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Impact of Environment and Technological Progress on Carbon Emission: Theoretical Mechanism

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Abstract: Under the background of realizing carbon peak and carbon neutralization, this paper explores the impact of environmental purification, technological progress and structural change on carbon emission. This paper puts an energy based economic growth model into endogenous population growth, and then analyzes the dynamic impact on carbon emissions. In the complex dynamic system of endogenous population growth with constant technology level, there are several types of stable states. If the technology level and the self purification ability of the environment are added to the model, there will be multiple sustainable growth paths in the variables in the economic system. The optimal social consumption is affected by the endogenous population growth rate. Finally, it is found that relying on technological progress and improving the self purification ability of the environment can achieve green and low-carbon growth. Using technological innovation and afforestation to improve the self purification ability of the environment can realize the "decarbonizatio" of the industrial system.

Keywords: Population; Technological progress; Self purification ability of environment; Carbon emissions; Multiple growth paths

1 Introduction

Due to the expansion of population size, developing countries widely implement the catch-up economic growth model of low technology. The expansion of energy consumption poses a serious threat to economic sustainable development and the environment. The problem of carbon emission has attracted increasing international attention, and the research on the factors affecting carbon emission has been gradually promoted. With regard to Ramsey model and carbon emission.Xiangyang Chen (2021) [1] put the endogenous population growth process into the energy based economic growth model to analyze its dynamic impact on carbon emissions, in the complex dynamic system of endogenous population growth with constant technical level, there are several types of possibilities of stable states and extraordinary comparative static equilibrium relative to the change of system parameters. When technological progress is added to the model, there are multiple sustainable growth paths in the variables of the economic system. Social optimal consumption is affected by endogenous population growth rate, which means that population growth rate affects consumption, thus affecting energy production and consumption, and then carbon emissions.Xiangyang Chen (2017) [2] chose the internalization of environmental costs and the transformation of economic growth mode as the research theme, trying to theoretically explore the internal mechanism between the internalization of environmental costs and the transformation of economic growth mode. Wen Guo and Tao Sun (2017)[3] found that the impact of population size, household consumption and urbanization on carbon emissions is significantly positive, and household consumption has the greatest impact on carbon emissions.Xizhe Peng and Qin Zhu (2010)[4] conducted an empirical study on the impact of China's population size and structure, consumption mode, technological progress and other factors on carbon emissions in the past 30 years.Shuijun Peng et al. (2015)[5] estimated that most of China's consumption side carbon emissions from 1995 to 2009 were domestic emissions.Xiaohui Song et al. (2012)[6] found that wealth consumption in developed countries is an important reason to promote carbon emissions. Haiming Li (2013) [7] started from the utility function of typical household consumption, used

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variational method or dynamic optimization method to explore the relationship between consumer welfare and economic growth, and found a dynamic optimal growth path tending to the steady-state equilibrium point. Liping Ma(2016) [8] considered that energy is one of the important factors to promote economic development. When fossil energy cannot be completely replaced by clean energy in the short term, reducing carbon emissions is bound to slow down economic growth and sacrifice the economic interests of contemporary people to meet the needs of sustainable development to a certain extent. This involves the problem of intertemporal resource allocation. According to Ramsey model, the economic growth under deterministic conditions and the intertemporal conditions of satisfying the path can be obtained. Caihong Zhang (2018) [9] explored and studied economic growth under low-carbon constraints and analyzed economic growth under resource and environmental constraints. Xin Wen (2009) [10] obtained the optimal intertemporal consumption conditions based on the analysis of Ramsey model, analyzed the parameters in the optimal intertemporal consumption conditions, and showed that residents' consumption and savings have intertemporal substitutability with the change of interest rate. Using the results of the model, this paper puts forward reasonable suggestions for expanding residents' consumption at the present stage. At present, the focus of China's carbon emissions has gradually shifted from the production side to the consumption side, and people's consumption of carbon emissions has gradually become a new growth mode of carbon emissions. Therefore, exploring the path of technological progress and the self purification ability of the natural environment affecting carbon emissions has become an important perspective to understand carbon neutralization. Based on Ramsey model, this paper introduces technological progress and environmental self purification ability to study the impact of structural change on carbon emission in theory.

2 The impact of environment and technological progress on carbon emissions: theoretical mechanism

Carbon dioxide emissions mainly come from the consumption of fossil energy. Energy is the main raw material for production and consumption. Therefore, carbon emissions can be divided into carbon emissions brought by production and carbon emissions brought by consumption. The carbon emission brought by consumption comes from the consumption of products. A country's consumption demand will determine the final carbon emission. The scale of final demand is positively correlated with the carbon emissions generated by consumption. At the same time, most of the domestic final demand is met by domestic production, so the continuous increase of the final demand scale will urge manufacturers to expand production. Expansion is also an important factor to promote the growth of carbon emissions on the production side. Production is for consumption, which means that consumption has a positive impact on carbon emissions. Consumption patterns are different based on people's gender, age, income level, psychology and other factors, and different consumption patterns have different effects on carbon emissions. Therefore, the growth of population size will increase carbon emissions from people's final demand. The increasing demand will urge manufacturers to expand production. Finally, people will consume the produced products through consumption, and consumption will further promote production. Population and consumption interact. Although their impact on carbon emissions is different, the expansion of total population and consumption scale will inevitably lead to the growth of energy consumption and carbon emissions, and the consumption mode is also affected by various complex factors. Therefore, in order to study the impact of population and consumption on carbon emissions, it is necessary to explore the internal mechanism between population, consumption and energy consumption. The following is based on the classical Ramsey growth model and analyzed by introducing the energy sector to build a theoretical model (Blanchard and Fisher, 1994).

2.1 Theoretical Model

2.1.1 When the technical level remains unchanged

Consider a simple general equilibrium economic model in which consumers consume a certain amount of energy E from the energy stock of each period. Due to energy development, the energy stock can increase, and the differential equation of energy change is:

$$\frac{dE}{dt} = M\left(E, L\right) - bE \tag{1}$$

$M(E, L)$ is the instantaneous growth function of energy, which is actually the total output or total real income of energy based economy,L is the labor force invested in energy production.b is the Exogenous energy consumption coefficient. Consistent with Ramsey's economic growth theory, $M(E,L)$ assume that it is linear homogeneous and second-order continuous differentiable,$M_{EL} \geq 0$,$M_E \geq 0$,$M_{EE} < 0$,$M_L > 0$,$M_{LL} < 0$ and satisfy the second-order condition:$M_{EE}M_{LL} > M_{EL}^2$.Assuming that the coefficient between consumption and energy is 1, considering energy consumption, equation (1) can be modified as:

$$\frac{dE}{dt} = M\left(E, L\right) - bE - C \tag{2}$$

In the classical Ramsey growth model, assuming that the total population is equal to the number of labor forces, we assume that the ratio of the total population to the number of labor forces changes according to the following formula:

$$\frac{dL}{dt} = n\left[m\left(e\right)\right] \times L \tag{3}$$

In equation (3), n Represents the population growth rate, dependent on $m\left(e\right) = \frac{M(E,L)}{L}$,$e = \frac{E}{L}$ is the per capita energy volume, indicating that the population growth rate is related to the instantaneous per capita energy growth rate. A representative consumer has a utility function , $U\left(c\right) = \frac{c^{1-\varepsilon}}{1-\varepsilon}$,$c = \frac{C}{L}$ is per capita consumption, Given an exogenous social time preference coefficient ρ is the discount rate. Representative individuals solve the following optimal problems:

$$\begin{aligned} &\max \int_0^t \left(\frac{c^{1-\varepsilon}}{1-\varepsilon}\right) e^{-\rho t} dt \\ &\frac{dE}{dt} = M(E,L) - bE - cL \\ &\frac{dL}{dt} = n\left[m\left(e\right)\right] \times L \\ &E\left(0\right) > 0, L\left(0\right) > 0 \end{aligned} \tag{4}$$

In the optimal control problem, the control variable is c. The state variable is E and L , if the state variable is transformed into per capita value, the optimal control problem can be transformed into the case of only one state variable. Making $e = \frac{E}{L}$, then it becomes the following:

$$\begin{aligned} &\max \int_0^t \left(\frac{c^{1-\varepsilon}}{1-\varepsilon}\right) e^{-\rho t} dt \\ &\frac{de}{dt} = M\left(e\right) - be - c - en\left[m(e)\right] \\ &e\left(0\right) > 0 \end{aligned} \tag{5}$$

The present value Hamiltonian function of the optimal control problem is:

$$H = \frac{c^{1-\varepsilon} - 1}{1-\varepsilon} + \lambda\left(g(e) - (b + n\left(g(e)\right))e - c\right) \tag{6}$$

In equation (6), λ is the present value shadow price of per capita energy, so the optimal conditions are:

$$\frac{\partial H}{\partial c} = c^{-\varepsilon} - \lambda \tag{7}$$

$$\dot{\lambda} = \rho\lambda - \frac{\partial H}{\partial e} \tag{8}$$

According to equation (7):

$$c^{-\varepsilon} = \lambda \tag{9}$$

According to equation (8):

$$\dot{\lambda} = \lambda\left(\rho + b + n_m m_e e - m_e\right) \tag{10}$$

Derive equation (9) to obtain:

$$\dot{\lambda} = \varepsilon c^{-(\varepsilon+1)} \tag{11}$$

Substitute equation (11) into equation (8):

$$\frac{dc}{dt} = -\frac{c}{\varepsilon}\left(\rho + b + n + en_m m_e - m_e\right) \tag{12}$$

Equations (5) and (12) give the optimal time path of per capita energy consumption$e$and per capita consumption c . From a dynamic point of view, consumption increases with the growth of population and per capita energy use, indicating that population growth will lead to consumption growth, resulting in the growth of energy and carbon emissions.

2.1.2 Dynamic characteristics and steady state

Whether there are one or more steady states in the above economic system. First, make $\frac{de}{dt}$ of equation (5) and $\frac{dc}{dt}$ of equation (12) equal to 0:

$$c = m - (b+n)e \tag{13}$$

$$\rho = m_e - (b+n) - en_m m_e \tag{14}$$

2.1.3 Consider technological progress and environmental absorption of carbon dioxide

In the above model, technological progress and environmental absorption of carbon dioxide can be introduced, and the energy production and consumption equation can be modified as follows:

$$\frac{dE}{dt} = M\left(NE, AL\right) - bNE - cL \tag{15}$$

In equation (15), A is a given rate of technological progress. N indicates the absorption rate of carbon by the environment. The above functional form is equivalent to assuming that technological progress increases the effective supply of labor, which can be interpreted as the number of " effective units" per unit of labor, assuming that the technology grows at the rate of γ :

$$\frac{dA}{dt} = \gamma A \tag{16}$$

Assuming that the self purification ability of the environment will improve the effective use of energy, it can be interpreted as the number of "effective units"per unit of energy.It is assumed that the self purification ability increases with the efficiency of a .

$$\frac{dN}{dt} = aN \tag{17}$$

When considering technological progress and the self purification ability of the environment. Assuming that the population grows with $n\left[\frac{M(NE,AL)}{AL}\right]$, that is, a representative economic individual with infinite survival, the following optimization problem is solved:

$$\begin{aligned}
&\max \int_0^t \left(\frac{c^{1-\varepsilon}}{1-\varepsilon}\right)e^{-\rho t}dt \\
&\frac{dE}{dt} = M\left(NE, AL\right) - bNE - cL \\
&\frac{dL}{dt} = n\left[\frac{M\left(NE \big/ AL\right)}{AL}\right]L \\
&\frac{dA}{dt} = \gamma A \\
&\frac{dN}{dt} = aN \\
&E(0) > 0; L(0) > 0; A(0) > 0; N(0) > 0
\end{aligned} \tag{18}$$

If $x = \frac{NE}{AL}$ is the unit effective labor equation (18) can be transformed into the following equation:

$$\max \int_0^t \left(\frac{c^{1-\varepsilon}}{1-\varepsilon}\right) e^{-\rho t} dt$$
$$\frac{dx}{dt} = Nm(x) + [a - b - \gamma - n(m(x))]\, x - NAc, \quad x(t) > 0 \tag{19}$$

According to the first mock exam (19) and the formula (5) have similar mathematical structure. This model is similar to that without technical progress. Given the technological progress and the self purification ability of the environment, there are multiple growth paths in the equilibrium solution, so the economic system with the same parameters may not converge to the same equilibrium path from different initial conditions of energy and population.

3 Conclusion

The above analysis shows that relying on technological progress or improving the self purification ability of the environment can achieve green and low-carbon growth, and the “decarbonizatio” of the industrial system can be realized by means of scientific and technological innovation and afforestation. The existing neoclassical growth model considering environmental factors and technological progress assumes that the population growth rate is constant, which will produce exponential population growth. This paper relaxes this unrealistic assumption and deduces the conclusion through the theoretical model: in the model considering technological progress and the self purification ability of the environment. There may be multiple balanced growth paths of consumption and energy, which means that the economy cannot be introduced into a growth path with sustained and high welfare in a single unrestricted market activity. We must rely on technological progress and improve the self purification ability of the environment to achieve low-carbon growth.

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