we simulate the impacts of production technology shocks and electricity price shocks on China's macroeconomy, such as consumption, investment, electricity consumption and environmental quality, and further analyze them with impulse response diagrams in Matlab.

3.1. Impulse response to the macroeconomic impact of electricity price shocks

The impact of a positive shock to the relative price of electricity on the economic variables in the system is shown in Figure 1. As the price of electricity rises, output tends to fall at the starting point and lasts for a longer period, indicating that the price of electricity has a greater impact on the total output of the economy. Moreover, the electricity consumption of clean and polluting manufacturers also declines, but the decline is greater for clean manufacturers, mainly because when the price of electricity rises, the consumption of electricity by intermediate producers declines and the quantity of intermediate products decreases, which ultimately leads to a decline in total output. In addition, this positive shock stimulates a rise followed by a fall in the capital stock. Rising electricity prices dampen consumption in the short run before stimulating positive fluctuations in consumption and then stabilizing.

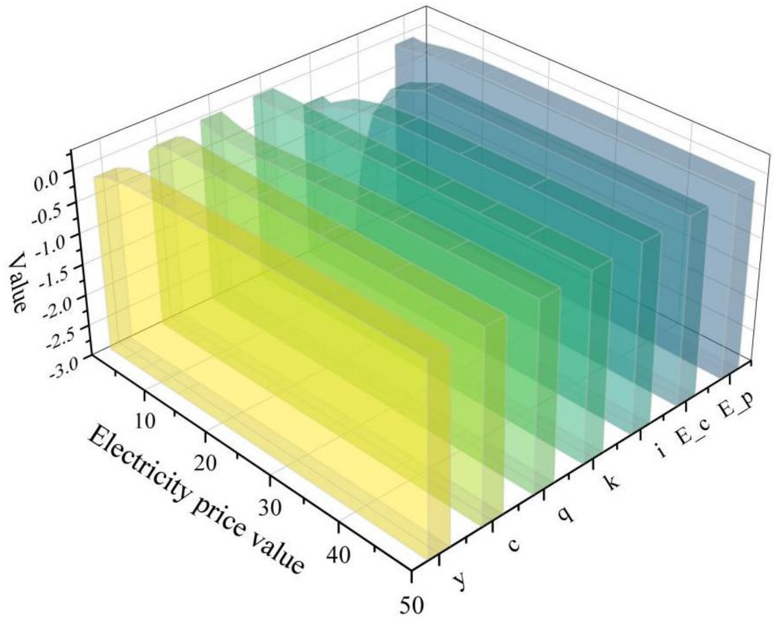


Figure 1. Impulse response of electricity price shock.

3.2. Impulse response to the macroeconomic impact of production technology shocks

The responses of the key variables to the standard deviation of the clean manufacturer's technology versus the standard deviation of the polluting manufacturer's technology are shown in Figure 2, portraying the behavior and outcomes of households and manufacturers. Observing the trend of total output, it will increase under a technology shock before converging.

Environmental quality improves under both technology shocks, but the technological progress of cleaner manufacturers clearly has a greater impact. The response of capital to the technological advances of polluting manufacturers is larger and is sharply higher. In addition, electricity consumption declines for both intermediate vendors under their respective favorable technological advances, with a larger decline for the polluting vendor. The extent of the response of capital is greater than the extent of the response of consumption, indicating that technological innovations have a great impact on the direction of capital flows, and that capital flows are the main conduit for technological innovations.

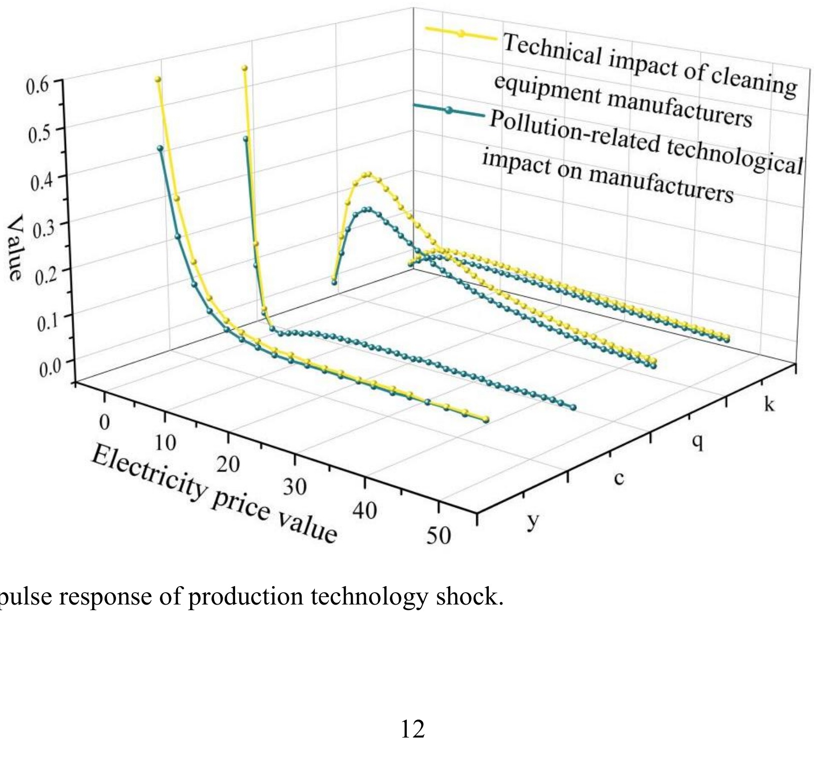


Figure 2. Impulse response of production technology shock.

4. Mechanisms for the macroeconomic impact of electricity price volatility

4.1. Modeling

4.1.1. Introduction to the VAR model

Vector Autoregressive Models (VARs) have been widely used to overcome the dilemmas of traditional econometric modeling, and are suitable for forecasting correlated time series, and for exploring changes in a system of variables caused by stochastic perturbations, so that it is possible to derive how the economic variables are shaping up and affecting the economy. The VAR model utilizes the full range of endogenous variables in the system, and extracts the lagged variables to derive a function, thus ignoring the rigidities imposed by structured models. The VAR model utilizes all the endogenous variables in the system, extracts the corresponding lagged variables to produce a function, and then constructs the model, thus ignoring the rigid requirements imposed by structured models.

The model takes the form of multiple equations, in which the lagged values of the endogenous variables in each equation are regressed to obtain the dynamic correlation between all the endogenous variables, i.e., each endogenous variable is treated as a function of the lagged values of all the endogenous variables to construct the model, and the order of lagging is determined and the parameters are estimated. The mathematical representation of the VAR(p) model is as follows:

$$y_t = A_1 y_{t-1} + A_2 y_{t-2} + \cdots + A_p y_{t-p} + Bx_t + \varepsilon \left(t = 1, 2, 3, \cdots T\right) \tag{40}$$

where p is the lag order, y_t is the endogenous variable, x_t is the exogenous variable, T is the number of samples, and ε is the disturbance vector.

4.1.2. Selection of variables

(1) Relevant Economic Variables

The economic variables such as output, consumption, employment, investment, and capital stock are not only affected by the technological shock, but also by the electricity price which lasts for a longer period of time, so the explained variables in the following are based on these five economic indicators. In order to more accurately analyze the impact of electricity price changes on China's macroeconomy, the data related to the economic variables are therefore subjected to HP filter decomposition.

(2) Electricity price variable

The price of electricity is expressed as the price index of electricity industrial products in the index of ex-factory prices of industrial products by industry, and the relevant data are obtained from the China Statistical Yearbook. At the same time, the electricity price index is logarithmized and abbreviated as INP.

4.2. Data processing and modeling preparation

Due to the limitation of the frequency of macroeconomic data, the data used in this study are monthly data from January 2024 to June 2025, which are sourced from the CEIC database, the National Bureau of Statistics, and so on.

4.2.1. Seasonal adjustment

Monthly macro data may contain seasonal factors, thus masking the objective law of the data itself, if the seasonal factors are not removed from the direct modeling, it is easy to get the wrong regression results, so the CensusX-12 adjustment method is used to seasonally adjust the industrial value added (IND) and consumer price index (CPI). Meanwhile, in order to avoid the problem of heteroskedasticity in the time series, the electricity price (EP) and CPI are processed by taking the logarithmic approach, and the industrial value added is logarithmized and then the growth rate is obtained by the first-order difference. The descriptive statistics of the processed data are shown in Table 3. It can be seen that the mean value of electricity price is 4.973, and the Jarque-Bera statistic is 20.386 and significant at the 1% level, which rejects the original hypothesis of normal distribution and conforms to the common asymmetric distribution characteristics of economic variables.

Table 3. Descriptive statistical results.

	Mean value	Maximum value	Minimum value	Standard deviation	Skewness	Kurtosis	JB statistic
EP	4.973	7.047	4.228	0.421	-0.703	2.186	20.386***
IND	0.014	0.297	-0.301	0.045	0.196	34.018	9873.145***
CPI	5.023	5.286	4.417	0.177	-0.061	1.686	19.476***

4.2.2. Stability tests

Non-stationary time series are prone to bring pseudo-regression, so it is necessary to carry out a smoothness test for variable data. In this paper, ADF test is used to carry out the unit root test to determine the smoothness of the variables, because the curve of industrial value added and consumer value index shows obvious trend characteristics, the test is selected with trend term, the test results are shown in Table 4. According to the ADF statistics and 1%, 5%, 10% significance level corresponding to the critical value can be seen, industrial value added (IND) at 1% significance level can be rejected with a unit root of the original hypothesis, the price of electricity (EP) and consumer price index (CPI) is then non-stationary. Therefore, the first-order difference treatment of EP and CPI, and then the ADF test, has met the smoothness requirements. Therefore, in the empirical analysis, the EP and CPI series after IND and differencing are used.

Table 4. Results of unit root test.

Variable	Inspection form	ADF statistic	Critical value (1%)	Critical value (5%)	Critical value (10%)	Conclusion
EP	(C,0,3)	-3.048	-4.115	-3.614	-3.225	Non-steady
DEP	(C,0,2)	-10.374	-4.115	-3.614	-3.225	Steady***
IND	(C,T,3)	-15.032	-4.382	-4.227	-3.992	Steady***
CPI	(C,T,3)	-3.755	-4.381	-4.227	-3.992	Non-steady
DCPI	(C,0,2)	-9.973	-4.115	-3.614	-3.225	Steady***

4.2.3. Selection of lag order

Before estimating the parameters of the VAR model, the optimal lag order of the model needs to be determined, and the results of lag order selection are shown in Table 5. According to the AIC quasi-measurement, it is chosen to build a VAR model with a lag order of 3.

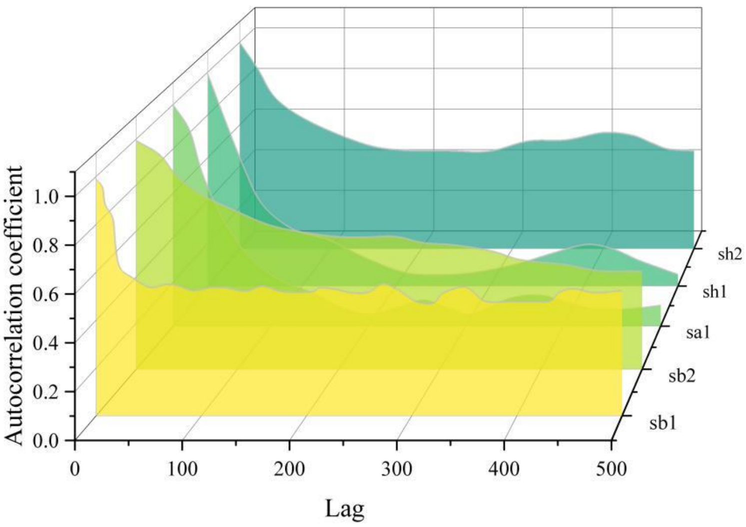
Table 5. Results of lag order selection.

Lag	LogL	LR	FPE	AIC	SC	HQ
0	2001.386	NA	0.000	-16.382	-16.154	-16.221
1	2248.183	238.901	0.000	-17.481	-17.252*	-17.324
2	2294.824	49.284	0.000	-17.748	-17.122	-17.393
3	2318.38	40.116	4.98e-13*	-17.801*	-17.013	-17.272
4	2345.43	31.058*	0.000	-17.937	-16.386	-17.371
5	2467.02	26.282	0.000	-17.826	-16.339	-17.876
6	2481.34	20.117	0.000	-17.664	-16.735	-17.442
7	2499.21	13.453	0.000	-17.038	-16.093	-17.301
8	2501.09	21.094	0.000	-17.117	-16.436	-16.526

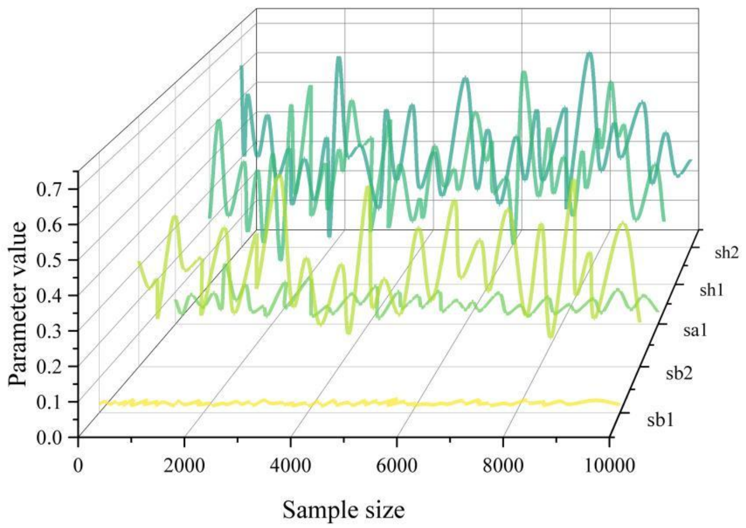
4.3. Empirical analysis

4.3.1. Model parameter estimation

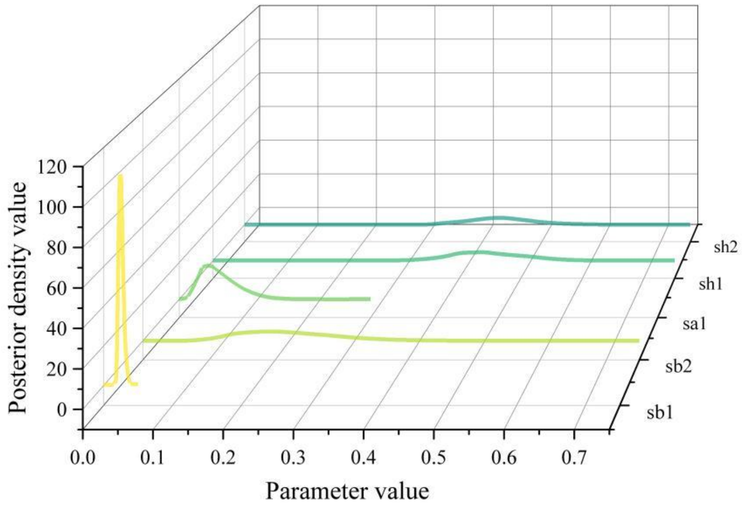
The sampling number is set to 10000 times, of which the first 800 samples are pre-burned and automatically discarded. The distributions of sample autocorrelation, sampling path and posterior density function parameters are shown in Fig. 3 (a~c), respectively. The sample autocorrelation coefficient decreases rapidly, indicating that the autocorrelation of the sample is effectively eliminated after pre-burning. The parameters basically fluctuate up and down around the mean value, proving that the parameters obtained from sampling are strongly independent. The posterior of the parameters roughly obey the normal distribution. In summary, the sampling is effective and the model setting is reasonable.



(a)Autocorrelation coefficient



(b)Sampling path

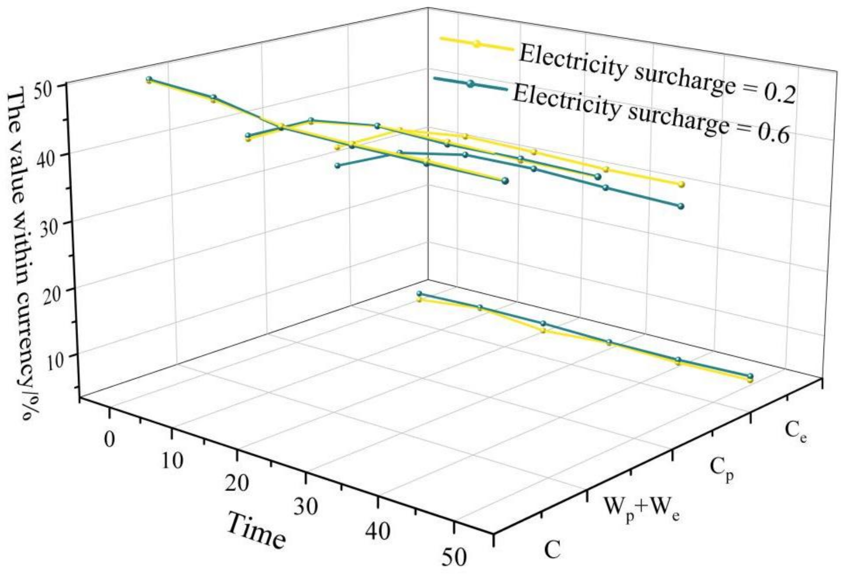


(c)Posterior density function

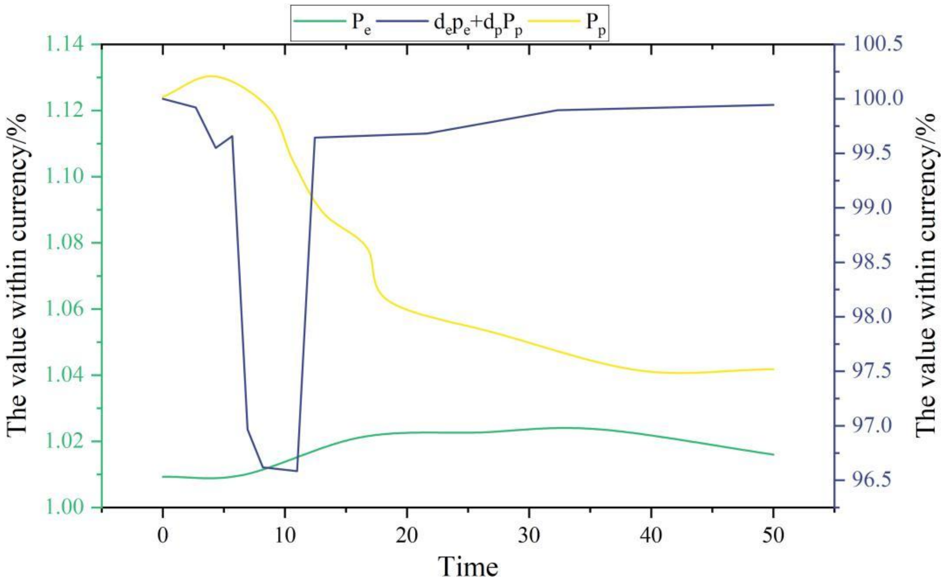
Figure 3. Distribution of Parameters.

4.3.2. Macroeconomic response to electricity price shocks

Increasing the electricity markup from 0.2 to 0.6, numerical simulations find that it will lead to an increase in electricity prices. From the immobility points calculated from the model stability analysis to initialize the model, the impact results are shown in Figure 4, with the horizontal axis indicating the timing of the exogenous increase in the electricity markup. Figure 4(a) shows that a decrease in electricity consumption leads to a decrease in demand, which in turn drives down wages, which in turn leads to a decrease in total consumption. Figure 4(b) shows that the price increase and real demand caused by the increase in the electricity markup evolve over time with a significant temporary decline that is permanent only if nominal government spending remains constant.



(a)Consumption



(b)Requirement

Figure 4. Impact results.

5. Conclusion

Through a systematic study of theoretical modeling, parameter estimation and empirical testing, this paper reveals the law and mechanism of the impact of electricity price fluctuations on the macroeconomy, and the main conclusions can be summarized as follows.

The variance decomposition shows that the clean manufacturer technology shock and the pollution manufacturer technology shock have a greater impact on the total output, accounting for 58.67%, while the electricity price shock ranks third, accounting for 25.91%. As the price of electricity increases, the output tends to decrease at the starting point and lasts for a longer period. The electricity consumption of both clean and polluting manufacturers also declined, with the decline being greater for clean manufacturers. In addition, positive shocks stimulate the capital stock to rise and then fall. The increase in electricity prices dampens residential consumption in the short run before stimulating positive fluctuations in consumption followed by a steady state. Increasing the electricity markup from 0.2 to 0.6, numerical simulations find that it will lead to an increase in the price of electricity. The decrease in electricity consumption leads to a decrease in demand, which in turn drives down wages, which in turn leads to a decrease in total consumption. The price increase and real demand caused by a rise in the electricity markup evolves over time with a significant temporary decline, which is permanent only if nominal government spending remains constant.

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