Influence of Governance and Technology on the Environment and Economy Under Dual-Carbon Target

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Abstract. As carbon emission increases significantly with the development of the economy, a series of environmental problems have occurred so far. The investigation of the dual-carbon target has become a frontier science to alleviate the contradiction between the environment and the economy. To investigate the effect of governance and technology on the environment and economy, dynamic stochastic general equilibrium (DSGE) model which is calibrated for the Chinese economy is proposed under the dual-carbon target. It can be observed from the results that technological innovation shows incentive to economic development. However, it shows differences in environmental improvement in the short and long terms, respectively. In addition, governance shows a negative influence on the economy. In order to be effective in emission reduction, governance needs to be combined with a carbon trading mechanism.

Keywords: Dual-carbon target · Dynamic stochastic general equilibrium model · Government governance · Technology innovation

1 Introduction

Industrial activities lead to a significant increase in carbon dioxide emissions. Large amount of carbon emission results in extreme weathers which shows huge effects on human survival and development. Thus, carbon emission reduction has become urgently needed at present. More than 200 countries have joined the United Nations Climate Change Conference and signed a series of agreements including the Kyoto Protocol, Copenhagen Agreement, Paris Agreement, and so on. Most of countries reduce carbon emissions to improve climate changes through cooperation [1]. In consideration of the human welfare and sustainable development, China has put forward the dual-carbon target. The increment of carbon emission can be regarded as one of the most important elements in market failure. As China is based on the conventional high-carbon economy, such circumstance severely limits the development. Thus, alleviating the contradiction between the environment and the economy has become a frontier science under the dual-carbon target.

Many scholars have carried out relevant research in the promoting low-carbon emission reduction which can be traced back to the 1970s [2]. The relevant work can be

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divided into two categories. One of the categories is to analyze the factors which affect the carbon reduction activities by constructing econometric models to provide the quantitative basis for policy formulation [3–5]. The other category focuses on the economic and environmental utility of carbon reduction policies. Through substituting the environmental factor into existed economic models, improved research follows the development of economic models. Among them, relationship between carbon emissions and economic growth was investigated through focusing on the short-term macroeconomic equilibrium from a micro perspective [6]. According to the evolutionary game model based on the game theory, behavior decisions between the corporate emission reduction and government under carbon emission reduction mechanisms were explored [7]. Owing to the basic neoclassical growth model, optimal carbon emission policy can be determined based on the main sources of uncertainty [8]. Through combining emission reduction cost equation and loss externality reduction mechanism of pollution on enterprise production with the model, relationship between carbon emissions and output was given [9]. Considering the cost of carbon emission reduction from the perspective of social welfare, Real Business Cycle (RBC) model for multiple industrial sectors was constructed. From the results, social welfare differences in environmental policies were caused by different industrial sectors with the impact of technological progress [10]. By expanding DICE and RICE categories in the integrated assessment models (IAMs) of climatic change, discount rates and the social costs of carbon emissions showed vital importance on policy implications for carbon emission reduction activities [11]. With the development of carbon emission reduction policy, potential conflict between economic development and environmental protection was highlighted [12, 13]. Many developing countries had partially alleviated the environmental pollution problem by encouraging alternative actions to reduce pollution through taxation. Thus, taxation is considered as a powerful method to alleviate the carbon emissions problem [14, 15]. Some scholars believe that technological progress can be regarded as an important factor in improving productivity and maintaining sustainable and stable economic growth under the constraints of carbon emission resources. The implementation of carbon emissions trading shows advantages to stimulate technological innovation in enterprises [16]. However, as major global emission reduction policies, carbon taxes and emission trading schemes have negative impact on the economic growth [17, 18].

Due to the difference between economic development and the industrial structure of countries, controversy is still held on the available investigations of carbon emission reduction policy [19–22]. In addition, the studies are mainly focused on the single rules-based orientation and single policy rather than the multiple interactions. The static research on policy lack of dynamic investigation which results in large social trial-and-error [23, 24]. Since China's economic development and factor utilization patterns are undergoing dynamic changes, carbon emission reduction policies show significant dynamic effects on the society and economy. The ability for responding the uncertainties in the highly complex market has become one of the most important indicators in the evaluation of policy effectiveness [25–32].

Here, economy-emission-environment dynamic stochastic general equilibrium (DSGE) model which is based on China's circumstance is proposed. Through the proposed model, environment quality and economy development can be simulated with the variation of governance and technological innovation. The main contributions can be described as follows:

1) Based on the factual characteristics of China's economy, price stickiness and investment adjustment cost are introduced to describe their potential impacts on the system. In addition, behavior path of carbon emissions is embedded into the constraint equation of representative residents' utility, enterprises' production activities and government expenditure. Such condition shows advantages in residents' pursuit of environmental quality, corporate marginal costs changes, social investment activities responses, and China's realistic institutional effects description.

2) Most of existed researches mainly focus on the productivity and policy shocks. In order to alleviate such condition, shock means can be developed by expanding the external impacts. In such circumstance, technological innovation under carbon trading activities is regarded as the shock of market emission reduction measures. Administrative emission reduction measures which can be represented by the government carbon emission reduction expenditure are employed as the governance shock. Owing to proposed method, influence of market mechanism and administrative means on the system transmission mechanism can be obtained.

From the aspect of theoretical significance, the proposed DSGE model combines both of the micro- and macro-perspectives. Meanwhile, the proposed model and calibrated parameters based on the facts in China, and carries out a bottom-up mechanism analysis of China's economic and environmental trends under the emission reduction mechanism. The results obtained from this study are not only full of economic significance, but also more in line with the reality of China.

2 Model Structure

Here, DSGE model with the environment and economy is developed with five sectors including households, intermediate goods sector, final goods sector, environmental quality sector and government. To investigate the dynamic impact of governance and enterprise technology on China's economy-emission-environment system, the variable share of output in the total government expenditures and the carbon trading cost are treated as an intermediate variable in the model. It is assumed that carbon emissions come from the production of intermediate goods. Therefore, whatever government emission reduction or carbon trading activity are incorporated in the production activities of enterprises and carbon emission function of the environmental sector.

2.1 Households

Assume a lot of homogeneous and infinitely lived households in the system. Such households maximize their lifetime utility by consuming goods, providing labor, and enjoying a good ecological environment. The utility function below:

$$U_t = M\,\mathrm{ax}E_t \sum_{t=0}^{\infty} \beta^t \left[\theta \ln(C_t) - \chi \frac{L_t^{1+\varphi}}{1+\varphi} + \gamma \ln(O_t) \right] \tag{1}$$

where E_t represents the mathematical expectation for the future values of all variables, $\beta^t \in (0, 1)$ is the subjective discount factor. C_t, L_t and O_t are current consumption level, labor input and environmental quality. θ, χ, φ, γ are consumption level, negative labor utility on households, Frisch's labor supply elasticity to actual wages, and environmental quality. In the period of t, budget constraints and capital accumulation conditions can be expressed as

$$\text{s.t.} \quad C_t + I_t + \frac{B_{t+1}}{\pi_t} + P_t O_t = w_t L_t + r_t^{\mathrm{k}} K_{t-1} + (1+R_{t-1})\frac{B_t}{\pi_t} + d_t + G_t \tag{2}$$

$$K_{t+1} = (1-\delta)K_t + I_t\left(1 - \frac{\phi}{2}\left(\frac{I_t}{I_{t-1}} - 1\right)^2\right) \tag{3}$$

where I_t is the private investment, B_t is government bonds, P_t is the price of ecological environment, w_t is wage level, d_t is the corporate dividends of residents, G_t is the environmental optimization for residents. $r_t^{\mathrm{k}} K_{t-1}$, δ and ϕ represent the capital gains, capital depreciation and investment adjustment cost parameters, respectively. $1 - (\phi/2)(I_t/I_{t-1} - 1)^2$ is the investment adjustment costs which are caused by the investment stickiness.

2.2 Final Goods Sector

The final goods market is perfectly competitive. Such sector utilizes the intermediate goods $Y_{mid,t}$ as factor input to produce the final goods Y_t, $mid \in (0, 1)$. In the circumstance, the output of the final goods sector can be obtained from the constant elasticity of substitution (CES) function

$$Y_t = \left(\int_0^1 Y_{mid,t}^{\frac{\varepsilon-1}{\varepsilon}} dmid\right)^{\frac{\varepsilon}{\varepsilon-1}} \tag{4}$$

where $\varepsilon > 1$ is the elasticity of substitution between different intermediate goods. The final goods sectors maximizing profits problem which is expressed by the function of $\max P_t Y_t - \int_0^1 P_{mid,t} Y_{mid,t} dmid$ can be solved according to the optimal first-order condition. Demand for production volume of intermediate goods sector can be obtained as

$$Y_{mid,t} = \left(\frac{P_{mid,t}}{P_t}\right)^{-\varepsilon} Y_t \tag{5}$$

Supposing that the final goods sector is with the non-profit in a perfectly competitive market, the aggregate price level in the product market can be written as

$$P_t = \left(\int_0^1 P_{mid,t}^{1-\varepsilon} dmid\right)^{\frac{1}{1-\varepsilon}} \tag{6}$$

2.3 Intermediate Goods Sector

Supposing that the intermediate goods sectors to produce intermediate goods in a monopolistic competitive market, a large amount of carbon dioxide is emitted during the production. In the closed model with no foreign sector, a representative sector's production activities are realized through the technological innovation A_t, the employed labor L_t and capital consumption K_t. The output $Y_{mid,t}$ can be given by the Cobb-Douglas production function as

$$Y_{mid,t} = A_t (K_t)^{\alpha} (L_t)^{1-\alpha} \tag{7}$$

where α and $(1-\alpha)$ denote the output elasticity of capital and labor, respectively. During the production process, the relationship between carbon dioxide emission and intermediate goods production is a positive correlation, and $\varphi (0 < \varphi < 1)$ is a comprehensive carbon emissions factor calculated according to per unit of output. In particular, the carbon emissions function can be described as follows

$$CO_{2t} = \varphi Y_{mid,t} \tag{8}$$

The innovation level of production technology A_t follows an AR(1) progress as

$$\ln A_t = \rho_a \ln(A_{t-1}) + \varepsilon_t^a \tag{9}$$

where ρ_a is the first-order autoregressive coefficient of the innovation technology shock. ε_t^a is the innovation technology shock which obeys the normal distribution as $\varepsilon_t^a \sim N\left(0, \sigma_a^2\right)$. Thus, the demand of carbon trading market quota can be given as

$$M\,\mathrm{ar}S_t = \left[\varphi - \frac{\eta(\varphi + \varphi_{rr})}{2}\right] Y_{mid,t} \tag{10}$$

where the term $[\eta(\varphi + \varphi_{rr})]Y_t \big/ 2$ represents the free carbon quota allocation. Thus, total cost minimization constraints faced by intermediate production enterprises can be given in the mathematical form as

$$\min_{K_t, L_t} TotalCo_t = w_t L_t + r_t^{\mathrm{k}} K_t + p(o)_t \left[\varphi - \frac{\eta(\varphi + \varphi_{rr})}{2}\right] Y_{mid,t} \tag{11}$$

where r_t^k, $p(o)_t$ are the prices of capital employment and carbon trading quota, respectively. The first-order conditions for optimal decision-making in intermediate sectors can be obtained through the employment of the Lagrange function and partial derivative manipulation as

$$L_t = \frac{(1-\alpha) nomc_t Y_{mid,t}}{w_t} \tag{12}$$

$$K_t = \frac{\alpha nomc_t Y_{mid,t}}{r_t^k} \tag{13}$$

$$p(o)_t = \frac{r_t^k \left(\frac{K_t}{L_t}\right)^{\alpha - 1}}{\alpha A_t \left[\varphi - \frac{\eta(\varphi + \varphi_{rr})}{2}\right]} \tag{14}$$

$$nomc_t = \frac{1}{A_t}\left(\frac{r_t^k}{\alpha}\right)^{\alpha}\left(\frac{w_t}{1-\alpha}\right)^{\alpha-1} \tag{15}$$

The actual marginal total cost of intermediate sectors including emission reduction can be given as

$$MC_t = nomc_t + p(o)_t\left[\varphi - \frac{\eta(\varphi + \varphi_{rr})}{2}\right] \tag{16}$$

where $nomc_t$ represents the actual marginal cost of each element. Since intermediate enterprises show certain pricing power in monopolistic competitive markets, maximizing profit for intermediate enterprises can be solved according to the regulation proposed by Calvo [33].

According to that regulation, σ represents the nominal price stickiness measure is introduced. There is a fixed probability $(1-\sigma)$ that intermediate sectors sell the goods with the optimal price level P* in the period of t, otherwise its price stays unchanged. The probability of changing price $(1-\sigma)$ is assumed to be independent of the time elapsed since the last adjustment. The maximizing production profits equations and constraints can be given as:

$$\max_{P_{mid,t}} E_t \sum_{i=0}^{\infty} (\beta\sigma)^i \left[\frac{P_{mid,t+i}Y_{mid,t+i} - P_{t+i}MC_{t+i}Y_{mid,t+i}}{P_{t+i}}\right] = 0 \tag{17}$$

$$\text{s.t.} \quad Y_{mid,t} = Y_t\left(\frac{P_{mid,t}}{P_t}\right)^{-\varepsilon} \tag{18}$$

Through the manipulation according to the recursive method, final general price level can be written as:

$$P_t = \left[\sigma P_{t-1}^{1-\varepsilon} + (1-\sigma)P_t^{1-\varepsilon}\right]^{\frac{1}{1-\varepsilon}} \tag{19}$$

2.4 Environmental Quality

Carbon dioxide emission brings negative externalities to society. In such circumstances, ecological environment quality shows the function of self-purification and the negative correlation with the current carbon dioxide emissions. The dynamic equation of environmental quality O_t can be given according to the method proposed by Annicchiarico and Di Dio [26] as

$$O_t = o\overset{\frown}{O} + (1-o)O_{t-1} - CO_{2t} \tag{20}$$

where $\overset{\frown}{O} \geq 0$ is the environmental quality without emissions, O_{t-1} is the environmental quality in the previous period of t-1, CO_{2t} is the total emissions in the period of t. $o(0 \leq o \leq 1)$ represents the natural attenuation rate of CO_{2t}.

2.5 Government

Supposing that government expenditure merely includes environmental governance cost which is related to output. Meanwhile, they are paid for by consumers and enterprises, given as

$$G_t = \Theta_t^g Y_t \tag{21}$$

$$G_t = P_t O_t \tag{22}$$

where Θ_t^g is the expenditure of environmental governance from a variable proportion of output, which follows an AR(1) progress

$$\Theta_t^g = (1 - \rho_\Theta)\Theta^g + \rho_\Theta \Theta_{t-1}^g + \varepsilon_t^\Theta \tag{23}$$

where ρ_Θ is the first-order autoregressive coefficient of environmental governance and ε_t^Θ is the governance shock which satisfies the normal distribution as $\varepsilon_t^\Theta \sim N\left(0, \sigma_\Theta^2\right)$. According to the Taylor rule, the government sets the nominal interest rate following as

$$R_t = \widehat{R}^{1-\rho_r}\left[(R_{t-1})^{\rho_r}\left(\frac{\pi_t}{\widehat{\pi}}\right)^{(1-\rho_r)\psi_\pi}\left(\frac{Y_t}{\widehat{Y}}\right)^{(1-\rho_r)\psi_Y}\right] \tag{24}$$

2.6 Aggregation and Market Clearing

Finally, clearing in the market can be expressed as

$$Y_t = C_t + I_t + \mathrm{G}_t \tag{25}$$

3 Model Solution and Parameterization

The parameters and steady-state of the proposed DSGE model should be determined before the calculation. Due to the externality of pollution discharge, first fundamental theorem of welfare economics is dissatisfied. Such condition results in the employment of the calibration method [9, 32]. Thus, parameters which are employed here mainly refers to the relevant research and official actual quarterly data in our country, as shown in Table 1.

Here, the approach for establishing the equilibrium model is realized through the Lagrange function to obtain the relationship between the constraint and target equations of each department. By employing the partial derivatives manipulations to each variable, the first-order conditions can be satisfied which results in the equilibrium solution of the model.

Table 1. Parameter calibrations.

	Description	Value	Source
β	Discount factor	0.99	Annicchiarico, *et al.* (2015)
θ	Elasticity of consumption	0.5	Zhang, *et al.* (2020)
χ	Elasticity of labour supply	7.5	Author's calculation
φ	Inverse of Frisch elasticity	1	Author's calculation
γ	Elasticity of environmental quality	0.2	Zhang, *et al.* (2020)
ϕ	Parameter of investment adjustment cost	2	Burnside et al. (2003)
ε	Elasticity of substitution	6	Chan, *et al.* (2020)
α	C-D parameter of capital	1/3	The convention in the literature
σ	Price parameter for nominal rigidities	3/4	The convention in the literature
Θ^g	Steady-state value of governance	0.2	Author's calculation
δ	Depreciation rate of capital	0.025	Annicchiarico, *et al.* (2015)
o	Natural decay rate	0.1	Angelopoulos, *et al.* (2013)
ρ_r	Smoothing coefficient of interest rate	0.7	Xiao, *et al.* (2021)
ψ_π	Parameter of inflation gap in Taylor rule	1.5	Xiao, *et al.* (2021)
ψ_y	Parameter of output gap in Taylor rule	0.01	Xiao, *et al.* (2021)
ρ_a	Persistence of technology shock	0.9	Xu, *et al.* (2015)
ρ_g	Persistence of governance shock	0.9	Xu, *et al.* (2015)
σ_a	Standard deviation of technology shock	0.01	Xu, *et al.* (2015)
σ_Θ	Standard deviation of governance shock	0.01	Xu, *et al.* (2015)

4 Empirical Results and Discussion

In order to analyze the dynamic properties of the economy and environment under different-oriented environment mechanism, technology and governance shocks are introduced in the proposed DSGE model. The horizontal and vertical axis represent the simulation periods and the degree of deviation from steady state.

Figure 1 shows the impulse responses of macroeconomic variables and environmental variables which are impacted by the shock of technological innovation under the carbon trading mechanism. Due to the sudden appearance of carbon-mitigation cost, instantaneous negative feedback occurs for the initial enterprise's production. Then, it rises rapidly to the peak in the 9-periods and maintains positive feedback. According to the supplied attribute of technological innovation, consumption and wages can be enlarged which results in decrement of the inflation rate. As the carbon emission still grows in short terms which is caused by high cost of technological innovation, environmental quality deteriorates in the first 30 periods. With the improvement of technological innovation, the decline in carbon emission reduces the enterprise marginal cost significantly, results in the improvement of environmental quality.

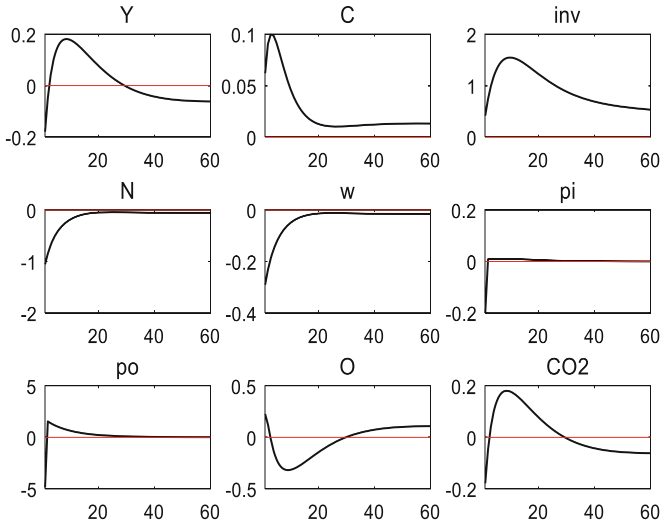

Fig. 1. Impulse response to a technology shock

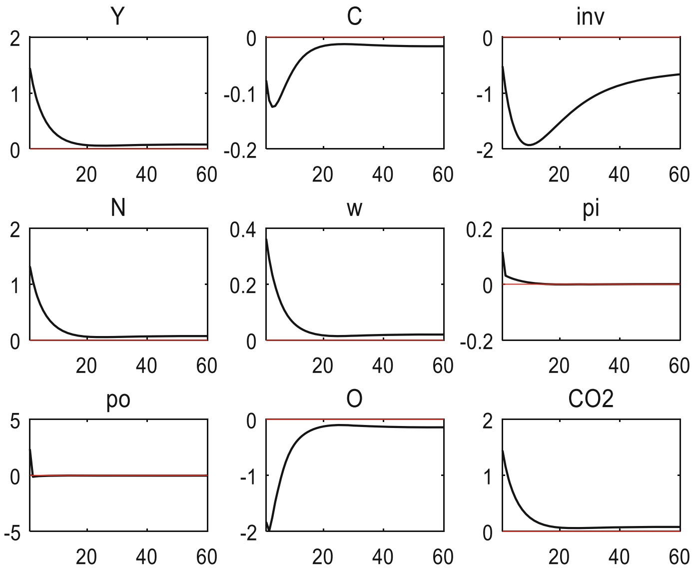

Fig. 2. Impulse response to a governance shock

Figure 2 shows the impulse responses of macroeconomic variables and environmental variables which are impacted by the shock of governance. With the positive unit governance shock, enterprise production behaviors decreasing utility in the positive feedback. The increase of government expenditure on environmental governance directly leads to a significant rise of enterprise production costs. In such circumstances, households' consumption and investment activities present different levels of a downward trend which results in the forming of serious crowding out effects. Meanwhile, it is accompanied by a rise in the rate of inflation. Thus, carbon emissions can be gradually reduced which results in the improvement of environmental quality.

5 Concluding Remarks

Here, DSGE model which is based on the China's reality is proposed to analyze the influence of governance and technology on the environment and economy in the carbon emission reduction. Time variation of the environment quality and economy development can be reflected by employing the proposed DSGE model. Through the results, several enlightenments can be obtained as follows:

Firstly, government should encourage technological innovation. From the perspective of economic development, technological improvement shows significantly promotion in outputs. Although the technological improvement shows limitation in environment quality in short term, it can significantly promote the environment development in the medium and long terms.

Secondly, the strategy of combining multiple types of carbon emission reduction measures is more conducive to alleviating the contradiction between economic development and environmental protection. The carbon trading mechanism based on carbon intensity shows advantages on technological innovation, and double dividend effect in the long-term development. In addition, it shows a significant impact on economic fluctuation in the short term. Meanwhile, it can merely improve the environmental quality. Such a condition can be further alleviated by combining the government's administrative emission reduction measures. Meanwhile, it can reduce the risks from the aspect of economic volatility in the short term.

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