Synergistic Effect of Environmental Taxes on Enterprises' Green Technology Progress: Analysis Based on Four-Sector DGE Model

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Abstract: This paper focuses on China's double carbon goal and addresses the challenges of high carbon emissions from excessive fossil fuel consumption and low energy efficiency, aiming to explore the impact mechanisms of environmental regulation with carbon tax as the core and technological progress on China's economy and environment. It constructs a dynamic general equilibrium model encompassing four sectors: household, government, polluting enterprises and non polluting enterprises as well as two systems: economic system and environmental system, with parameters calibrated based on China's actual economic data and existing literature research methods, and dynamic market clearing analysis involving administrative and market behaviors adopted for in-depth research. The study finds that increasing environmental taxes leads to U-shaped growth in residents' utility with short-term decline due to enterprises delayed technological adjustment and tax transfer while long-term improvement driven by technological progress, and environmental taxes also promote enterprises green technological innovation and output expansion; notably, the synergistic effect of environmental regulation and technological progress significantly boosts enterprise productivity, increases the production share of non polluting goods and strengthens the government's environmental governance capacity, ultimately achieving a win-win for economic development and environmental improvement. To advance the carbon peaking and carbon neutrality goals, China should prioritize tax-based environmental regulation, improve the national carbon emission monitoring and management platform, vigorously promote industrial structure upgrading, increase support for green technology research and development, expand government investment in pollution control and fully implement supporting policies to optimize the energy structure and ecological environment.

Keywords: Synergistic Effect; Environmental Regulation; Energy Saving and Emission Reduction; Dynamic General Equilibrium (DGE)

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1 Introduction

With the increase of global attention to climate change, countries have successively announced that they expect to achieve carbon neutrality ahead of schedule, and address climate change through documents or conferences such as the United Nations Framework Convention on Climate Change and the Kyoto protocol. In 2021, the Chinese government issued the Working Guidance For Carbon Dioxide Peaking And Carbon Neutrality In Full And Faithful Implementation Of The New Development Philosophy, implementing the two-stage "double carbon" goal. Due to the high intensity of carbon emissions caused by excessive consumption of fossil fuels and the low level of energy efficiency in China, adjusting environmental and economic policies and improving the industrial struc-

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ture have become the key measures to support the dual carbon goal.

The analysis method of general equilibrium is often used in systems containing multiple interacting intertemporal trading entities. Kydland and Prescott first used the dynamic stochastic general equilibrium model to consider the intertemporal decision-making of economic entities [1]. The DGE model has the characteristics of overall description of the economy and "bottom-up" modeling. It is suitable for studying impact transmission research and policy simulation. Synergy refers to that when multiple elements work together, the overall effect exceeds the sum of the effects when individual elements work alone. As important means of industrial restructuring, environmental taxes and the advancement of green technology in enterprises are particularly crucial for promoting the sustainable development of China's economy and ecological environment [2].

At present, most of the research on environmental regulation focuses on the verification of Porter hypothesis, and rarely carries out mechanism analysis from the perspective of general equilibrium. Taking carbon tax as the embodiment of environmental regulation, this paper first constructs a four sector DGE model, uses the calibration method to set parameters, and introduces the administrative and market behavior to conduct market dynamic clearing analysis, studies the impact of carbon tax and technological progress on economy and environment, verifies the synergy effect, and strives to obtain an appropriate and efficient growth mode that can promote the "win-win" of environment and economy.

2 Literature Review

The "double carbon" goal is a major strategic decision made by China based on the responsibility of promoting the construction of a community with a shared future for mankind and the internal requirements of achieving sustainable development. Under the guidance of the "double carbon" goal vision, China will vigorously promote the revolution of energy production and consumption, and explore a green economic development model that maintains industrial competitiveness, promotes sustained and stable economic growth, and strongly reduces emissions, which will not only better promote the high-quality development of China's economy, but also enable China to take the initiative in reshaping the international economic pattern [3].

Porter hypothesis believes that the main way for environmental protection policies to have an impact on the economy is to promote technological innovation of enterprises, improve the production efficiency of enterprises in the long term, and promote economic growth. This paper discusses the model from the following three aspects:

(1) Research on green technology progress caused by environmental regulation. As for the effectiveness of environmental regulation on enterprise green innovation, there are three main views in the academic community at present: "positive impact", "inhibitory effect" and "U" relationship [4]. Fischer and Springborn used RBC model to study the relationship between environmental regulation and carbon emission targets [5]. In terms of domestic related aspects, Wu Xiaoli considered energy conservation and emission reduction factors and explored the transmission mechanism between environmental regulation and ecological environment quality [6]. Zhan Lei et al. believed that China's environmental regulation intensity had a promoting effect on industrial upgrading [7].

(2) The synergy effect analysis of carbon tax and enterprise green technology progress. Carbon tax is an important way for the government to promote social and economic growth and environmental improvement. After the introduction of the carbon tax policy, enterprises follow the principle of utility maximization to adjust the structure. Li Tengteng extended the synergy theory to the field of economic management and found that the progress of green technology in enterprises has a significant positive role in promoting utility growth [8]; The higher the degree of development of environmental tax, the greater the degree of green technology progress of enterprises, and the stronger the synergistic effect on economic growth.

(3) The debate and Research on the policy of environmental regulation and green technology progress. As for the effect analysis of environmental regulation, neutral economists believe that Porter hypothesis has spatial heterogeneity and suggest that the differences of environmental regulation should be reflected according to the actual situation of the region [9]. Based on the threshold effect, Jiang Fuxin, Ji Yue and Bai Junhong proposed that the regulatory means should be enriched and the policy system should be improved [10]. In general, Porter

hypothesis believes that only strict environmental regulation can promote the progress of green technology, and can achieve the win-win goal of economic growth and environmental improvement in general.

On this basis, this paper puts forward three hypotheses:

Hypothesis 1: as an environmental regulation, the promotion of carbon tax has a U-shaped impact on Residents' utility, and the marginal utility increases first and then decreases gradually.

Hypothesis 2: technological progress will reduce the cost of enterprises, increase the output of polluting enterprises and increase the share of polluting products in the short term.

Hypothesis 3: the synergistic effect of environmental regulation and technological progress can increase the share of non polluting products, increase the investment in environmental governance and improve the production efficiency of enterprises.

This paper will verify the above hypothesis in the following part.

3 Research Design

3.1 Model Setup

In order to better meet the actual market situation and improve the resolution of the model, this paper establishes a DGE model including four departments, two systems and two behaviors. The four sectors are: household, government, polluting enterprises and non polluting enterprises; The two systems are economic system and environmental system respectively; The two behaviors are administrative behavior and market behavior.

3.1.1 Household

Suppose there are countless homogeneous families in the economic system and they can survive indefinitely. Families provide labor and capital for firms. As shown in Figure 1, the firm provides products as compensation, and uses SCES type utility function:

$$ft.util = \alpha_7[\beta_{13}(\frac{np.prod}{\beta_{13}})^{\frac{e_{s5}-1}{e_{s5}}} + \beta_{14}(\frac{p.prod}{\beta_{14}})^{\frac{e_{s5}-1}{e_{s5}}}] \quad (1)$$

Among them, α_7 is the household efficiency parameter, β_{13} is the household utility share of non polluting goods, β_{14} is the household utility share of polluting goods, and e_{s5} is the household utility substitution elasticity.

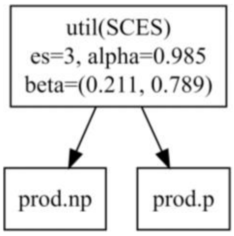

Figure 1 Representative Family Demand Structure Tree

3.1.2 Government

Based on the assumption of promising government, this paper sets the government expenditure in each period for transfer payment, energy conservation and emission reduction subsidies and pollution treatment. As shown in Figure 2, the government's revenue in each period mainly comes from enterprise income tax, output tax and other taxes. In order to measure the impact of environmental regulation on the system, this paper sets carbon tax as one of the sources of government revenue. In the demand structure, the government is regarded as a consumer, so there is a SCEs type utility function:

$$gt.util = \alpha_8[\beta_{15}(\frac{np.prod}{\beta_{15}})^{\frac{e_{s6}-1}{e_{s6}}} + \beta_{16}(\frac{p.prod}{\beta_{16}})^{\frac{e_{s6}-1}{e_{s6}}}] \quad (2)$$

β_{15} is the utility share of government's non polluting goods, β_{16} is the utility share of government's polluting goods, α_8 is the government's efficiency parameter, and e_{s6} is the substitution elasticity of government utility.

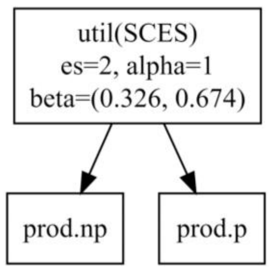

Figure 2 Government Demand Structure Tree

3.1.3 Firms

Suppose that there are homogeneous non polluting and polluting enterprises in a perfectly competitive market. Representative firms use capital and labor to produce non polluting products and polluting products. As shown in Figure 3, assuming that the manufacturer adopts Cobb-Douglas production function, there is a production function for non polluting firms:

$$pnp.va = \alpha_1 aii.np^{\beta_1} va.np^{\beta_2} \quad (3)$$

Among them, $pnp.va$ is the value of products produced by non polluting firms, $aii.np$ is the total intermediate investment of non polluting firms, and $va.np$ is the added value of non polluting firms. β_1 and β_2 are the products and endowment shares of non polluting firms respectively, and α_1 is the technical parameters of non polluting firms.

Total intermediate investment of non polluting firms:

$$ii.np = \alpha_2[\beta_3(\frac{np.prod}{\beta_3})^{\frac{e_{s1}-1}{e_{s1}}} + \beta_4(\frac{p.prod}{\beta_4})^{\frac{e_{s1}-1}{e_{s1}}}] \quad (4)$$

Among them, $np.prod$ and $p.prod$ are the quantity of non polluting products and polluting products respectively, and e_{s1} is the product substitution elasticity of non polluting firms. β_3 and β_4 are the shares of non polluting products and polluting products of non polluting firms respectively. α_2 is the production technology of non polluting firms.

Added value of non polluting firms:

$$va.np = \alpha_3[\beta_5(\frac{cap}{\beta_5})^{\frac{e_{s2}-1}{e_{s2}}} + \beta_6(\frac{lab/\varepsilon_1}{\beta_6})^{\frac{e_{s2}-1}{e_{s2}}}] \quad (5)$$

Among them, cap is capital input, lab is labor input, and e_{s2} is the endowment substitution elasticity of non polluting firms. α_3 is the endowment production technology of non polluting firms, β_5 and β_6 are the capital and labor shares of non polluting firms respectively.

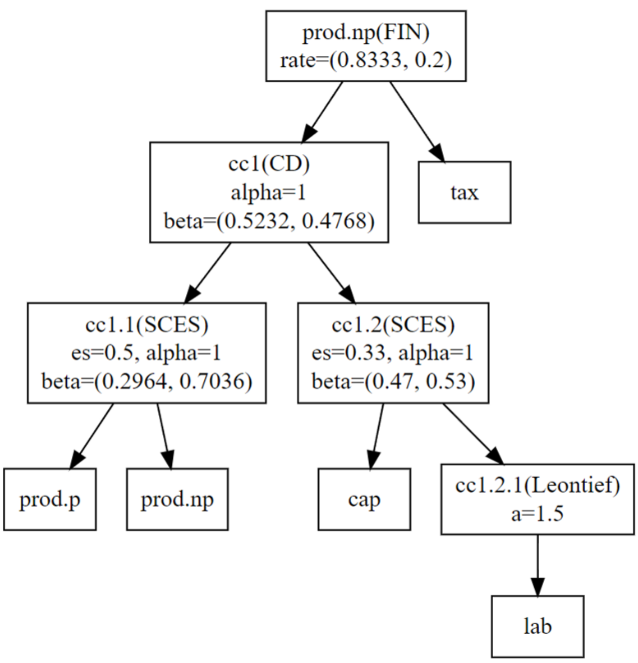

Figure 3 Non-Polluting Manufacturer Demand Tree

As shown in Figure 4, polluting firms have a preference for non polluting products compared with non polluting firms, and the demand for endowment in resource endowment is greater than that of raw materials, so polluting firms have a production function:

$$pp.va = \alpha_4 aii.p^{\beta_7} va.p^{\beta_8} \quad (6)$$

Among them, $pp.va$ is the value of products produced by polluting firms, $aii.p$ is the total intermediate investment of polluting firms, and $va.p$ is the added value of polluting firms. β_7 and β_8 are the products and endowment shares of polluting firms respectively, and α_4 is the technical parameters of polluting firms.

Total intermediate investment of polluting firms:

$$aii.p = \alpha_5[\beta_9(\frac{np.prod}{\beta_9})^{\frac{e_{s3}-1}{e_{s3}}} + \beta_{10}(\frac{p.prod}{\beta_{10}})^{\frac{e_{s3}-1}{e_{s3}}}] \quad (7)$$

Among them, e_{s3} is the product substitution elasticity of polluting firms. β_9 and β_{10} are the shares of polluting products and non polluting products of polluting firms respectively, and α_5 is the production technology level of polluting firms' products.

Added value of polluting firms:

$$va.p = \alpha_6[\beta_{11}(\frac{cap}{\beta_{11}})^{\frac{e_{s4}-1}{e_{s4}}} + \beta_{12}(\frac{lab/\varepsilon_2}{\beta_6})^{\frac{e_{s4}-1}{e_{s4}}}] \quad (8)$$

Among them, e_{s4} is the endowment substitution elasticity of polluting firms. α_6 is the production technology of polluting firms, β_{11} and β_{12} are the capital and labor shares of polluting firms respectively.

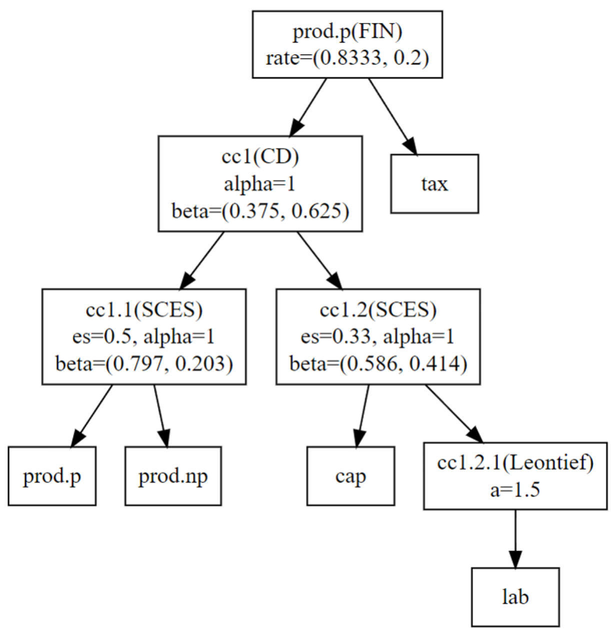

Figure 4 Polluting Manufacturer Demand Tree

3.1.4 Environmental System

The pollution of the environmental system mainly comes from the negative effects brought by the carbon emissions of enterprises and polluting products. Non polluting enterprises and non polluting products produced will bring positive effects to the environment, and part of the government tax will be used for environmental pollution treatment, which will improve the environmental system.

$$Emission = apnp.va^{\gamma_1} pp.va^{\gamma_2} (tax/d)^{\gamma_3} \tag{9}$$

Among them, $Emission$ is the carbon emission, a is the carbon emission coefficient, γ_1 is the positive effect intensity of non polluting products (γ_1>0), γ_2 is the negative effect intensity of polluting products (γ_2<0), tax is the total government tax, d is the reciprocal of the government expenditure on pollution control, and γ_3 is the intensity of pollution control.

3.1.5 Market Clearing

The economic activities of the model include the process of resource allocation and the process of production and consumption. The output comes from $pp.va$ produced by polluting firms, $pnp.va$ produced by non polluting firms, and the demand comes from $ft.util$ produced by households and $gt.util$ produced by governments. The sequential transaction assumption is made in the intertemporal model.

$$D_t = ft.util_t + gt.util_t \tag{10}$$

$$D_t = ft.util_t + gt.util_t \tag{11}$$

$$D_t = ft.util_t + gt.util_t \tag{12}$$

Where D_t represents the total demand of the model and S_t represents the total output of the model.

3.2 Calibration of Parameters

In this model, it is necessary to calibrate and analyze the parameters used, combined with China's actual economic data and existing literature processing methods to make the parameters conform to the actual situation. Table 1 shows the results of parameter calibration.

In the non polluting firms sector, using Wang Sheng's research for reference, β_1 and β_2 are set at 0.518 and 0.472 respectively, β_3 and β_4 are set at 0.326 and 0.774 [11]. Using Zhang Jun's parameters, β_5 and β_6 are set at 0.47 and 0.53 [12], and the technical parameters α_1, α_2 and α_3 are estimated at 1 by default, and e_{s1} and e_{s2} are estimated at 0.5 and 0.33 according to Bian Zhicun [13] and Sun Zhaoming [14]. According to the research of Annicchiaico and Di DIO, considering the increase of technological innovation intensity and tax incentive policies of non polluting firms in China in recent years [15], ε_1 is set to 1.5, and r_1 is initially set to 20%.

The parameters of polluting enterprises are roughly the same as those of non polluting enterprises. Since polluting firms tend to invest in factor endowments, β_7 and β_8 are set at 0.375 and 0.625, respectively. According to the research method of Zhang Jun, β_9 and β_{10} are set at 0.797 and 0.203 [12]. According to the method of Yang Ao and Liu Jixian, β_{11} and β_{12} are set at 0.586 and 0.414 [16]. α_4, α_5 and α_6 are estimated to be 1 by default. According to the research of Annicchiaico and Di DIO [15], considering the lack of technological innovation motivation of polluting firms in China and the effect of tax regulation, ε_2 is set at 2.5, and r_2 is initially set at 20%.

In the household sector, refer to the method of Liu Bin to set α_7 as 0.985 [17], refer to the method of Fuent-Albero to set β_{13} and β_{14} as 0.211 and 0.789 [18], and refer to the method of Hu Yonggang and Guo Xinqiang to set e_{s5} [19], and consider the family demand for the two products and determine it as 3.

Since there are few models that regard the government as a consumer, this paper refers to the family parameter setting and the actual situation of the government. The default value of α_8 is set to 1, referring to the method of Zhu Jun [20], β_{15} and β_{16} are set to 0.326 and 0.674, and e_{s6} is set to 2 according to the method of Hu Yonggang and Guo Xinqiang [19] combined with the government's demand for the two products.

Table 1 Calibration Estimation Results of Static Parameters

Department	Name	Symbol	Estimated Value
	Share of factors	(β1, β2)	(0.518, 0.472)
	Share of products	(β3, β4)	(0.326, 0.774)
Non-polluting firms	Share of endowment	(β5, β6)	(0.47, 0.53)
	Elasticity of substitution of factor	(es1, es2)	(0.5, 0.33)
	Vector of technology	(α1, α2, α3, ε1)	(1, 1, 1, 1.5)
polluting firms	Share of factors	(β7, β8)	(0.375, 0.625)

Department	Name	Symbol	Estimated Value
	Share of products	(β9, β10)	(0.797, 0.203)
	Share of endowment	(β11, β12)	(0.586, 0.414)
	Elasticity of substitution of factor	(es3, es4)	(0.5, 0.33)
	Vector of technology	(α4, α5, α6, ε2)	(1, 1, 1, 2.5)
	Share of utility	(β13, β14)	(0.211, 0.789)
Household	Elasticity of utility substitution	es5	3
	Efficiency parameter	α7	0.985
	Share of utility	(β15, β16)	(0.326, 0.674)
Government	Elasticity of utility substitution	es6	2
	Efficiency parameter	α8	1

4 Market Clearing Analysis

4.1 Administrative Behavior: Effect Analysis Under Impact of Carbon Tax

Figures 5 and 6 describes the market clearing path under the impact of carbon tax administrative action, which can be regarded as an approximation of the optimal path under the intertemporal decision-making sequential transaction. The impact of carbon tax on the price of each factor and output utility occurred in the fifth period. The price of polluting goods increases with the increase of tax rate, the price of capital and labor both decrease, and the proportion of tax increases. The effectiveness of government will continue to rise in the short term and then gradually stabilize.

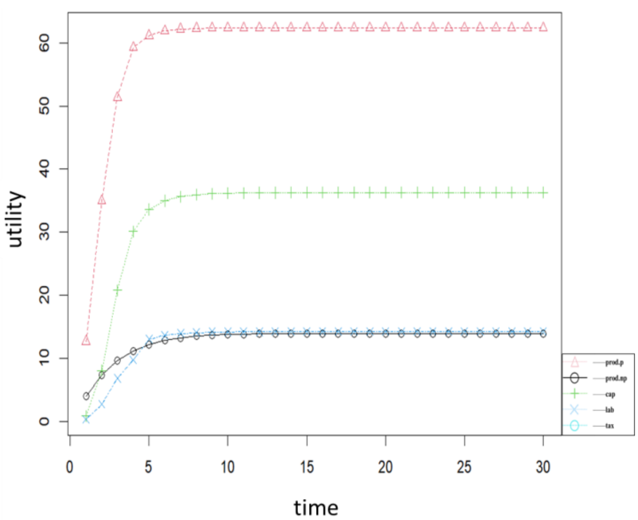

Figure 5 Utility Under the Impact of Carbon Tax

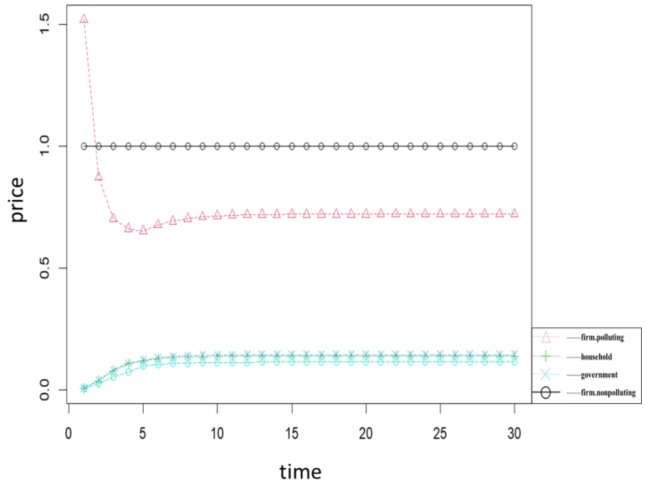

Figure 6 Price Under the Impact of Carbon Tax

In the equilibrium value demand matrix, the demand of non polluting firms for various factors of production has increased, the scale of polluting firms has continued to decline, and the demand of households and governments is more inclined to non polluting products; In the equilibrium value supply matrix, the output scale of firms has expanded, the factors of production (labor and capital) provided by households have decreased, and the government expenditure has gradually increased. In this scenario, the utility of polluting products in various sectors is reduced, and non polluting products are preferred. For firms, the output of non polluting firms is increased, while the output of polluting firms is decreased, and the utility of household residents is reduced in the short term, but in the long term, the utility curve is U-shaped, and when the tax rate reaches 28%, the time effect is almost no longer increased. Hypothesis 1 is proved.

4.2 Market Behavior: Effect Analysis Under Impact of Technological Progress

Figures 7 and 8 describes the market clearing path of the impact of technological progress on market behavior, showing that the optimal path in the intertemporal transaction is approximate. In the model, it is set as the continuous progress of labor technology and occurs in the seventh period. With technological progress, the prices of non polluting and polluting products produced by firms have declined, but the prices of labor and capital have risen slightly, the proportion of taxes has decreased, and firms have increased intermediate investment, which generally shows that the cost of firms has decreased. In the equilibrium path, the price of polluting goods first fell sharply and then retreated upward. In the process of increasing the rate of technological progress, the output of non polluting firms gradually decreases while the output of polluting firms increases, and the household utility increases while the government utility decreases.

In the equilibrium value demand matrix, the demand of non polluting firms for various factors of production has declined, while the demand of polluting firms has generally increased, the number of households for polluting goods has increased, and the government's demand for both goods has declined due to the decline in income. In the equilibrium value supply matrix, the output of non polluting goods decreased while the output of polluting goods increased, the labor and capital supplied by households increased, and the government expenditure decreased due to the reduction of income. Hypothesis 2 is proved.

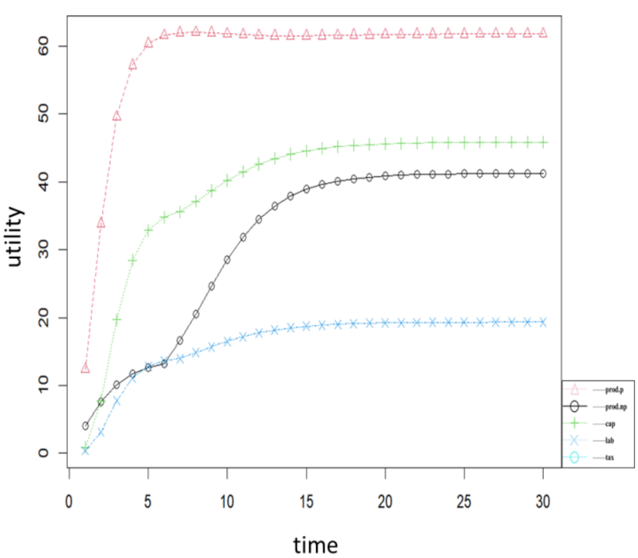

Figure 7 Utility Under Impact of technological progress

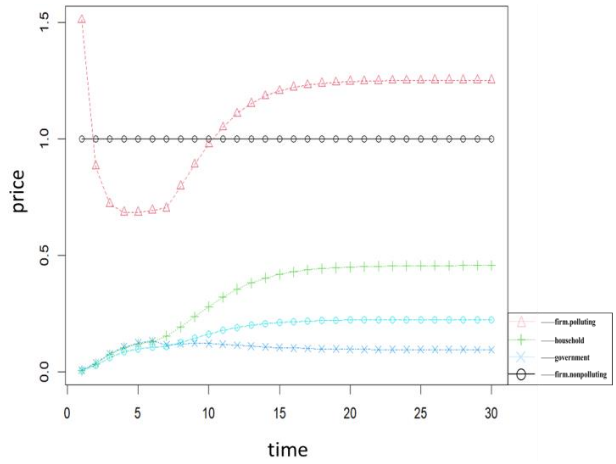

Figure 8 Price Under Impact of technological progress

4.3 Synergy Effect: Dynamic Effect Analysis of Technological Progress Caused by Carbon Tax

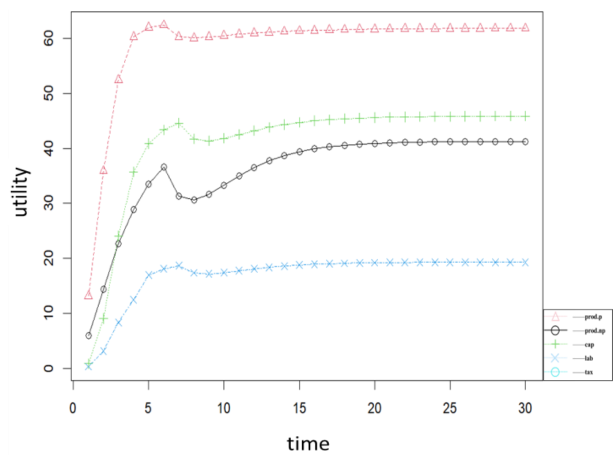

Figure 9 Utility of economic entities Under Synergy Effect

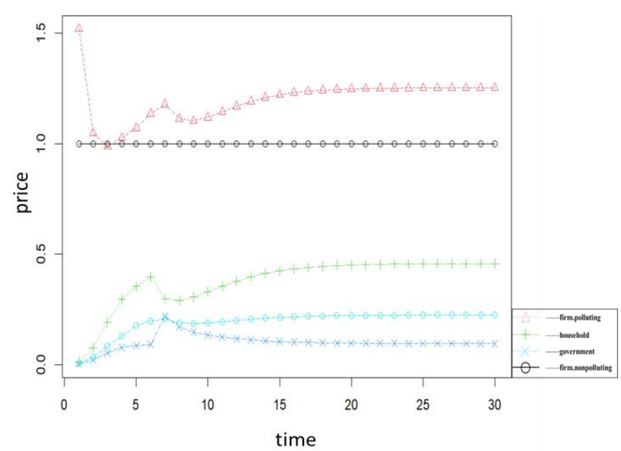

Figure 10 Price of economic entities Under Synergy Effect

Figures 9 and 10 shows the market clearing path when the tax rate is 25% and the technological progress rate is 0.05. Under the synergy effect, carbon tax, as an environmental regulation, will cause technological progress of firms. Due to the lag of this effect, it is assumed that the impact of carbon tax will occur in the fifth period and technological progress will occur in the seventh period. With the improvement of environmental regulation, the price of polluting goods gradually rises, while the price of production factors such as capital and labor decreases. In the approximate optimal path, the price of each product drops sharply and then slowly rises. At the same time, the output of non polluting firms gradually expands, the output of polluting firms decreases, the household utility decreases and the government utility increases, the government income increases and the consumer utility decreases in the short term.

In the equilibrium value demand matrix, the demand of non polluting firms for all kinds of factors except labor has generally increased, the demand of polluting firms for all kinds of factors has decreased, and the demand of households and governments for non polluting products has increased. In the equilibrium value supply matrix, the supply of non polluting firms increases while the supply of polluting firms decreases, the supply factors of households decrease, and the government expenditure increases. Technological progress leads to the fact that households do not need to supply too much labor, and because of the tax increase, the government will use more funds for environmental governance. Hypothesis 3 is proved.

5 Conclusions and Policy Implications

This paper constructs a four sector two system DGE model to study the impact of the synergy between the environmental regulation and the technological progress on China's economic system and environmental system. The research shows that:

(1) for the economic system, the impact of carbon tax will reduce the utility of household residents in the short term due to firms' failure to timely adjust technology and tax transfer. In the long term, the utility improvement brought by technological progress will cover the tax loss, and the utility improvement effect is the most significant when the carbon tax is 5%, and the marginal utility of non polluting goods will decline after 8%, and the utility of residents will be stable.

(2) For the environmental system: the synergistic effect of carbon tax and enterprise technological progress can enhance the government's investment in environmental governance, reduce the output of pollutants and optimize the environmental system. The collection of carbon tax can expand government revenue, allocate resources between non polluting firms and polluting firms, and use more funds for environmental pollution control. The administrative impact of carbon tax cannot have a general impact on the environmental system in the short term, but will play a sustained effect in the long term.

This paper also gives the following policy implications:

(1) improve the carbon emission monitoring platform and carbon tax system. The government can further improve the carbon tax system, implement carbon emission reduction policies and urge firms to adjust the industrial structure and promote green technology progress;

(2) Strengthen green technology innovation and promote the transformation of polluting firms. The government should increase funding for research and development of emission reduction technologies, and improve the carbon market or emissions trading system. Support polluting firms to obtain technical and financial support for technology upgrading and production improvement;

(3) Increase government investment in pollution control and optimize the energy structure. The government can increase the fiscal expenditure on improving environmental pollution control, reduce the economic burden of low-income families and polluting firms, and reduce the negative carbon emissions to optimize the energy structure.

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