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The Innovation Mechanism of Green Economic Growth and Energy Extraction

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Abstract: This paper studies the closed economic system in which enterprises and residents actively, consciously, and self-discipline practice green behaviors as a universal form, and green innovation is transformed into an endogenous element of the economic system. The Schumpeterian model driven by green behaviors, is established by considering quality innovation green innovation, integrating clean energy dynamics, heterogeneous labor, green demand structure. Where, green innovation increases the green degree of goods; The green degree of goods is the environmental friendliness of goods. This paper demonstrates the innovative mechanism of heterogeneous labor for green economic growth and energy extraction under the combination of different implementation conditions of green demand structure and technological frontier distance.

Keywords: Green Schumpeterian model; Green innovation; Green degree; Green demand structure

1 Introduction

The application of Schumpeterian endogenous growth model to study green development was first raised by [1] by introducing environmental pollution and non-renewable resources into their Endogenous Growth Theory. [2] studied the interaction between technological change, resource scarcity and population dynamics in a Schumpeter model with endogenous fertility. [3] examines how renewable energy access regimes affect economic sustainability, growth and social welfare in the context of modern endogenous growth theory. [4] found that there is an optimal growth path along which sustainable growth of the green economy can be achieved, the quality of the environment and the utilization of resources can be improved. [5] integrates fertility choice and exhaustible resources into a Schumpeterian model, showing that under the right conditions, the interdependence of population, exhaustible resources, and technology can lead to sustainable economic growth based on knowledge innovation. Existing literatures have not analyzed the impact and role of green innovation on green economic growth a from the perspective of green innovation as an endogenous element of the economic system.

2 Model Setting

This green economic system is composed of four parts: household, production, innovation and clean energy.

2.1 Production Module

The production module includes the green final good production sector and the green intermediate good production sector.

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2.1.1 Green Final Good Producer

The representative enterprises in the perfectly competitive market actively, consciously and self-discipline practice green behavior to produce a green final good Y. The production technology with respect to green intermediate good is

$$Y(t) = \int_0^1 X_i^\theta \left(Z_i^\alpha Z^{1-\alpha} G_i^\beta G^{1-\beta} L_Y^\gamma R^{1-\gamma} \right)^{1-\theta} di \tag{1}$$

where, X_i is the quantity of the green intermediate good i, Z_i and G_i , respectively, are the quality and the green degree of the green intermediate good, $Z = \int_0^1 Z_i di$ and $G = \int_0^1 G_i di$, respectively, are the average quality and the average green degree of the green intermediate good, L_Y is the effective green labor, R is clean energy usage. The demand of each green intermediate good is obtained by maximizing the profit of green final good producer

$$X_i = \left(\frac{\theta}{P_i} \right)^{\frac{1}{1-\theta}} Z_i^\alpha Z^{1-\alpha} G_i^\beta G^{1-\beta} L_Y^\gamma R^{1-\gamma} \tag{2}$$

where, P_i is the price of green intermediate good i. The total compensation paid by green final good producer to green intermediate product suppliers, productive labor and clean energy are

$$\int_0^1 P_i X_i di = \theta Y \qquad \int_0^1 P_i X_i di = \theta Y \qquad \int_0^1 P_i X_i di = \theta Y$$

where, ω is average wage rate, P_R is the price of clean energy.

2.1.2 Green Intermediate Good Producer

The typical production technology of green intermediate producers is that each unit of green intermediate good needs one unit of green final good. The gross profit of green intermediate good producer at time t is

$$\Pi_i = (P_i - 1) X_i = \theta \left(Z_i^\alpha Z^{1-\alpha} G_i^\beta G^{1-\beta} L_Y^\gamma R^{1-\gamma} \right)^{1-\theta} X_i^\theta - X_i \tag{3}$$

By maximizing intermediate producer profits

$$X_i = \theta^{\frac{2}{1-\theta}} \left(Z_i^\alpha Z^{1-\alpha} G_i^\beta G^{1-\beta} L_Y^\gamma R^{1-\gamma} \right) \tag{4}$$

Therefore, the net present value of the intermediate producer is

$$V_i = \int_t^\infty (P_{it} - 1) X_{it} e^{-r(s-t)} ds = (1-\theta) \theta^{\frac{1-\theta}{1+\theta}} Z G L_Y^\gamma R^{1-\gamma} \int_t^\infty e^{-r(s-t)} ds \tag{5}$$

2.2 Innovation Module

This paper mainly considers two innovation directions: quality innovation and green innovation. The firm can improve quality and green degree according to technology

$$\begin{cases} \frac{\dot{Z}}{Z} = \xi_Z \frac{L_Z}{L} + \frac{L_\mu}{L} \frac{Z'_{t-1}}{Z_{t-1}} \\ \frac{\dot{G}}{G} = \xi_G \frac{L_G}{L} + \frac{L_\mu}{L} \frac{G'_{t-1}}{G_{t-1}} \end{cases} \tag{6}$$

where, ξ_Z and ξ_G respectively are exogenous quality innovation and green innovation capability absorbed from the previous period, Z'_{t-1} and G'_{t-1} respectively are potential quality technology frontier and green technology frontier. L_Z and L_G are quality R&D labor and green R&D labor, respectively, L_μ is imitation labor. Let, $\Theta_Z = \frac{Z'_{t-1}}{Z_{t-1}}$ and $\Theta_G = \frac{G'_{t-1}}{G_{t-1}}$ respectively are the distance to the frontier of quality technology and the distance to the frontier of green technology .
Based on the value of the knowledge produced by the innovation sector is equal to the present value of the monopoly profit of the intermediate good producer, $P_{ZG} = V_t$. Therefore, the no-arbitrage condition of the innovation sector $P_{ZG} (\dot{ZG}) = \omega (L_Z + L_G + L_\mu)$ can be simplified as

$$\begin{aligned}&(1-\theta)\,\theta^{\frac{1-\theta}{1+\theta}} Z_t G_t L_Y^{\gamma} R^{1-\gamma}\left(\xi_Z\frac{L_Z}{L}+\frac{L_\mu}{L}\Theta_Z+\xi_G\frac{L_G}{L}+\frac{L_\mu}{L}\Theta_G\right) Z_{t-1}G_{t-1}\int_t^{\infty} e^{-r(s-t)}ds \\ &=\gamma\,(1-\theta)\,\theta^{\frac{1-\theta}{1+\theta}} Z_t G_t L_Y^{\gamma-1} R^{1-\gamma}\left(L_Z+L_G+L_\mu\right)\end{aligned} \tag{7}$$

Therefore, the market interest rate level is

$$r=\frac{\theta}{\gamma}\frac{L_Y}{L_Z+L_G+L_\mu}\left[\xi_Z\frac{L_Z}{L}+\xi_G\frac{L_G}{L}+\frac{L_\mu}{L}\left(\Theta_Z+\Theta_G\right)\right] Z_{t-1}G_{t-1} \tag{8}$$

2.3 Household Module

It is assumed that the utility function of household is determined by the green demand structure and consumption level.

$$U\left(0\right)=\int_0^{\infty} e^{-\rho t}\left(\frac{D_2}{D_1}\right)^{\varsigma}\frac{C^{1-\eta}}{1-\eta}dt \tag{9}$$

where, 0 is the time point at which households make green consumption decisions, ρ is the time discount rate, η is the inverse of the intertemporal elasticity of substitution. $D_2=\varphi * A$ is the green consumption demand, which is proportional to the wealth accumulation of the family, $D_1=A-\varphi * A$ is the non-green consumption demand, and $\frac{D_2}{D_1}=\frac{\varphi}{1-\varphi}$ is the green consumption demand structure, where, φ is the green consumption demand coefficient, which is assumed to be affected by household wealth in this paper, so let $\varphi=\kappa A-b$, where, κ, b are non-negative constants. The budget limit of household green consumption is

$$\dot{A}=rA+\omega L+P_R R-C \tag{10}$$

where, A is the asset held, r is the return on the asset and P_R is the price of clean energy.

2.4 Clean Energy Module

The stock of clean energy obeys the differential equation

$$\dot{S}=-R \tag{11}$$

Build the Hamiltonian function of the present value

$$\hat{H}=\left(\frac{\varphi\left(A\right)}{1-\varphi\left(A\right)}\right)^{\varsigma}\frac{C^{1-\eta}}{1-\eta}+\lambda_A\left(rA+\omega L+P_R R-C\right)-\lambda_S R \tag{12}$$

Where, λ_A and λ_S are the shadow value of household wealth and clean energy, respectively. According to the maximum principle, the growth rate of green economy and clean energy extraction path are obtained

$$g_Y=\frac{1}{\eta}\left\{\frac{\theta}{\gamma}\frac{L_Y}{L_Z+L_G+L_\mu}\left[\xi_Z\frac{L_Z}{L}+\xi_G\frac{L_G}{L}+\frac{L_\mu}{L}\left(\Theta_Z+\Theta_G\right)\right] Z_{t-1}G_{t-1}-\rho-\varsigma\frac{\kappa}{\varphi\left(1-\varphi\right)}\frac{C}{1-\eta}\right\} \tag{13}$$

$$g_R=\frac{\dot{Y}}{Y}-\frac{\dot{P}}{P}=\left(1-\eta\right)\frac{\dot{C}}{C}-\rho \tag{14}$$

3 Comparative Static Analysis

According to (13) and (14), we first analyze the driving effect of heterogeneous labor on economic growth and clean energy extraction under the conditions of different technological frontier distances, as shown in Table 1. Next, we analyze the driving effect of green demand structure on green economic growth and clean energy extraction. According to (13), we take the partial derivative of g_Y with respect to the green demand coefficient φ.

$$\frac{\partial g_Y}{\partial\varphi}=\varsigma\frac{\kappa\left(1-2\varphi\right)}{\varphi^2\left(1-\varphi\right)^2}\frac{C}{\eta\left(1-\eta\right)} \tag{15}$$

Table 1: The driving effect of heterogeneous labor on economic growth and clean energy extraction

Heterogeneous Labor	Green Economic Growth			Clean Energy Extraction		
Productive Labor	$\frac{\partial g_Y}{\partial L_Y} > 0$	$\frac{\partial^2 g_Y}{\partial L_Y \partial \Theta_Z} > 0$	$\frac{\partial^2 g_Y}{\partial L_Y \partial \Theta_G} > 0$	$\frac{\partial g_R}{\partial L_Y} < 0$	$\frac{\partial^2 g_R}{\partial L_Y \partial \Theta_Z} < 0$	$\frac{\partial^2 g_R}{\partial L_Y \partial \Theta_G} < 0$
Quality R&D Labor	$\frac{\partial g_Y}{\partial L_Z} > 0$	$\frac{\partial^2 g_Y}{\partial L_Z \partial \Theta_Z} > 0$		$\frac{\partial g_R}{\partial L_Z} < 0$	$\frac{\partial g_R}{\partial L_Z} < 0$	
Green R&D Labor	$\frac{\partial g_Y}{\partial L_G} > 0$		$\frac{\partial^2 g_Y}{\partial L_G \partial \Theta_G} > 0$	$\frac{\partial g_R}{\partial L_Z} < 0$		$\frac{\partial^2 g_R}{\partial L_G \partial \Theta_G} < 0$
imitation labor	$\frac{\partial g_Y}{\partial L_\mu} > 0$	$\frac{\partial^2 g_Y}{\partial L_\mu \partial \Theta_Z} > 0$	$\frac{\partial^2 g_Y}{\partial L_\mu \partial \Theta_G} > 0$	$\frac{\partial g_R}{\partial L_\mu} < 0$	$\frac{\partial^2 g_R}{\partial L_\mu \partial \Theta_Z} < 0$	$\frac{\partial^2 g_R}{\partial L_\mu \partial \Theta_Z} < 0$

Because $\kappa > 0, \eta > 1^*$, $\frac{\partial g_Y}{\partial \varphi} < 0$ for $0 < \varphi < \frac{1}{2}$; $\frac{\partial g_Y}{\partial \varphi} > 0$ for $\varphi > \frac{1}{2}$. According to (14), we take the partial derivative of g_R with respect to the green demand coefficient φ.

$$\frac{\partial g_R}{\partial \varphi} = \varsigma \frac{\kappa (1 - 2\varphi)}{\varphi^2 (1 - \varphi)^2} \frac{C}{\eta (1 - \eta)} \tag{16}$$

Because $\kappa > 0, \eta > 1$, $\frac{\partial g_Y}{\partial \varphi} > 0$ for $0 < \varphi < \frac{1}{2}$; $\frac{\partial g_Y}{\partial \varphi} < 0$ for $\varphi > \frac{1}{2}$.

4 Conclusions

After the above analysis, we can draw the following conclusions. Productive labor positively affects green economic growth and negatively affects the growth rate of clean energy extraction. When the distance from the technological frontier is farther, productive labor can drive economic growth faster and make a greater compensation for clean energy. Quality R&D labor and green R&D labor positively affect impact on green economic growth. When the distance from the technological frontier is closer, quality R&D labor and green R&D labor have a greater impact on the economy and can reduce the dependence of economic growth on clean energy. The green demand coefficient has a positive U-shaped impact on economic growth, and an inverted U-shaped impact on the growth rate of clean energy extraction.

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[*] [6] and [7] show that the inverse of the intertemporal elasticity of substitution $\eta > 1$.