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Economic Growth and Renewable Resources: The Interaction between Economic System and Ecological System

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Abstract

This paper formulates a two-sector endogenous growth model by incorporating knowledge capital and environmental capital into account to investigate the interaction relationship between economic growth and environmental quality. The decision maker values both goods and environment consumption, and the important decision in this model is to decide the optimal allocation of knowledge capital and environmental capital across the sectors. It is through the interaction between the economic system and ecological system that generates fruitful results in understanding the relationship between economic growth and environmental quality. In this model there exists a long-run balanced growth path for both goods production and environmental quality. Moreover, a positive productivity shock of the goods sector is also beneficial to the environmental sector. Policy implications and a reconsideration of the concept of Green GNP are also discussed.

Keywords: economic system, ecological system, knowledge capital, environmental capital, renewable resources
JEL: O40, P60, Q20

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I. Introduction

The surge of environmental protection after rapid economic development has become a critical issue in recent decade, many developed countries were aware of this trend by engaging more resources into enhancing environmental quality such as forest-building and nature resources reservation to preserve or revitalize resources. The fruits of economic development should not only provide better material living but also offer a better environment for our next generations. Conventional wisdom thought that there is inevitability a trade-off between economic growth and environment preservation as resources are limited. Therefore, economic growth will be at the expense of sacrificing environmental quality, while preserving better environment will diverge resources from putting into goods production.

In the literature of environment and growth, most of researches focus on the negative effect of pollution on economic production, capital accumulation vis-à-vis pollution accumulation, see, e.g., Huang and Cai（1994）and Withagen（1995）. In this type of model, the economy will grow at the expense of environmental deterioration, and then as living standard improves people demand a better quality of environment, thus the emerge of environmental protection acts to improve the quality of the environment which diverts the resources from capital accumulation and thus deters the long-run growth of the economy. However, Beckerman (1972) and Simon (1981) point out that there may be positive effect of environmental quality on economic growth, and this positive effect is later documented in many researches by the evidence of so-called Environmental Kuznet's Curve. Clark (1976) views environmental resources as a kind of capital since natural resources are usually renewable, hence it should be a part of resource constraints. Based on this line of thinking, Bovenberg and Smulders (1995) and Smulders (1999) construct a growth model includes accumulations of both physical capital and environmental capital, which generates a long-run balanced growth path for nature resources, pollution, and capital.

This paper goes one step further by viewing both economic growth and environmental quality as needs for the decision makers and hence they are in the decision maker's utility function. By incorporating the concept of renewable resources and allowing the interaction between the economic system and ecological system, this paper provides a different look at the relationship between economic growth and environmental quality. In this model, there exists a long-run balanced growth path for both the goods production and environment quality. Moreover, a positive productivity shock of the goods sector is also beneficial to the environment sector. This paper thus provides a win-win solution for preserving both economic growth and environmental quality.

II. The model

2.1 Technology

Consider an AK model for goods production where the capital is broadly defined as knowledge capital, a combination of physical and human capitals. Thus the production function for the final goods sector is expressed as

$$Y = A(1-u)H \text{ , } 0 < u < 1, \tag{1}$$

where Y is the final output, H is knowledge capital, $(1-u)$ is the share of knowledge capital spend in goods production and A is the productivity level of the goods industry. There is another sector called environmental sector which is a joint product of environmental capital and knowledge capital with constant return to scale technology and expressed as

$$E(N,H) = BN^{\eta}(uH)^{1-\eta} \text{ , } \eta > 1-\eta, \tag{2}$$

where, E is the output of the environmental sector, N is the environmental capital, u is the share of knowledge capital spent on environment production and B is the productivity in the environmental sector. Environmental capital can be viewed as environmental quality or nature resources.[1] Equation (2) implies that environment production requires capital input; moreover, environment itself is an important input in its own production. This is the concept of renewable resources as pointed out by Clark (1976). There is obviously a trade-off that the decision maker needs to decide how many knowledge capitals should be put between goods production and environment production. The condition that $\eta > (1-\eta)$ for the environmental sector implies that the renewability of natural resources is more important than capital input in the production of new environment, or the production of environment sector involves a more environmental capital-intensive process. The law of motion for human capital and environmental capital evolved as

$$\dot{H} = A(1-u)H - C - \delta H \tag{3}$$

$$\dot{N} = BN^{\eta}(uH)^{1-\eta} - R - \delta N \tag{4}$$

Where, C is the consumption of final goods and R denotes the consumption of environment. For simplicity the depreciation of knowledge and environmental capital δ is assumed the same.[2] The depreciation of natural capital may be due to either the destruction of environment during goods production or nature depletion of the resources.

2.2 Preferences

In the literature the representative household consumes only final goods,

[1] Thereafter, the terms environmental quality and renewable resources are interchangeable in the text.

[2] The adoption of different depreciation rates for knowledge and environment capitals does not change the main results of the model.

however, in the model environment is also considered as a kind of consumption goods in household's utility as household apparently demands better environment and enjoys the improvement in the environmental quality.[3] Thus, the utility of the representative household is expressed as

$$U(C,R) = \frac{C^{1-\theta}-1}{1-\theta} + \frac{R^{1-\theta}-1}{1-\theta} \tag{5}$$

where, C and R are the consumption of final goods and environment, respectively, and θ is the inverse of intertemporal elasticity of substitution, which is assumed constant over time and is the same for both goods and environment consumption.

III. Equilibrium analysis

According to the setup in section 2, the infinite-lived household maximizes his intertemporal utility defined by equation (5) at any given point of time subject to the resource constraints of equations (3) and (4) given the initial values of knowledge and environmental capital, that is

$$Max \quad \int_0^\infty e^{-\rho t}\left(\frac{C^{1-\theta}-1}{1-\theta} + \frac{R^{1-\theta}-1}{1-\theta}\right)dt$$

$$Subject\ to \quad \dot{H} = A(1-u)H - C - \delta H$$

$$\dot{N} = BN^{\eta}(uH)^{1-\eta} - R - \delta N$$

where constant ρ is the discount rate of time preference. Let ν and μ be the current value of shadow prices for knowledge capital and environmental capital, respectively. The first order conditions for the solution of optimization are

$$C^{-\theta} = \nu\,, \tag{6}$$

$$R^{-\theta} = \mu\,, \tag{7}$$

$$\nu A H = \mu(1-\eta)B\left(\frac{uH}{N}\right)^{-\eta} H\,, \tag{8}$$

$$\nu[A(1-u)-\delta] + \mu(1-\eta)B\left(\frac{uH}{N}\right)^{-\eta} u = \rho\nu - \dot{\nu}, \tag{9}$$

$$\mu\left[\eta B\left(\frac{uH}{N}\right)^{1-\eta} - \delta\right] = \rho\mu - \dot{\mu}, \tag{10}$$

and the transversality conditions are

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[3] Some papers treat pollution as a bad in household's utility function, see, for example. .

$$\lim_{t\to\infty} e^{-\rho t}\nu(t)H(t) = \lim_{t\to\infty} e^{-\rho t}\mu(t)N(t) = 0. \tag{11}$$

Equations (6) and (7) show that the marginal utility of consumption for final goods and environment equals to their shadow price respectively, and equation (8) implies that the marginal revenue products of knowledge capital are equal across sectors. Given any point in time, the decision maker's optimization also satisfied the condition that the marginal rate of substitution between the consumption of final goods and environment equals to their relative price, *P*, which is just the ratio of the shadow prices of the environmental capital and knowledge capital. This gives

$$\left(\frac{C}{R}\right)^{\theta} = P = \frac{\mu}{\nu} = \frac{A}{B(1-\eta)}\left(\frac{uH}{N}\right)^{\eta}. \tag{12}$$

Let $g_i = \dot{i}/i$, from equations (8), (9), and (10) we thus obtain the growth rate of shadow price for knowledge and environment capitals

$$-g_{\nu} = A - \delta - \rho, \tag{13}$$

$$-g_{\mu} = \eta B\left(\frac{uH}{N}\right)^{1-\eta} - \delta - \rho. \tag{14}$$

Taking logarithmic form for equations (6) and (7) and differentiating with respect to time *t* together with the results in equations (13) and (14) yields the growth rates for goods consumption and environment consumption

$$g_C = \frac{1}{\theta}\left(A - \delta - \rho\right), \tag{15}$$

$$g_R = \frac{1}{\theta}\left[\eta B\left(\frac{uH}{N}\right)^{1-\eta} - \delta - \rho\right]. \tag{16}$$

From equations (12), (13), and (14) gives

$$g_P = g_{\mu} - g_{\nu} = A - \eta B\left(\frac{uH}{N}\right)^{1-\eta}, \tag{17}$$

or

$$g_P = A - \eta B\left(\frac{A}{B(1-\eta)}\right)^{\frac{\eta-1}{\eta}} P^{\frac{1-\eta}{\eta}}. \tag{18}$$

From equation (18), $(\partial g_P / \partial P) < 0$, which ensures the stability of the system and the existence of a steady state. From equation (17), the steady state value of *P* is

$$P^* = \left(\frac{A}{B(1-\eta)}\right)\left(\frac{A}{\eta B}\right)^{\frac{\eta}{1-\eta}}. \tag{19}$$

From equation (12), in steady state the ratio of goods consumption and environment consumption is equal to

$$\left(\frac{C}{R}\right)^* = \left(P^*\right)^{1/\theta}. \tag{20}$$

Equations (19) and (20) imply that in state steady the ratio of environmental capital to knowledge capital will be constant so is the ratio of final goods consumption and environment consumption, which in turn depends on the structure (*A*, *B*, and η) of the economy. Therefore, in steady state the system has a balanced growth path

$$g_C = g_R = g_N = g_H = \frac{1}{\theta}\left[A - \delta - \rho\right]. \tag{21}$$

IV. Transitional Dynamics

From equations (3) and (4), the growth rates of knowledge capital and environmental capital are

$$g_H = A(1-u) - \frac{C}{H} - \delta\,, \tag{22}$$

$$g_N = Z - \frac{R}{N} - \delta\,, \tag{23}$$

where, $Z = B\left(\frac{uH}{N}\right)^{1-\eta}$ stands for the average product of renewable resources in the environment sector. *Z* increases as knowledge capital accumulates, while it diminishes as environment capital accumulates. Therefore, the value of *Z* governs the transitional dynamics of the system and can also be viewed as an index for the renewability of the environment.

Taking logarithmic transformation of equation (12) and then differentiating with respect to time *t* gives

$$g_P = \eta(g_u + g_H - g_N)\,. \tag{24}$$

Combining with equations (17), (22), and (23) gives the growth rate of share of knowledge capital devoted in environment sector

$$g_u = \chi - A(1-u) - \varphi + \frac{A}{\eta}\,, \tag{25}$$

where $\chi = C/H$ and $\varphi = R/N$. Defined the ratio of environmental capital to knowledge capital as $w = N/H$, and from equations (15), (16), (22), and (23) the transitional dynamics of the system can be summarized by the evolutions of χ, φ, and w, which are

$$g_\chi = g_C - g_H = \frac{1}{\theta}(A - \delta - \rho) + \chi - A(1-u) + \delta\,, \tag{26}$$

$$g_{\varphi} = g_R - g_N = \frac{1}{\theta}[\eta Z - \delta - \rho] - Z + \varphi + \delta\,, \tag{27}$$

$$g_w = g_N - g_H = \chi - A(1-u) - \varphi + Z\,. \tag{28}$$

In the steady state, equations (25) (28) will all converge to zero. Equation (20) renders $\frac{\chi^*}{w^*} = \varphi^*\left(P^*\right)^{1/\theta}$ and the steady state values of the respective variables are

$$Z^* = \frac{A}{\eta}\,, \tag{29}$$

$$\varphi^* = A\left[\frac{\rho + \delta(1-\theta)}{A\theta} + \frac{1}{\eta} - \frac{1}{\theta}\right], \tag{30}$$

$$u^* = \frac{A - \frac{1}{\theta}\left[A - \rho - \delta(1-\theta)\right]}{A + \Omega}\,, \tag{31}$$

$$\chi^* = \Omega\left\{\frac{A - \frac{1}{\theta}\left[A - \rho - \delta(1-\theta)\right]}{A + \Omega}\right\}, \tag{32}$$

$$w^* = \frac{A - \frac{1}{\theta}\left[A - \rho - \delta(1-\theta)\right]}{A + \Omega}\left(\frac{A}{\eta B}\right)^{\frac{-1}{1-\eta}}, \tag{33}$$

where $\Omega = \varphi^*\left(P^*\right)^{1/\theta}\left(\frac{A}{\eta B}\right)^{\frac{-\eta}{1-\eta}}$.

Together with equations (25), (28), and (29), the transitional dynamics reduced to

$$g_Z = (1-\eta)(g_u - g_w) = -(1-\eta)(Z - Z^*)\,, \tag{34}$$

$$g_P = \eta(g_u - g_w) = -\eta(Z - Z^*)\,, \tag{35}$$

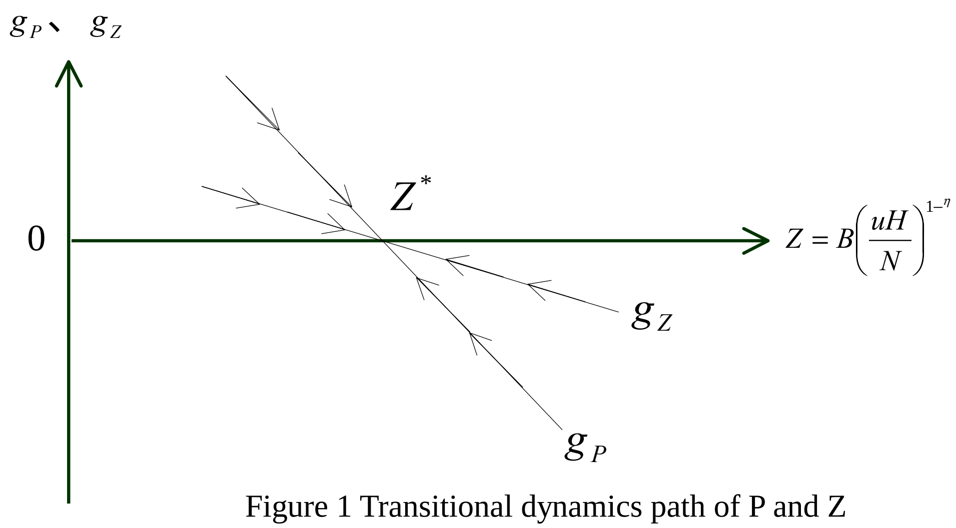

Figure 1 Transitional dynamics path of P and Z

Figure 1 depicts the paths of transitional dynamics. When the economy starts with abundant environmental capital relative to knowledge capital, i.e., lower value of *Z*, it will start to accumulate knowledge capital and stimulates goods production. During the transition the average product of renewable resources and the relative price of the environment sector to final goods sector will all increase and approach toward their steady states. This is because the depletion of environment increases the marginal utility of environment consumption, while the increase in final goods production reduces the marginal utility of final goods consumption. In contrast, if the economy starts at abundant knowledge capital relative to environment capital, i.e., the value of *Z* is high. This implies that the economy is relatively scare of environment and the marginal utility of environment consumption is greater than the marginal utility of final goods consumption, therefore the environmental quality becomes a big issue and the economy starts to accumulate environmental capital and devotes more knowledge capital on environment sector. Hence, during the steady state the average product of renewable resources and the relative price of the environment sector to final goods sector all decrease and approach toward their steady states.

As for the transitional paths of u, φ and χ, substituting equations (29) (32) into (25) (27) gives

$$g_u = A(u-u^*) - (\varphi - \varphi^*) + (\chi - \chi^*), \tag{36}$$

$$g_\varphi = \left(\frac{\eta - \theta}{\theta}\right)(Z - Z^*) - (\varphi - \varphi^*), \tag{37}$$

$$g_\chi = A(u-u^*) + (\chi - \chi^*). \tag{38}$$

Combining equations (36) (38) with (34) and assuming $\theta > \eta$ yields the transitional dynamic of *Z*, u, φ, and χ

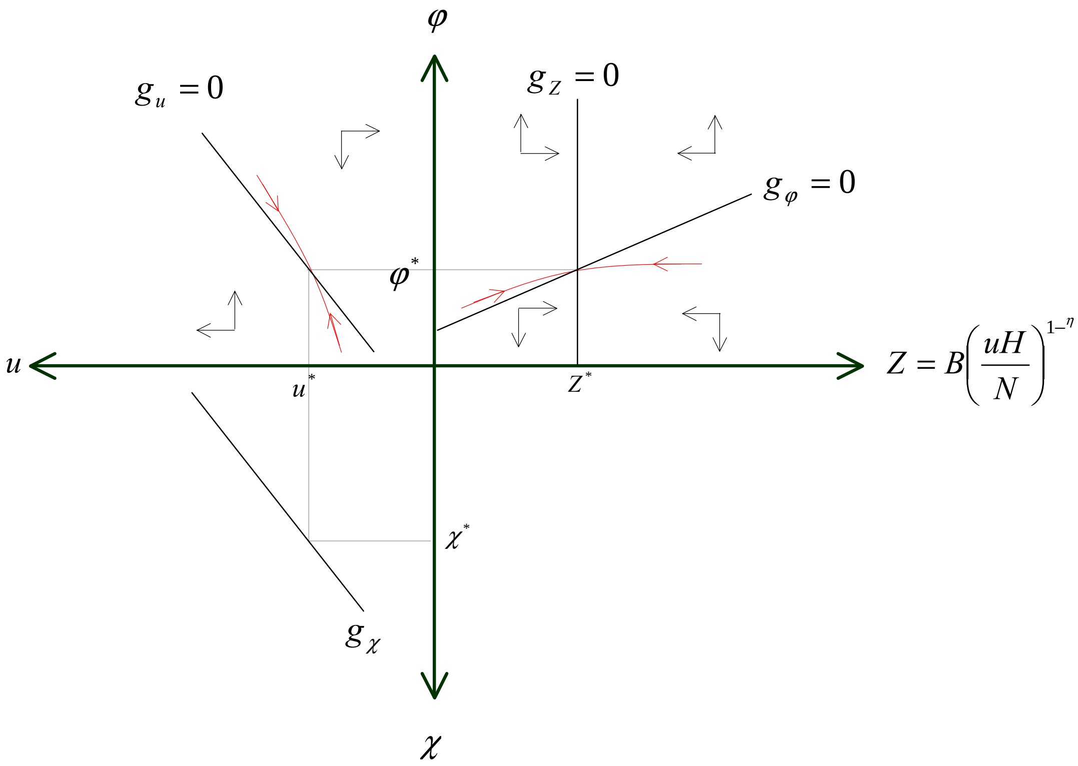

Figure 2. The transitional dynamics of Z , u , φ and χ

From Figure 2, if initial values of $Z(0)$, $\varphi(0)$, and $u(0)$ are below their steady state values, Z, u, and φ will all increase over time towards their steady state values. This represents that as the economy begins to growth, people starts to accumulate the relatively scared knowledge capital, while the environmental quality deteriorates as the consumption of environment increases and the environment capital depletes. Hence the ratio of environment consumption to environment capital, φ, also rises. Therefore, in order to balance the relative decline of environmental quality more inputs of knowledge capital will be drawn from final goods sector to environment sector as the decision maker also cares about environment consumption.

In contrast, if the initial $Z(0)$, $\varphi(0)$, and $u(0)$ are greater than their steady state values, i.e., the economy is in its over-production situation as the ratio of knowledge capital is relatively higher than environment capital, environmental quality becomes a great issue and people care about the environment and hence people starts to reduce environment consumption and accumulates environment capital. Hence the ratio of environment consumption to environment capital, φ, will decrease. However, in order to maintain the level of final goods consumption the share of knowledge capital will shift more towards goods production. Therefore, the improvement of environment needs not to scarify the path of economic growth. It is clear from the discussion of transitional dynamics that if the decision maker cares about both final goods consumption and environment consumption under the interaction of economic system and ecology system, the goals of economic growth and environment quality need not be conflicted each other and there is a way for win-win solution.

V. Comparative statics

5.1 Technological improvement in the final goods sector

We first consider the impact of technological change on the final goods sector, i.e., a permanent increase of productivity parameter A. From equations (29) (31), we have

$$(\partial Z^* / \partial A) > 0, (\partial \varphi^* / \partial A) > 0, \text{ and } (\partial u^* / \partial A) \gtrless 0.$$

This can be shown in Figure 3.

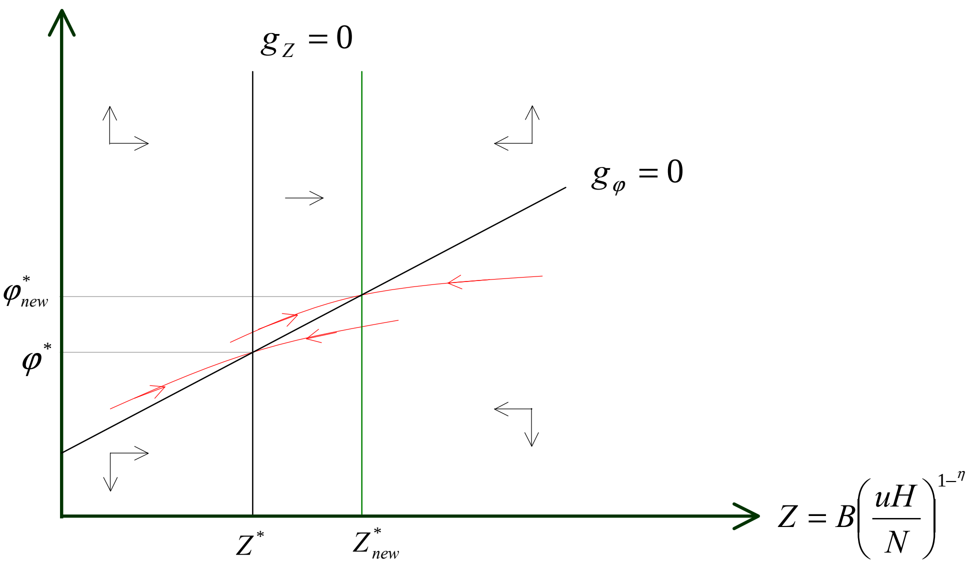

Figure 3. The effect of technological improvement in the final goods

From figure 3, the improvement in the technology of final goods sector will shift g_Z curve to the left and leave g_ϕ curve intact. This will result in the increase of the steady state values of Z^* and φ^*. The reason is that the improvement in the technology of final goods sector encourages the accumulation of knowledge capital and also increases the consumption of environment. From equations (19) and (21), the relative price of the two sectors will also increase and so is the long-run growth rate of the economy.

The uncertainty effect on the share of knowledge capital spent on environment sector, u, is mainly due to two offsetting forces: The technology improvement in the final goods sector will increase the marginal product of knowledge capital, hence more knowledge capital will be drawn to the final goods sector, while the technology improvement in the final goods sector will also drive up the average product of renewable resources, Z^*, hence induces more knowledge capital to engage in the reproduction of environment sector. Therefore, the impact on u^* depends on the net effect of these two competing forces.

5.2 Technological improvement in the environment sector

A technological improvement in the environment sector reflects in the increase of parameter B, which will shift g_u curve up and leave g_Z and g_ϕ unchanged (see Figure 4). Comparative statics shows that $(\partial Z^* / \partial B) = 0$, $(\partial \varphi^* / \partial B) = 0$, and $(\partial u^* / \partial B) < 0$. The technological improvement in the environment sector does not change the steady state values of Z and φ, hence the economy's long-run growth rate remains the same. This is because the source of economic growth is mainly driven by the accumulation of knowledge capital, which does not be influenced by the production structure of environment sector. However, the share of knowledge capital spent on environment sector will decrease. This is because for producing a given level of environment the increase in the environment productivity will result in less input of knowledge capital in that sector. From equation (19), it gives $(\partial P^* / \partial B) < 0$. Thus, productivity improvement in the environment sector will reduce the relative price of the two sectors.

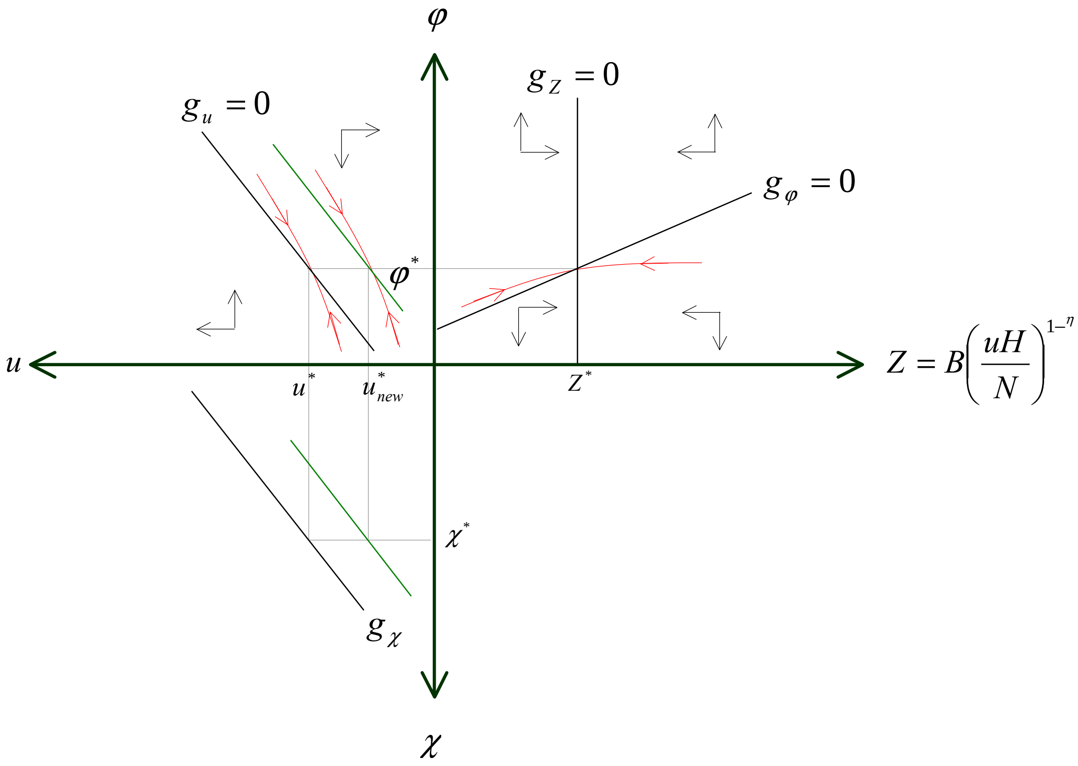

Figure 4. The technological improvement in the environment sector

VI. Discussion and Conclusion

This paper constructs a two-sector growth model by allowing economic system to interact with ecological system in which the decision maker cares not only material goods consumption but also the consumption of the environment. We show that there need not exist a trade-off between economic growth and preserving of environmental quality. On the contrary, there is a win-win solution that in the long run the economic growth and environment quality can go hand in hand following a balanced growth path.

When the economy starts at its early developmental stage with a relatively lower level of knowledge capital compared to that of environment capital, the transitional dynamics will begin by accumulating knowledge capital to foster economic growth, as a result the consumption of environment will also increase which deteriorates the environmental quality as most of the developing countries did. However, people cares about environmental quality too, in order to compensate the decline in environmental quality the decision maker will draw a larger share of knowledge capital into environment sector to uphold the level of environment. Therefore, in the long run both goods production and environment can growth at the same rate. The whole transitional process depicts the pattern of so-called Environmental Kuznet's Curve. If the economy starts at a relatively higher level of knowledge capital with respect to environment capital, a situation characterized by most of the developed countries, the transitional dynamics will begin by consuming less of the environment to accumulate the relative scarce environmental capital and produces higher environmental quality. However, in order to maintain the level of final goods consumption, the decision maker will increase the share of knowledge capital input in the final goods production. As a result, in the long run both goods production and environmental quality grow at a balanced rate.

If the technology improves in the final goods sector, the technological improvement in the final goods sector will increase the marginal product of knowledge capital and hence stimulates the accumulation of knowledge capital. The expansion of final goods sector will also induce more consumption of the environment and the accumulation of knowledge also augments the production of environment. Hence, the long run growth rates of final goods production and environment will all increase. However, the impact on the share of knowledge capital spent on environment sector is uncertain depending on the net effect of the two competing forces. Productivity effect draws knowledge capital away from environment sector, while the accumulation of knowledge capital enhances the average product of renewability of the natural resources, and in turn attracts more knowledge capital to be put into environment sector. Hence, the technological improvement in the final good sector is beneficial to the long run growth of the economy and the environment as well.

If the technological improvement is in the environment sector, it will not affect the accumulation of knowledge capital, therefore, no effect on long run growth rate. However, for a given output level of environment sector, the increase in the productivity of the sector will result in a decrease of the input of knowledge capital in environment sector. Hence, the share of knowledge capital spent on the production of environment sector will be declined.

Thus, the policy implications of the paper are that both policies in fostering technological improvement of goods or environment sector are beneficial for each other. The productivity increase in environment sector will free more knowledge capital that can be used in the final goods sector, while the productivity growth in goods sector also enhances the average product of the renewable resources and hence induces the accumulation of environmental capital and improvement in the environmental quality. The development of goods technology can actually lead to a better environment!

Finally, as the accumulation of environmental capital is helpful for the renewability of the resources and environmental quality is valued by the decision maker, therefore, in term of the concept of Green GDP this paper suggests that the value of increments in environmental capital through technological change or putting more capital input into the environment sector should be also taken into account, no merely considering the consumption or depletion of the environment due to goods production.

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