Non-Renewable Resources and the Possibility of Sustainable Economic Development in a Positive or Negative Population Growth Economy

Sasaki, Hiroaki

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Hiroaki Sasaki†

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Abstract

The purpose of this study is to investigate how the long-run growth rate of per capita output is determined when an economy is subject to non-renewable resource constraints and the population growth is negative by using a theoretical model. From this, we can examine the effect of population decline and the effect of depletion of natural resources on economic growth. Our results show that irrespective of whether the population growth rate is positive or negative, the long-run growth rate of per capita output can be positive depending on conditions. This result suggests that even an economy with non-renewable resources and declining population can obtain sustainable economic growth.

Keywords: non-renewable resources; declining population; endogenous growth

JEL Classification: O13; O44; Q32; Q43

1 Introduction

So far, there have been many studies that investigate how non-renewable resources such as petroleum and natural gas affect economic growth. For example, Stiglitz (1974) models a situation in which final goods production needs capital stock, labor, and non-renewable resources, and shows that technological progress is necessary for sustainable economic

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†Graduate School of Economics, Kyoto University. E-mail: sasaki@econ.kyoto-u.ac.jp

growth.[1] Non-renewable resources will be constraints on economic growth. To alleviate these constraints, some researchers have developed growth models in which resource-saving technical change is endogenously produced. For example, Suzuki (1976) presents a growth model in which investment in research and development activity by firms accumulates knowledge stock, which leads to technological progress.[2]

At the same time, there have been many studies that investigate whether population growth will be a constraint on economic growth. The seminal paper of Jones (1995) presents a semi-endogenous growth model, which is a kind of the endogenous growth model, and shows that the long-run growth rate of per capita output is increasing in population growth.[3] That is, the larger the population growth rate is, the higher the per capita output growth rate is.

Groth and Schou (2002) integrate these two strands of research. They show that even in non-renewable resources constrain economic growth, per capita output can grow sustainably provided that the population growth rate is positive and the production function exhibits increasing returns with respect to capital stock and labor. In their model, increasing returns are merely assumed and are not occurred by some mechanism.[4] Bretschger (2013) incorporates research and development activity of firms into an endogenous growth model with non-renewable resources, and shows that the per capita output growth rate can be positive in the long run as long as population grows.

It is true that world population continues to increase. However, population in developed countries does not grow so much. On the contrary, some countries such as Japan experiences population decline. Table 1 shows that population growth will decelerate over time. For this reason, to investigate how non-renewable resources affect economic growth when population growth is positive and negative, we build an economic growth model that considers both positive population growth and negative population growth.

Few economic growth models consider population decline. Ritschl (1985) shows that if negative population growth is considered in Solow's (1956) model, a negative saving rate is necessary for the steady state per capita capital stock to be positive. Christiaans (2011)

1) For initial contributions that consider the relationship between non-renewable resources and economic growth, see Solow (1974) and Dasgupta and Heal (1974). Malaczewski (2018) points out that capital stock and non-renewable resources are complements and not substitutes assumed in many former studies, and presents a growth model in which capital stock and non-renewable resources are complements.

2) For endogenous growth models that incorporate non-renewable resources into final goods production, see Barbier (1999) and Cabo *et al.* (2016).

3) The semi-endogenous growth model is developed to overcome the problem of scale effects inherent in the endogenous growth model. Scale effects are effects such that the larger the population is, the higher the economic growth is. For scale effects and attempts to remove scale effects, see Jones (1999).

4) Groth (2007) presents a growth model in which production exhibits increasing returns with respect to capital stock, labor, and non-renewable resources because of a positive externality effect arising from capital accumulation. Results obtained are similar to results of Groth and Schou (2002).

	World	Developed countries	Developing countries	Japan
2000	1.3	0.4	1.7	0.2
2010	1.2	0.4	1.5	0
2020	1	0.3	1.3	−0.4
2030	0.9	0.2	1.1	−0.6
2040	0.7	0.1	0.9	−0.8
2050	0.6	0	0.7	−0.9

Table 1: Annual average growth rates of population (%). Source: Statistics Japan (2018)

presents a semi-endogenous growth model in which production exhibits increasing returns to scale due to a positive externality effect of capital accumulation, and investigates whether positive per capita output growth is possible when the population growth rate is negative.[5)] He reveals that the long-run per capita output growth rate can be positive if the absolute value of the negative population growth rate is large. Sasaki (2015) builds a small open economy growth model with negative population growth, and investigates the relationship between trade patterns and economic growth. Sasaki and Hoshida (2017) introduce negative population growth into Jones' (1995) semi-endogenous growth model. These studies find that per capita output can grow sustainably even if population growth is negative. However, all existing studies do not consider non-renewable resources in production.

Population decline is widely believed to have a negative effect on economic growth. For example, in the sustainability of pension system and in tax revenue, reduction of pie of the economy due to population decline seems to have a negative effect on the economy. However, to think economically, it is the level of per capita income that matters for economic welfare. As long as national income is constant, that is, even if the economy does not grow, a decrease in population increases per capita output and improves the economic welfare. Accordingly, a decrease in population does not necessarily have a negative effect on economic welfare.

The main purpose of this paper is to investigate whether or not positive per capita output growth is possible when non-renewable resources are used for final goods production and population growth is positive or negative. Is it possible that the economy grows at a positive rate even when there are two potential negative factors for production, that is, population decline and depletion of natural resources? To tackle this problem, we can investigate how population decline and depletion of natural resources, which actually occur in reality, affect economic growth. Results of our analysis can contribute to policy proposals for the

5) Christiaans (2017) builds a two-sector growth model with negative population growth in which labor moves from a rural sector to an urban sector.

realization of sustainable society.

Our study has two originalities.

First, as stated above, few studies consider negative population growth in the economic growth theory. Almost all existing studies assume positive population growth and do not at all consider the possibility of negative population growth. In reality, because population growth can be negative, those existing studies are not sufficient. The seminal work of Chrisitiaans (2011) shows that incorporating negative population growth into growth models is more complicated than replacing a positive population growth rate with a negative population growth rate. In addition, considering negative population growth in growth models produces interesting results (Christiaans, 2011; Sasaki and Hoshida, 2017; Christiaans, 2017).

Second, to the author's knowledge, no study considers both negative population growth and non-renewable resources in production. Negative population growth and the possibility of depletion of natural resources are observed in reality. To incorporate these two phenomena into a growth model is important when we consider sustainable economic development.

The remainder of this paper is organized as follows. Section 2 presents our growth model with population growth and non-renewable resources. Section 3 examines long-run situations under the assumption that population growth is positive or negative. Section 4 investigates whether long-run growth rate of per capita output can be positive. In doing so, we seek the combination of the population growth rate and the input rate of non-renewable natural resources that generates a positive long-run growth rate of per capita output. Section 5 concludes the paper.

2 Model

Our model is based on the model of Stiglitz (1974) and that of Groth and Schou (2002). The production function of final goods is constant returns to scale with respect to input factors and given by

$$Y = AK^{\alpha}L^{\beta}R^{1-\alpha-\beta}, \quad 0 < \alpha < 1,\ 0 < \beta < 1,\ 0 < \alpha + \beta < 1, \tag{1}$$

where Y denotes output; K, capital stock; L, labor input; R, non-renewable resources; A, total factor productivity; α, capital elasticity of output; β, labor elasticity of output; and $1-\alpha-\beta$, non-renewable resources elasticity of output. We use the Cobb-Douglas production function because we want to investigate an intermediate case with respect to the size of the elasticity of substitution between input factors. When the elasticity of substitution is more than unity, non-renewable resources are not essential in production and not indispensable. When the elasticity of substitution is less than unity, on the other hand, output approaches zero in the long run.[6] To consider that non-renewable resources are essential in production and to investigate the possibility of sustainable economic growth, it is appropriate to use the Cobb-Douglas production function whose elasticity of substitution is unity.

We introduce a positive externality effect related to capital accumulation.

$$A = K^{\gamma}, \quad 0 < \gamma < 1. \tag{2}$$

This can be interpreted as capturing the learning by doing effect of Arrow (1962), and the positive parameter γ captures the extent of positive externality. According to Graham and Temple (2006), such an positive externality is reasonable in reality.

Substituting equation (2) into equation (1), we obtain

$$Y = K^{\alpha+\gamma} L^{\beta} R^{1-\alpha-\beta}. \tag{3}$$

Summing up the exponents, we have $\alpha+\gamma+\beta+1-\alpha-\beta = 1+\gamma > 1$, and hence, production exhibits increasing returns to scale. In contrast, Stiglitz (1974) assumes constant returns to scale and introduces a positive exogenous technological progress rate and a positive population growth rate.

We impose the following restriction on the parameter of the production function:

Assumption 1. *The restriction $\alpha + \gamma < 1$ holds.*

This assumption implies that production is diminishing returns to capital stock, and the extent of increasing returns to scale is not so large. If $\alpha + \gamma > 1$, then Y will be infinity within finite time, which is unrealistic. If $\alpha + \gamma = 1$, then we have an AK growth model as long as both L and R are fixed, which produces endogenous growth. However, since both L and R are not fixed in reality, this case is also unrealistic.

To find a technologically feasible growth rate and to simplify analysis, we assume that saving is a constant fraction s of output.[7] From the goods market equilibrium condition, gross investment and saving are equal. Hence, net investment is given by

$$\dot{K} = sY - \delta K, \quad 0 < s < 1,\ 0 \leq \delta < 1, \tag{4}$$

6) For the debate on the role of the size of the elasticity of substitution in the economic growth model with non-renewable resources, see Groth (2007).

7) As stated above, we consider negative population growth as well as positive population growth. An analysis of the optimal growth path with dynamic optimization in the negative population growth case will be left for future research.

where δ denotes the capital depreciation rate. The assumption of the constant saving rate is also recently used by Malaczewski (2018) who investigates the relationship between non-renewable resources and economic growth.

We assume that labor is fully employed. For ease of exposition, we assume that labor is equal to population and that population grows at a constant rate.

$$\frac{\dot{L}}{L} = n \gtreqless 0. \tag{5}$$

The population growth rate can be positive, zero, or negative.

The initial stock of non-renewable resources is given by

$$S(0) = S_0 > 0. \tag{6}$$

Since non-renewable resources will decrease due to input into production, we can obtain the following relation:

$$\dot{S} = -R. \tag{7}$$

Therefore, the following constraint holds.

$$\int_0^{+\infty} R(t)\, dt \leq S_0. \tag{8}$$

Suppose that the input rate of non-renewable resources is s_R. Then, we obtain

$$R = s_R S. \tag{9}$$

Here, according to Jones and Vollrath (2013), we assume that s_R is constant through time. This assumption is reasonable in investigating the long-run situation. From this, we have $\dot{S} = -s_R S$, which leads to

$$\frac{\dot{S}}{S} = -s_R < 0. \tag{10}$$

Accordingly, we obtain

$$\frac{\dot{R}}{R} = -s_R < 0. \tag{11}$$

Therefore, R continues to decrease at a constant rate.

For the analysis of dynamics, we introduce the following variable, that is, the output-capital ratio

$$z \equiv \frac{Y}{K}. \tag{12}$$

On the balanced growth path, the output-capital ratio z is constant. Taking logarithms of the production function and differentiating the resultant expression with respect to time, we obtain

$$g_Y = (\alpha + \gamma)g_K + \beta g_L + (1 - \alpha - \beta)g_R \tag{13}$$
$$= (\alpha + \gamma)(sz - \delta) + \beta n - (1 - \alpha - \beta)s_R, \tag{14}$$

where g_x denotes the growth rate of a variable x and $g_x = \dot{x}/x$. From equation (4), we obtain $g_K = sz - \delta$.

Using $g_K = sz - \delta$ and equation (14), we obtain the dynamical equation of z as follows:

$$\dot{z} = [-s(1 - \alpha - \gamma)z + \Theta]z, \tag{15}$$
$$\text{where } \Theta \equiv (1 - \alpha - \gamma)\delta + \beta n - (1 - \alpha - \beta)s_R. \tag{16}$$

The set of the parameters Θ can be positive or negative. When the capital depreciation rate δ is large, the population growth rate n is positive, Θ is likely to be positive. When the input rate of non-renewable resources s_R is large, the extent of capital externality γ is large, and the population growth rate n is negative, Θ is likely to be negative.

Finally, the growth rate of per capital output $y = Y/L$ is given by

$$g_y = g_Y - n = s(\alpha + \gamma)z - (\alpha + \beta)\delta + (\beta - 1)n - (1 - \alpha - \beta)s_R. \tag{17}$$

This equation depends on z, and hence, g_y changes with a change in z.

3 Long-run situations

We must note that long-run values such that $\dot{z} = 0$ are different according the sign of Θ. Hence, we proceed analysis according to the sign of Θ.

When $\Theta > 0$, the dynamics of z is represented in Figure 1, which shows that z stably converges to the following value:

$$z^* = \frac{\Theta}{s(1 - \alpha - \gamma)} > 0, \tag{18}$$

where "$*$" denotes a value on the balanced growth path.

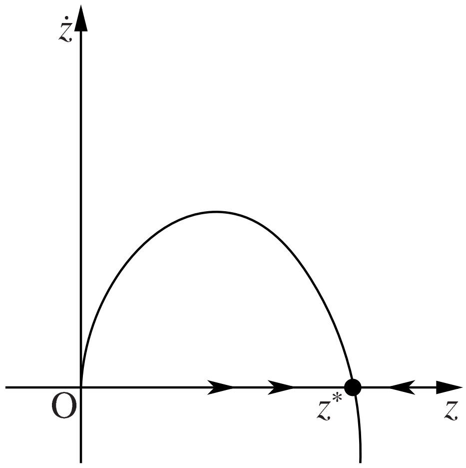

Figure 1: Convergence to long-run equilibirum z^* when $\Theta > 0$

In this case, the economic growth rate and the per capita output growth rate are given by

$$g_K^* = g_Y^* = \frac{\beta n - (1 - \alpha - \beta)s_R}{1 - \alpha - \gamma}, \tag{19}$$

$$g_y^* = g_Y^* - n = \frac{(\alpha + \beta + \gamma - 1)n - (1 - \alpha - \beta)s_R}{1 - \alpha - \gamma}. \tag{20}$$

When $\Theta < 0$, the dynamics of z is represent by Figure 2, which shows that z asymptotically approaches zero. In this case, we cannot obtain balanced growth. However, we can investigate a long-run situation such that $t \to +\infty$. Christiaans (2011) investigates the negative population growth in the Solow-type growth model and explains that the situation $z = 0$ is never achieved and $z = 0$ is infinitely far away. Therefore, in this sense, $z = 0$ is not a usual steady state but an asymptotic steady state.

When $z \to 0$, we obtain $\lim_{t\to+\infty} g_K = -\delta < 0$ from $g_K = sz - \delta$. Hence, the capital accumulation rate and the output growth rate in the long run are given by

$$g_K^{**} = -\delta < 0, \tag{21}$$

$$g_Y^{**} = -(\alpha + \gamma)\delta + \beta n - (1 - \alpha - \beta)s_R < 0, \tag{22}$$

where "$**$" denotes a asymptotic long-run value. Since $\Theta = \delta-(\alpha+\gamma)\delta+\beta n-(1-\alpha-\beta)s_R < 0$, we have $g_Y^{**} < 0$. The per capita output growth rate is given by

$$g_y^{**} = g_Y^{**} - n = -(\alpha + \gamma)\delta + (\beta - 1)n - (1 - \alpha - \beta)s_R. \tag{23}$$

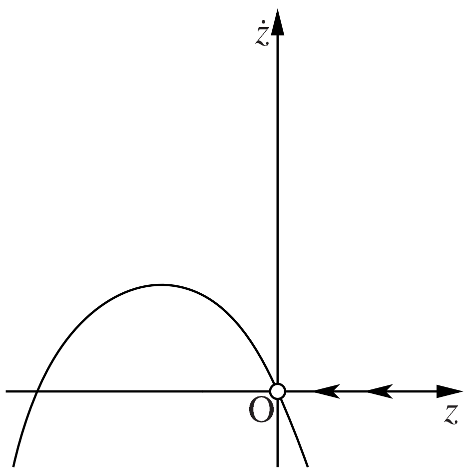

Figure 2: Asymptotic approach to $z = 0$ when $\Theta < 0$

As stated above, we cannot have $z = 0$ within finite time, g_y^{**} means the asymptotic per capita output growth rate. As long as $z > 0$, the per capita output growth rate is given by equation (17). Hence, an increase in the saving rate s increases the per capita output growth rate. In this sense, when $\Theta < 0$, the semi-endogenous growth model can be the endogenous growth model (Christiaans, 2011).

4 Possibility of positive per-capita output growth

In the following analysis, we examine the conditions under which g_y^* and g_y^{**} are positive. For this purpose, we focus ourselves on the two parameters n and s_R, and find combinations of n and s_R that produce a positive growth rate of per capita output.

To begin with, we find regions of (n, s_R) such that $\Theta > 0$ or $\Theta < 0$.

$$\Theta \gtrless 0 \Longrightarrow s_R \lessgtr \frac{\beta}{1-\alpha-\beta} n + \frac{(1-\alpha-\gamma)\delta}{1-\alpha-\beta} \quad \text{(double-sign corresponds).} \tag{24}$$

The boundary is a straight line with positive slope and a positive intercept. With $s_R > 0$, we can draw Figure 3. The value of n_1 in Figure 3 is given by

$$n_1 = -\frac{(1-\alpha-\gamma)\delta}{\beta} < 0. \tag{25}$$

We have $\Theta > 0$ below the boundary while we have $\Theta < 0$ above the boundary.

Next, we find regions of (n, s_R) such that $g_y^* > 0$ in the case of $\Theta > 0$. From equation

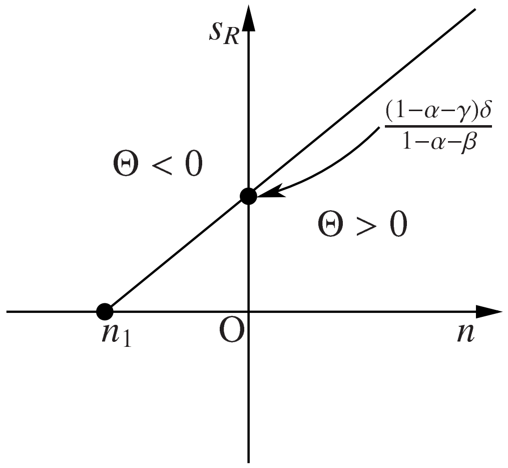

Figure 3: Region of $\Theta > 0$ and region of $\Theta < 0$

(20), we obtain

$$g_y^* > 0 \Longrightarrow s_R < \frac{\alpha + \beta + \gamma - 1}{1 - \alpha - \beta} n \tag{26}$$

The boundary is straight line through the origin. The slope of boundary is positive when $\alpha + \beta + \gamma - 1 > 0$ and negative when $\alpha + \beta + \gamma - 1 < 0$. When $\alpha + \beta + \gamma - 1 > 0$, production exhibits increasing returns with respect to labor and capital. On the other hand, when $\alpha + \beta + \gamma - 1 < 0$, production exhibits decreasing returns with respect to labor and capital. Note that even when production exhibits decreasing returns with respect to labor and capital, it exhibits increasing returns to scale, that is, with respect to all factor inputs (K, L, R). When $\alpha + \beta + \gamma - 1 > 0$, the slope of the boundary of $g_y^* > 0$ is always smaller than the slope pf the boundary of $\Theta > 0$. Regions such that both $\Theta > 0$ and $g_y^* > 0$ are shown in Figures 4–7. Figures 5 and 7 corresponds to the case in which the capital depreciation rate is zero. If the capital depreciation rate is zero, from Figure 7, we see that we cannot obtain $g_y^{**} > 0$ when both $\Theta > 0$ and $\alpha + \beta + \gamma < 1$ hold.

Then, we find regions of (n, s_R) such that $g_y^{**} > 0$ in the case of $\Theta < 0$. From equation (23), we obtain

$$g_y^{**} > 0 \Longrightarrow s_R < -\frac{1 - \beta}{1 - \alpha - \beta} n - \frac{(\alpha + \gamma)\delta}{1 - \alpha - \beta}. \tag{27}$$

The boundary is a straight line with negative slope and a negative intercept. The value of n_2

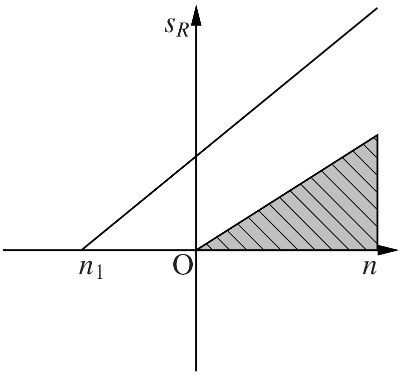

Figure 4: Regions of (n, s_R) such that $g_y^* > 0$ when $\Theta > 0$, $\alpha + \beta + \gamma > 1$, and $\delta > 0$

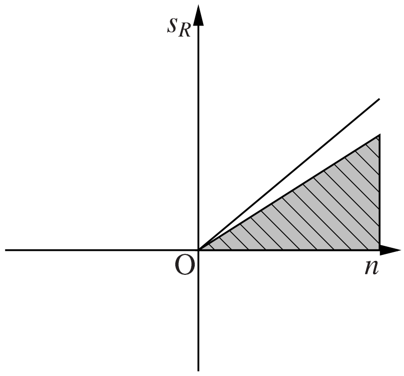

Figure 5: Regions of (n, s_R) such that $g_y^* > 0$ when $\Theta > 0$, $\alpha + \beta + \gamma > 1$, and $\delta = 0$

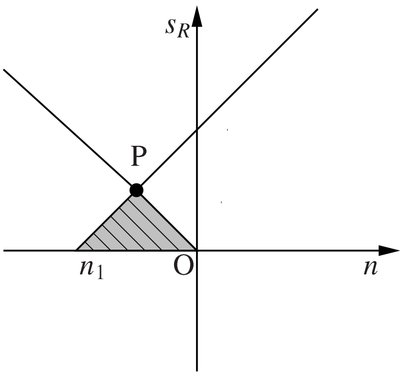

Figure 6: Regions of (n, s_R) such that $g_y^* > 0$ when $\Theta > 0$, $\alpha + \beta + \gamma < 1$, and $\delta > 0$

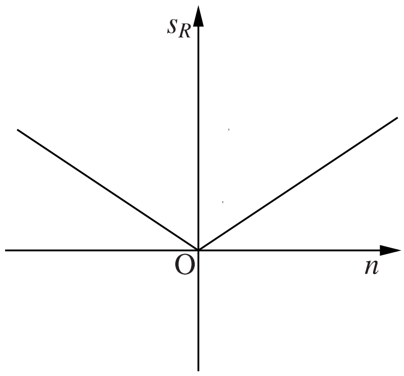

Figure 7: Regions of (n, s_R) such that $g_y^* > 0$ when $\Theta > 0$, $\alpha + \beta + \gamma < 1$, and $\delta = 0$ (empty set)

in Figure 8 is given by

$$n_2 = -\frac{(\alpha+\gamma)\delta}{1-\beta} < 0. \tag{28}$$

We investigate which is larger, n_1 and n_2. Since we have

$$n_1 - n_2 = \frac{(\alpha+\beta+\gamma-1)\delta}{\beta(1-\beta)}, \tag{29}$$

we obtain the following relation:

$$\alpha+\beta+\gamma-1 \gtreqless 0 \Longrightarrow n_1 \gtreqless n_2 \quad \text{(double-sign corresponds)}. \tag{30}$$

Regions such that both $\Theta < 0$ and $g_y^{**} > 0$ are shown in Figures 8–10. Figure 9 corresponds to the case in which the capital depreciation rate is zero. When the capital depreciation rate is zero, Figures 8 and 10 will be Figure 9.

The corodinates of point P in Figures 6 and 10 are identical and given by

$$n = -\delta < 0, \tag{31}$$

$$s_R = \frac{(1-\alpha-\beta-\gamma)\delta}{1-\alpha-\beta} < 1. \tag{32}$$

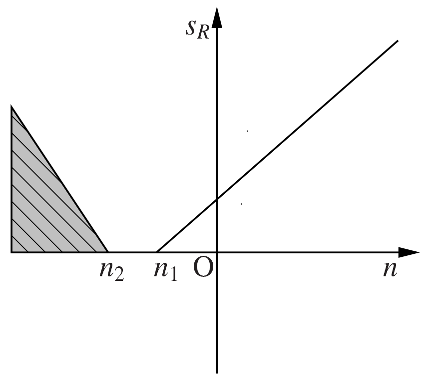

Figure 8: Regions of (n, s_R) such that $g_y^* > 0$ when $\Theta < 0$, $\alpha+\beta+\gamma > 1$, and $\delta > 0$

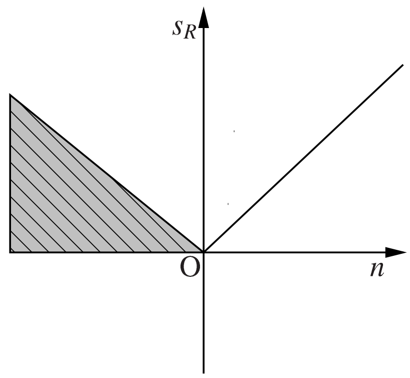

Figure 9: Regions of (n, s_R) such that $g_y^* > 0$ when $\Theta < 0$, $\alpha+\beta+\gamma > 1$, and $\delta = 0$

According to the combinations of the signs of Θ and $\alpha+\beta+\gamma-1$, we classify four cases as follows:

Case 1 : $\Theta > 0$ and $\alpha+\beta+\gamma > 1$

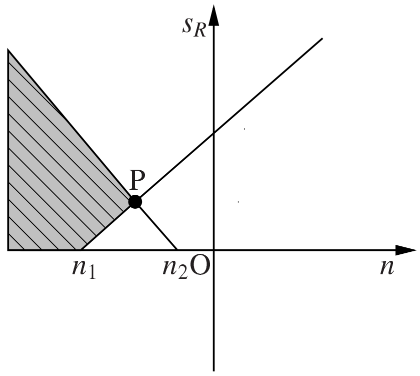

Figure 10: Regions of (n, s_R) such that $g_y^* > 0$ when $\Theta < 0$, $\alpha + \beta + \gamma < 1$, and $\delta > 0$

Case 2 : $\Theta > 0$ and $\alpha + \beta + \gamma < 1$

Case 3 : $\Theta < 0$ and $\alpha + \beta + \gamma > 1$

Case 4 : $\Theta < 0$ and $\alpha + \beta + \gamma < 1$

Based on Figures 4, 6, 8, and 10, we investigate the combinations of n and s_R that produce $g_y > 0$ in the long run.

Case 1 : This case corresponds to Figure 4. If the population growth rate is positive and large, the positive per capita output growth rate is possible even if the non-renewable resources input rate is large. It is this case that Groth and Schou (2002) and Groth (2007) investigate. They show that as long as the population growth rate is positive and production is increasing returns with respect to labor and capital, the positive per capita output growth rate is possible even when non-renewable resources are essential in production. We obtain the same result in Case 1 in our model. The long-run per capita output growth rate can be positive because the positive effect of increasing returns with respect to labor and capital on Y dominates the negative effect of a decrease in R on Y.

Case 2 : This case corresponds to Figure 6. When production is decreasing returns with respect to labor and capital, the positive per capita output growth rate is possible if the population growth rate is negative. However, the combinations (n, s_R) that produce $g_y^* > 0$ are limited. Christiaans (2011) shows that with the negative population growth rate and the positive capital depreciation rate, one can obtain the positive per capita output growth rate when the absolute value of $n < 0$ is relatively large. In contrast, in our model that incorporates non-renewable resources, we can obtain the positive per capita output growth rate even when the absolute value of $n < 0$ is relatively small because of the introduction of $s_R > 0$. The reason why we obtain Case 2 is opposite to the reason why we obtain Case 1. When production is diminishing return with respect to labor and capital, an increase in labor (i.e., population) has a negative effect on the level of per capita output. In contrast, a decrease in labor has a positive effect on the level of per capita output. From this, in the case of diminishing returns with respect to labor and capital, a decrease in population positively affects the long-run growth rate of per capita output. Note that Case 2 is impossible when the capital depreciation rate is zero (Figure 7).

Case 3 : This case corresponds to Figure 8. Even if s_R is large, the positive per capita output growth rate is possible when the population growth rate is negative and its absolute value is large. In this case, all production factors—capital stock, labor, and non-renewable resources—continues to decrease through time. Then, total output Y continues to decrease. However, a decrease in population increases per capita output $y = Y/L$ if other conditions are constant. When a positive effect of a decrease in labor on per capita output dominates a negative effect of a decrease in labor on per capita output, per capita output increases. This positive effect gets larger as the absolute value of $n < 0$ gets larger.

Case 4 : This case corresponds to Figure 10. This case is basically similar to Case 3. When the capital depreciation rate is zero, Cases 3 and 4 are identical, which shows that the positive per capita output growth rate is possible even if the absolute value of $n < 0$ is small (Figure 9).

From the above analysis, we obtain the following two propositions:

Proposition 1. *Suppose that $\Theta > 0$. Then, there exists the steady-state value of the output capital ratio $z^* > 0$. If the production function exhibits increasing returns with respect to both capital and labor, then per capita output can grow at a positive constant rate as long as both the population growth rate and the input rate of non-renewable natural resources are located within some positive region. On the other hand, if the production function exhibits decreasing returns with respect to both capital and labor, then per capita output can grow at a positive constant rate as long as the population growth rate is located within some negative region and the input rate of non-renewable natural resources is located within some positive region.*

Proposition 2. *Suppose that $\Theta < 0$. Then, the output-capital ratio asymptotically approaches $z = 0$. In this case, if the population growth rate is negative and the absolute* *value of it is large, then the per capita output can grow at a positive constant rate irrespective of whether the production function exhibits increasing returns with respect to both capital and labor or decreasing returns with respect to both capital and labor.*

5 Conclusions

We have built a simple economic growth model with non-renewable resources, and investigated whether or not positive per capita output growth is possible. In the analysis, we have assumed that production exhibits increasing returns to scale, that is, with respect to capital stock, labor, and non-renewable resources because of a positive externality effect of capital accumulation. Then, we have analyzed both the case of positive population growth and the case of negative population growth.

Our analysis has shown that not only in the case where population growth is positive and production exhibits increasing returns with respect to labor and capital stock but also in the case where population growth is negative and production exhibits diminishing returns with respect to labor and capital stock, positive per capita output growth is possible.

Results of this study suggest that sustainable per capita output growth will be possible even in an economy that needs inputs of non-renewable resources and experiences population decline.

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