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Economic development under the constraints of environmental policy: scenario analysis based on the endogenous growth model

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ABSTRACT

Using fossil fuel emits various types of pollution and greenhouse gas such as CO_2, SO_2 and NO_2. Effective environmental policy is the important approach to enhance the environmental quality and reduce the energy consumption quantities. The environmental policy model based on endogenous growth theory is built in this paper. Both environmental quality control methods are considered into this model, the first is environmental tax， it is a kind of indirect environmental control policy. The other is the pollution governance investment. This is a kind of direct environmental policy. We propose different scenarios to simulate and analysis the effects of environmental tax and pollution governance investment. The results show environmental tax has a better response to double dividend hypothesis, and this approach also has better effecting than pollution governance investment. In order to make enterprises automatically reduce emission, increase energy efficiency and ultimately correcting market failures. The implement of environmental tax will not only reasonable transfer the social cost caused by the environmental pollution to the enterprises, but also enables enterprises to avoid facing too much taxes. The redistribution of the revenue collecting from environment tax also needs to be flexible in order to avoid aggravating the conduction effect of social injustice.

Keywords: Endogenous growth model; Environmental tax; Pollution governance investment; Economic development; Scenario analysis.

INTRODUCTION

With the increasing inputs of fossil fuels, not only promote unprecedented scientific and technological progress, but also cause negative externalities for modern social and environmental[1]. How to develop appropriate environmental policies to effective control the balance among the energy consumption, economic growth and environmental protection has been a key issue faced by governments and academia.

The approach of environmental control policy is usually divided into two categories: direct control method and indirect induction method [2]. Direct control methods usually prohibit or constraint pollution behaviour through regulatory or punishment way, such as mandatory determine the amount of pollution governance investment, pollution fine, and prevent using some contaminated materials [3]. The short-term effect is obvious when government implements these measures, but it is lack of response to changes in the external environment, for example, the restrictions such as the industry condition, professional, information costs and other constraints [4]. Meanwhile, for the enterprise, there are only two options to be selected, the first is compliance with mandatory environmental control standards, and the second is not meet the standard, so they are lack of motives to further enhance environmental quality by themselves [5].

Indirect induction method is a market-based approach, such as regulating energy consumption through environmental tax. Arthur C. Pigou first proposed that tax should be levied on polluters based on the harm caused by pollution, and the revenues of tax are used to compensate the gap between private costs and social costs, this is defined as the famous "Pigouvain tax". But Pigouvain tax was founded on the premise that no other tax distortions and the social marginal cost could be accurately measured, it was feasible in theory, but would face many challenges in practice [6]. Terkla first introduced the concept of the "double dividend", and then he thought environmental tax would improve distortion taxes [7]. Lee further researched on the "optimal pollution tax rate" which could make a maximum effect for double dividend, and the new definition of Pigouvain tax was proposed on the condition of the general assumption [8].

The value of environmental tax was often emphasized on environmental policy-making. This system can be used to reduce the economic distortions caused by other taxes. However, collecting environmental tax also increase the private marginal cost of production and thereby reducing the GDP, and whole welfare of society [9]. Therefore, there always different perspective in academia for the role of environmental tax in environmental controls [10-12]. The model is built on the basis of endogenous growth theory, both of environmental quality control approach including environmental tax and pollution governance investment are considered in this model, and the effects of two approaches on energy intensity and economic growth are also studied through scenario analysis respectively.

EXPERIMENTAL SECTION

1.1 Basic assumptions

For simplicity, the system is assumed to be a closed economic system, only a single product, and there are infinite numbers of homogeneity individual, each individual not only a producer but also a consumer, the form of Cobb-Douglas production function is taken in this paper.

$$y_t = A \cdot k_{1t}^{\alpha} \cdot f_t^{(1-\alpha)},\ 0 < A < 1 \tag{1}$$

Where, A is comprehensive technical level, f_t is the energy input, k_{1t} is a generalized factor inputs including the productive government expenditure, human capital, efficient labour or the natural resource, etc., α is the output elasticity factor and measures the inputs impact on the output, $0 \le \alpha \le 1$, $(1-\alpha)$ is the energy input and output elasticity. Here, assume only a part of the cumulative factor k_t is used for the next production cycle, i.e. k_{1t}, another part for pollution governance, defined as k_{2t}. Above factors all have positive effects on output; Cumulative factor satisfies the equation (2), (3) and (4) respectively.

$$k_t = k_{1t} + k_{2t} \tag{2}$$

$$k_{1t} = \zeta_t \cdot k_t \tag{3}$$

$$k_{2t} = (1 - \zeta_t) \cdot k_t = r_t \cdot k_t \tag{4}$$

Production cumulative factors account for the proportion of the total cumulative factors is ζ_t, $0 \le \zeta_t \le 1$; Pollution governance cumulative factors account for the proportion of the total cumulative factors is r_t , $0 \le r_t \le 1$. Utility function as equation (5), c_t represents consumption, σ is the elasticity of marginal utility, $0 < \sigma < 1$.

$$U(c_t) = \left(c_t^{(1-\sigma)} - 1\right) / (1 - \sigma) \tag{5}$$

1.2 Pollution and energy consumption

The production is assumed to have negative impact on environmental quality in this model. The degree of negative impact is a decreasing function of environmental tax γ_t. In addition, there is a positive correlation between the extent of the negative impact on the environmental quality through production, the number of outputs, and the proportion of the cumulative capital used in production, show as the formula (6).

$$b_t = \zeta_t (1 - \gamma_t) y_t \tag{6}$$

Where, b_t is the negative impact on environmental quality by production. γ_t is environmental tax, ζ_t is the proportion of cumulative factors used for the production, y_t is output. The ratio between the energy input f_t and production output y_t is defined as energy intensity τ_t, and it also be defined as the per unit energy consumed.

$$f_t = \tau_t \cdot y_t \tag{7}$$

Energy consumption Φ_t is the multiplication of energy input f_t and energy prices β_t, energy markets are perfectly competitive market and energy prices are exogenous.

$$\phi_t = \beta_t \cdot f_t = \beta_t \cdot \tau_t \cdot y_t \tag{8}$$

1.3 Equilibrium

The objection of social planner is to seek the maximization utility for representation individual in the infinite horizon.

$$\underset{c_t}{Max} \int_0^{\infty} e^{-\rho t} \cdot U(c_t)dt \tag{9}$$

ρ is the pure rate of time preference, the cumulative factors of each representative individual satisfy the following constraint equation.

$$\dot{k}_t = y_t - (1+\gamma_t) \cdot \phi_t - b_t - c_t \tag{10}$$

(9) and (10) are combined and converted to nonbinding conditions. Optimal growth path achieved by Hamilton function as follows.

$$\underset{c_t}{Max} \left\{ \int_0^{\infty} e^{-\rho t} \cdot \left[\left(c_t^{(1-\sigma)} - 1 \right) / (1-\sigma) \right] + \lambda \cdot \left[y_t - (1+\gamma_t) \cdot \varphi_t - b_t - c_t - \dot{k}_t \right] \right\} dt \tag{11}$$

$$H = e^{-\rho t} \cdot \left[\left(c_t^{(1-\sigma)} - 1 \right) / (1-\sigma) \right] + \left[\lambda \cdot y_t - (1+\gamma_t) \cdot \beta_t \cdot \tau_t \cdot y_t - \zeta_t \cdot (1-\gamma_t) \cdot y_t - c_t - k_t \right] \tag{12}$$

λ is the shadow price of consumption. For the control variables c_t and k_t, the first-order condition of the maximizing Hamilton function H satisfies the following co-state equation (13) and coupling equation (14). Transversality condition is (15).

$$\dot{\lambda} = -\partial H / \partial k_t \tag{13}$$

$$\partial H / \partial c_t = 0 \tag{14}$$

$$\lim_{t \to \infty} e^{-\rho t} \cdot \lambda \cdot k_t = 0 \tag{15}$$

By the equation (1), (3) and (7), the production function can be rewritten as.

$$y_t = A^{\frac{1}{\alpha}} \cdot \zeta_t \cdot k_t \cdot \tau_t^{\frac{(1-\alpha)}{\alpha}}, \quad 0 < A < 1 \tag{16}$$

Partial derivative of formula (16) with respect to cumulative factor k_t yields (17).

$$\frac{\partial y_t}{\partial k_t} = A^{\frac{1}{\alpha}} \cdot \zeta_t \cdot \tau^{\frac{(1-\alpha)}{\alpha}} \tag{17}$$

Therefore, formula (18) can be derived from co-state equation (13) and (17).

$$\frac{\dot{\lambda}}{\lambda} = -\left[1 - (1+\gamma_t) \cdot \beta_t \cdot \tau_t - \zeta_t \cdot (1-\gamma_t) \right] \cdot A^{\frac{1}{\alpha}} \cdot \zeta_t \cdot \tau_t^{\frac{(1-\alpha)}{\alpha}} \tag{18}$$

By the coupling equation, Euler equation can be expressed as follows.

$$R_c = \frac{\dot{c}_t}{c_t} = \frac{1}{\sigma} \cdot \left\{ -\rho + \left[1 - (1+\gamma_t) \cdot \beta_t \cdot \tau_t - \zeta_t \cdot (1-\gamma_t) \right] \cdot A^{\frac{1}{\alpha}} \cdot \zeta_t \cdot \tau_t^{\frac{(1-\alpha)}{\alpha}} \right\} \tag{19}$$

R_c is the equilibrium consumption growth rate, the parts in braces can be understood as the social marginal outputs produced from physical capital. Therefore, the consumption growth rate reflects the changes of representative individual's utility, the faster increasing of consumption growth rate, the faster increasing of the representative individual's utility, Furthermore, the increasing of effectiveness of the whole society is also faster and indicate that the faster economic growth. Moreover, consumption growth rate may reflect the level of economic development. Consumption growth rate depends on the level of integrated technology, inputs scale of production factor, environmental tax, energy intensity and other factors. Since the elasticity consumption of marginal utility satisfies $0<\sigma<1$, so if the consumption growth rate is positive, the following conditions must be satisfied.

$$\rho_{up} > \rho > \rho_{down} \tag{20}$$

$$\rho_{down} = (1-\sigma) \cdot \left[1 - (1+\gamma_t) \cdot \beta_t \cdot \tau_t - \zeta_t \cdot (1-\gamma_t) \right] \cdot A^{\frac{1}{\alpha}} \cdot \zeta_t \cdot \tau_t^{\frac{(1-\alpha)}{\alpha}} \tag{21}$$

$$\rho_{up} = \left[1 - (1+\gamma_t) \cdot \beta_t \cdot \tau_t - \zeta_t \cdot (1-\gamma_t) \right] \cdot A^{\frac{1}{\alpha}} \cdot \zeta_t \cdot \tau_t^{\frac{(1-\alpha)}{\alpha}} \tag{22}$$

Partial derivative of formula (19) to energy intensity τ_t can obtain (23). Where, τ_t^* is the equilibrium energy intensity, the consumption growth rate is maximization at this point.

$$\tau_t^* = \frac{(1-\alpha)}{\beta_t (1+\gamma_t)} \cdot \left[1 - \xi_t \cdot (1-\gamma_t) \right] \tag{23}$$

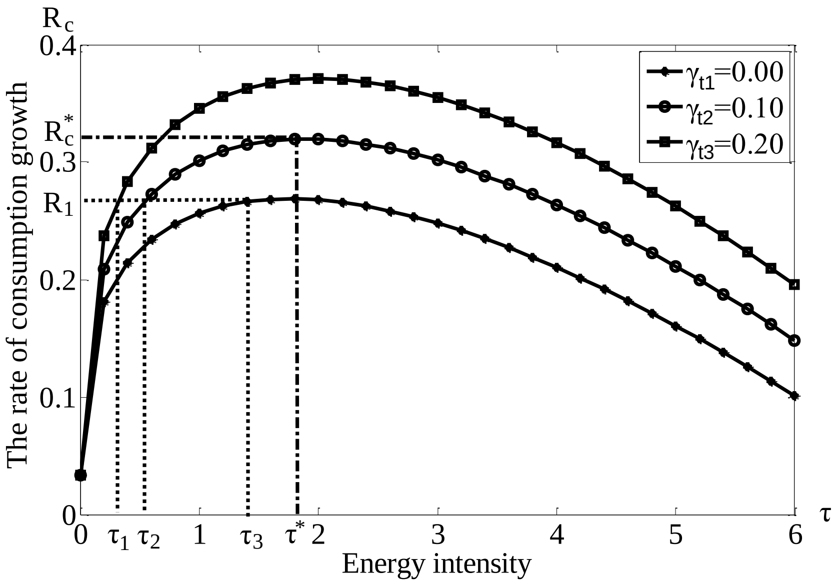

Figure 1. Implementation of environmental tax, the relationship between the rate of consumption growth and energy intensity

2. Scenario Analysis

2.1 Environmental tax

2.1.1 Energy price remains constant

The parameters are set as: A=1.50, ρ=0.05, σ=1.5, β=0.05, ζ=0.65, α=0.75 in Figure 1. The rate of consumption growth increases at first with increasing of the energy intensity, and then the consumption growth rate will fall and showing inverted U-shaped followed by a further increase in energy intensity. This reflects the characteristics of environmental Kuznets curve (EKC) between the energy intensity and consumption growth. When the energy intensity at equilibrium state τ_t^* =1.8864, the consumption growth rate reaches a maximum value R_c^* =0.3193 (Figure 1).

(1)Environmental tax γ_t has a dual impact including positive effect and negative effect on consumption growth rate. The same energy input consumed need larger funds with environmental tax increasing. This will slow the consumption growth. But the negative impact on the environmental quality caused by the production is reduced, so the damage to production factors is also reduced, thus increasing the consumption growth rate.

(2)Similarly, the energy intensity τ_t also has a dual impact including positive effect and negative effect on consumption growth rate. The consumption growth rate is directly slowed with the reduction of the energy intensity. But energy consumption also will be reduced with the reducing of the energy intensity, so that consumption cumulative factors of representative individual will increase, which induce the increasing of consumption growth rate.

(3)Overall, the higher environmental tax, the lower energy intensity, if the economic growth rate in the same case. Figure 1 shows if the consumer growth rate is R_1, the environmental tax satisfies the following conditions, $(\gamma_{t3}=0.00)<(\gamma_{t2}=0.10)<(\gamma_{t1}=0.20)$, and energy intensity satisfies $\tau_3>\tau_2>\tau_1$.

2.1.2 Energy intensity remains constant

The parameters in Figure 2 are set as: A=1.50, ρ=0.05, σ=1.5, ζ=0.75, α=0.75.

(1)Energy intensity remains unchanged in the case of higher energy prices, consumption growth rate is lower, Figure 2 shows when γ_{t1}=0.00 and τ_{t1} =1.50, the consumption growth rate is a monotonically decreasing function of energy prices.

(2)Energy intensity remains τ_{t3} =4.50, two cases are compared each other if the regulation of environmental tax is taken into account. First, the environmental tax is levied as γ_{t3}=0.00. Second, the environmental tax is levied as γ_{t4}=0.30. Consumption growth-energy price curve exists intersection point Q_m in both cases, at this point, energy prices β_m =0.17, consumption growth rate R_m =-0.6328. In left side of Q_m, the energy prices is lower, the increasing of environmental tax will contribute to the reduction of negative effect on environmental quality caused by production, the resulting effect on promotion of consumption growth rate is greater than the increasing of energy inputs cost caused by the increasing environmental tax. Therefore, the overall effecting of environmental tax has positive utility. That is, at the same energy prices, the higher environmental tax, the higher consumption growth rate. In right side of Q_m, the energy prices is higher, the effect on promotion of consumption growth rate is lower than the increasing of energy inputs cost caused by the increasing environmental tax. Therefore, the overall effecting of environmental tax has negative utility. That is, at the same energy prices, the higher environmental tax, the lower consumption growth rate.

(3)The energy intensity τ_{t3} =4.50 and the environmental tax constraints is considered. When energy prices β increases from 0 to β_m =0.17, environmental tax γ_{t1}=0.00, consumption growth rate decreased from the initial value 0.3877 to R_m =-0.6328. When the environmental tax γ_{t4}=0.30, the consumption growth rate decreased from the initial value 0.7066 to R_m =-0.6328 (Figure 2). This shows the energy consumption growth rate is more sensitive to price changes with the larger environmental tax, if the energy intensity is a constant.

2.1.3 Energy intensity changes

In the case of energy intensity changes while considering the constraints of environmental tax. When energy prices β increases from 0 to β_1 =0.23, environmental tax γ_{t1}=0.30, energy intensity τ_{t1} =1.50, consumption growth rate decreased from the initial value 0.5002 to R_1=0.0785. If energy intensity increases as τ_{t4} =4.50, the consumption growth rate decreased from the initial value 0.7066 to R_2= -1.1176 (Figure 2). This shows the energy consumption growth rate is more sensitive to price changes with larger energy intensity, if the environmental tax is a constant.

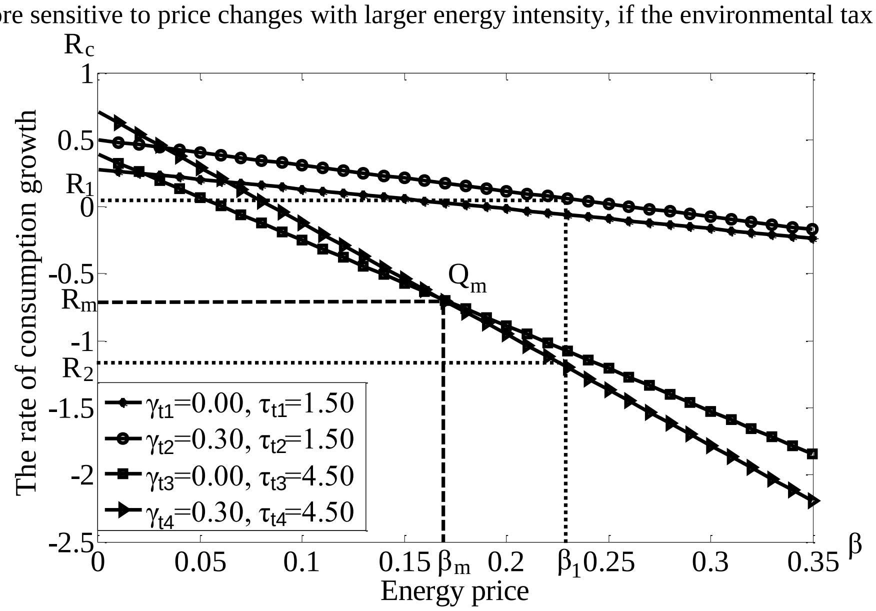

Figure 2. Implementation of environmental tax, the relationship between the rate of consumption growth and energy price

2.1.4 The proportion of cumulative factors used for the production changes

Partial derivative the equilibrium energy intensity τ_t^* to the environmental tax γ_t, the following equation can yields according to the equation (23).

$$\frac{\partial \tau_t^*}{\partial \gamma_t} = \frac{(1-\alpha)}{\beta_t \cdot (1+\gamma_t)^2} \cdot (2\zeta_t - 1) \tag{24}$$

Since $0 \le \alpha \le 1$, therefore, $(1-\alpha) \ge 0$, the value of the proportion of production cumulative factors ζ_t accounts the total cumulative factors will affect the relationship between energy intensity and environmental tax(Figure 3). The parameters are: A=1.50, ρ=0.05, σ=1.5, β=0.05, α=0.75.

(1)ζ_t>0.5, the growth rate of energy intensity τ_t^* will accelerate with the growth of the proportion of production investment. However, the growth rate energy intensity τ_t^* will slow down with the increase in environmental tax γ_t.

(2)ζ_t=0.5, the growth rate of energy intensity τ_t^* unchanged with the growth of the proportion of production investment ζ_t, and the changes of environmental tax γ_t has no effect on the growth rate of energy intensity τ_t^*.

(3)ζ_t<0.5, the growth rate of energy intensity τ_t^* will slow down with the growth of the proportion of production investment. However, the slowing rate of energy intensity τ_t^* will increase with environmental tax γ_t increasing.

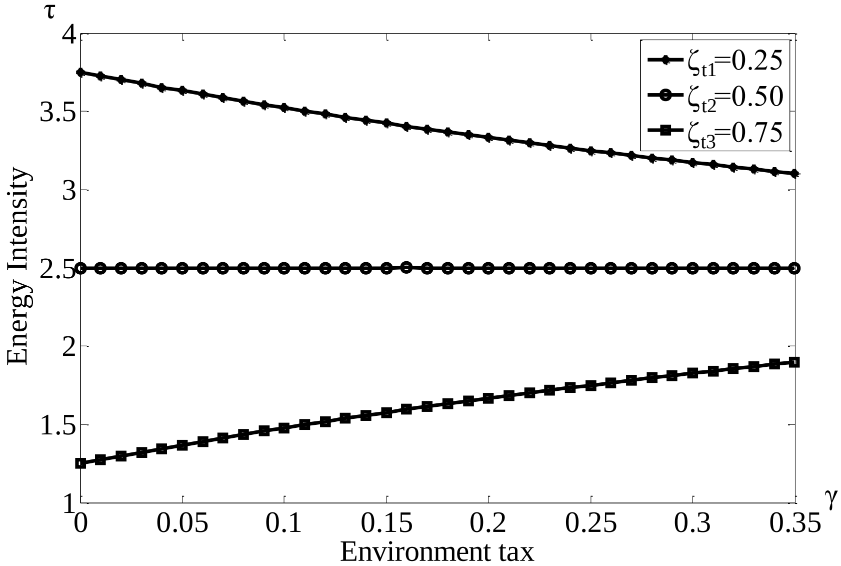

Figure 3. The proportion of production cumulative factors changes, the relationship between energy intensity and environmental tax

2.2 Pollution governance investment

In order to investigate the relationship between the economic development and the input ratio of pollution governance factors, environmental tax is set to be 0. The variation of energy intensity and the consumption growth rate is shown in Figure 4. The parameters are set as A=1.50, ρ=0.05, σ=1.5, β=0.05, γ=0.00, α=0.75, while the proportion of factor inputted into pollution governance is changed.

If all of the cumulative factors are used for the pollution governance investment, when the ratio of factors inputs into pollution governance is set to be r_{t1} =1.00, the consumption growth rate will maintain a constant and does not vary with the changes of energy intensity. Furthermore, if no cumulative factors are used for the production, even with the increasing energy intensity, the economy is impossible to keep a long-term growth status (Figure 4).

If all of the cumulative factors are used to production, which means the ratio of factors inputs into pollution governance is set to be r_{t5} =0.00, consumption growth rapid decline with the energy intensity increases, because the production has negatively impact on the environmental quality, and this negative impact can not be eliminated, and ultimately will affect the consumption growth rate for no investment in pollution governance (Figure 4).

When the proportion of cumulative factors used for pollution governance is set between 0 and 1, consumption growth increases with the energy intensity increases at first, and then decline with energy intensity increasing, there is a turning point. According to equation (4) and (19), the consumption growth rate is partial derivative to the proportion of cumulative factors used for pollution governance r_t, energy intensity τ_e^* satisfies the following equation at the turning point where the consumption growth rate changed.

$$\tau_e^* = 1/(1+\beta_t \cdot \tau_t) \quad (25)$$

The greater proportion of cumulative factor used for environmental governance does not mean the higher the growth rate of consumption (Figure 4). In the left of point $G_0(r_0,R_0)$, The consumption growth rate when r_{t1} =0.50 is higher than consumption growth rate when r_{t1} =0.75 with energy intensity increasing. Another interesting phenomenon can be founded that the consumption growth rate when r_{t1} =0.50 is also higher than consumption growth rate when r_{t1} =0.25 with energy intensity increasing. On the contrary, in the right of point $G_0(r_0,R_0)$. The consumption growth rate when r_{t1} =0.50 is lower than consumption growth rate when r_{t1} =0.25 with energy intensity increasing. This shows that the proportion of cumulative factor used for pollution governance must be selected appropriately.

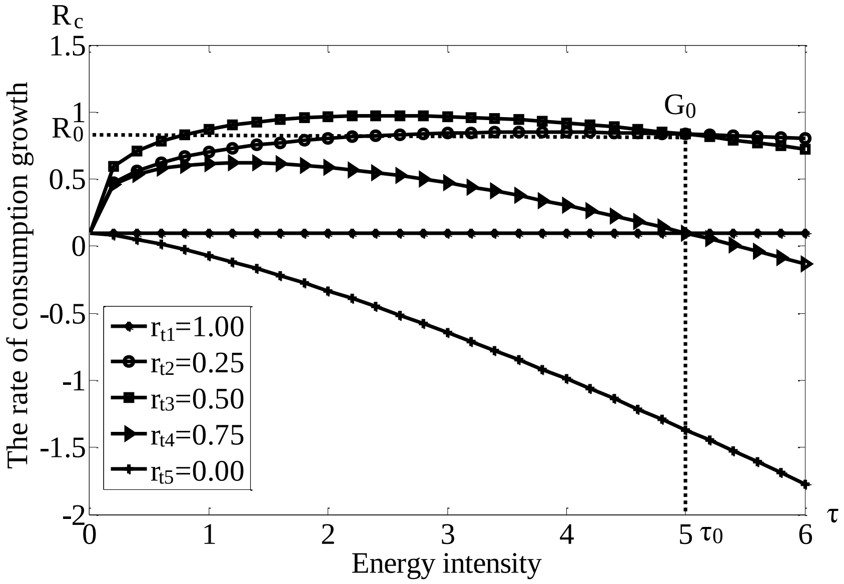

Figure 4. The proportion of cumulative factors used for pollution governance changes, the relationship between the rate of consumption growth and energy intensity

Although the production inputs will reduce, when proportion of pollution governance investment increase. Therefore, the overall utility is positive at this time. Moreover, under the same energy intensity, the greater investments proportion of pollution governance, the higher consumption growth rate.

The energy intensity is higher in the right of point $G_0(r_0, R_0)$, the proportion of factors used for production is declined with the increasing of the proportion of cumulative factors used for pollution governance investment, and the negative effects of reduced environmental quality are not enough to offset the reduced utility, which caused by the reduction factor inputs for production. Overall utility generated by environmental governance is negative, that is, under the same energy intensity, the greater investments proportion of pollution governance, the lower consumption growth rate.

CONCLUSION

This paper discusses the role of direct and indirect environmental policy, and the following conclusion are obtained. (1) Environmental tax has dual effects including positive and negative impact on consumption growth rate. (2) The proportion of cumulative factor for pollution governance investment will has an important influence on the economic development and environmental quality. It must be selected as a suitable value. (3) The effecting of indirect induction environmental control policy is better than direct environmental control policy. (4) Design of environmental tax collection system needs to meet the "minimum harm principle", that is, the environmental tax has the minimum harm to taxpayers and the same sources of pollution or pollution body does not be levied duplicity. Environmental tax should not only be designed to achieve objectives of environmental policy, but also not more than the actual demand capability.

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