Health, Longevity, and the Productivity Slowdown*

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First version: March 22, 2001
Current version: July 15, 2002 – Version 3.0

Abstract

In this paper, we develop an endogenous growth model that integrates skill driven technological change, human capital accumulation through formal schooling, with health capital accumulation. The relationships among economic growth, average health level, labor allocation, and longevity of the population are investigated. Within this framework, the present model shows that the improved public health environment is indispensable for sustainable development. The better growth situation only appears when an economy has a higher level of public health as a social basis. Therefore, a healthy body, which is sustained by the improved public health environment and individual's health investment, becomes a necessary condition for long-term development. Moreover, we apply a model part to the explanation of productivity slowdown in Western economies. First, it is theoretically shown that the productivity slowdown has a possibility to occur with aging of the population. In this connection, our conjecture that the slowdown is caused by aging phenomenon through rises in longevity is investigated by the simple econometric tests. Within the narrow limits of our studies, as for the phenomena of continuously slowdown in advanced economies, the possibility to be the inevitable ones is indicated.

JEL classification: I12; O30; O41.

Keywords: Skill driven technological change; Health capital; Human capital; Aging; Productivity slowdown; Longevity.

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* I gratefully acknowledge input from Tadahiko Tokita, Kazumi Asako, Shinsuke Ikeda, Maki Nakaizumi, Tokuo Iwaisako, Naohito Abe, Keiko Ito, Yukinari Hayashi, and Hisao Kumamoto. I am also grateful to the Research Network Program of Contemporary Economics at Hitotsubashi University for providing research facilities. Needless to say, I am solely responsible for any remaining defects and opaqueness of this article.
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1. Introduction

In this paper, we focus on health aspect in long-term development and examine the equilibrium properties of an endogenous growth model with human capital, health capital, and physical capital accumulation under existing *skill* or *knowledge* driven technological change.

The role of the formation of human capital in the growth process has been extensively analyzed in many theoretical literatures. The seminal paper by Robert Lucas (1988), "On the Mechanics of Economic Development," is one of the most stimulating papers in new growth theory (i.e. endogenous growth theory). In his pioneering model, human capital directly participates in production process as a productive factor. In this sense, the accumulation of human capital would directly contribute the growth of output. He argues that the importance of human capital accumulation for economic growth and development in a simple framework of two-sector endogenous growth model. The model we introduce here shares the property of Lucas's human capital production technology.

On the other hand, it has been recognized that expenditures on medical services and exercise can be viewed as investments in health capital and analyzed using the frameworks of capital theory. Michael Grossman's (1972) human capital model of the demand for health, in particular, has been argued by some to be one of the major theoretical innovations to have emerged from health economics. In Grossman model, individuals may invest in health by combining time with purchased inputs. The incentive for investing in health is that by increasing the health stock the individual increases the amount of time available for earning income or for producing consumption goods. As a consequence, health contributes to welfare and economic performances.

We take into account that health influences intertemporal decision-making in several different channels. First, it serves as the sub-engine to the supply of human capital services. This is because that the effective labor force needs for not only human capital but also a certain level of health. Second, the provision of health services directly competes with the supply of labor services allocated to the good production and the human capital production through formal schooling. In terms of a growth perspective, the positive contribution of a good health to labor productivity is particularly important. However, the supply of health service requires labor resources. Accordingly, there seems to be a direct trade-off between health and human capital accumulation. That is, an expansion of the health sector may promote growth through increased health of the population, while a contraction of the health sector could also free the labor resources necessary to promote growth by means of an increase in human capital production. In the same way, there is also a direct trade-off between the resources used in the health sector and the final good sector. Third, a good health influences intertemporal decision-making follows from the observation that health can generate positive utility of its own. To capture the feature, we incorporate health in the utility function next to consumption.[1] Moreover, we take into account of intertemporal welfare effects of providing health services through the positive impact on longevity of the population.

Allowing for the above characteristics about health and human capital, we introduce the effects of skill driven technological change (henceforth SDTC) to the model, since this enables us to analyze the technological development process in developing countries. The original idea of SDTC specification is presented by Easterly *et al*. (1994) and Jones (1996, 1998) that represents the effects of a highly

[1] This means that the utility function contains health.

skilled worker can use more *physical capital goods* than a lower one. This implies the number of capital goods that workers can use is limited by their (average) human capital level.[2] On the basis of three main factors of the model (human capital, health, and specific technological change), we extend the notable two-sector growth models of Uzawa (1965) and Lucas (1988, 1993) following van Zon and Muysken (1997, 2001). By this extension, we can study in detail the relations among the trade-off between health and human capital, the effects of the SDTC, and their consequences for economic development.

As for the analytical methods and the model specifications, our model has mainly four distinct features. First, we concentrate on the command optimum solution of the model. In the presence of external effects, it will not be the case that the command optimum paths and the competitive equilibrium paths coincide.[3] However, in this model, several externalities are present which would be ignored in individual decision-making. Second, we only study the steady-state situations with balanced growth paths, thus the transitional dynamics to the steady-state is not part of our studies. Third, concerning the production structure, we assume that the health capital generation is specified as decreasing returns, whereas the human capital generation is characterized by constant returns.[4] These specifications followed a pioneering and an insightful research of Baumol (1967). Fourth, to simplify our studies, we assume that in the

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[2] In many R&D based growth models, e.g. Romer (1990), Grossman and Helpman (1991), Aghion and Howitt (1992), Jones (1995), Segerstrom (1998), and Young (1998), etc., they focused on the invention of new capital goods as an *main engine* of growth for the world economy. On the other hand, we will have opposite focus in our studies. We assume that we are examining the economic performance of a single small country (in developing process), potentially far removed from the technological frontier. This country grows by learning to utilize the more advanced capital goods that are already available in the rest of the world, and thus the SDTC specification is best applied to a specific economy.

[3] In the competitive equilibrium case, the agents are consuming, producing, and accumulating in response to market prices.

[4] Concerning the constant returns specification in the human capital generation, see for example Lucas (1988, 1993), Becker, Murphy, and Tamura (1990), and Redding (1996).

steady-state both the average health level and the population size are constant.

On the basis of the frameworks, the present model shows that the improved public health environment is indispensable for sustainable development. The main difference to existing contributions in the literature is that we integrate the technological progress in developing economy into the endogenous growth structure with health capital, owing to analyze a complicated development process. Although a healthy body is sustained by the health investment and the improved public health environment, the better growth situation only appears when an economy has a higher level of public health as a social basis. Therefore, a healthy body with the improved public health environment becomes a necessary condition for long-term development. Moreover, our conjecture on aging problem from the theoretical analysis has explanatory power for the recent productivity slowdown in advanced economies. The validity of the conjecture is tested in the simple econometric tests.

The remainder of the paper is organized as follows. In Section 2 we introduce the skill driven growth model with health capital accumulation. Section 3 presents some of interesting and typical implications. In Section 4 alternative explanations on productivity slowdown in advanced economy are presented. Section 5 provides the concluding remarks.

2. The model

We present an endogenous growth model with health service generation (or health capital accumulation).[5] The model we develop here is an extended version of van Zon and Muysken's (2001) model to incorporate skill or knowledge driven technological

[5] The notion of health capital has been used in many literatures; see for instance Grossman (1972), Cropper (1977), Wolfe (1985), Dardanori (1986), Wagstaff (1986), Foster (1989), Ehrlich and Chuma (1990), Muysken, Yetkiner, and Ziesemer (1999), and van Zon and Muysken (1997, 2001).

progress.

The total population in this economy consists of two parts: a part that is actively engaged in producing activities, and a part that only consumes output and health services. Individuals live up to age T, but are actively involved in productive activities till a constant age A (i.e. retirement age). For analytical simplicity, we assume that each year n persons are born and live for T years with health level g and human capital level h. At age T, individuals leave the population set through sudden death. Following van Zon and Muysken (2001), we assume that longevity T is proportional to the average health level g of the population. It means

$$T = \mu g \,, \tag{1}$$

where μ is a constant parameter.

According to the above description, the number of inactive people is equal to $(T - A)n$. That is to say, the total population will increase with longevity since the retirement age A is fixed. Here, when we stabilize the health level of the population, the number of births per period exactly matches the number of deaths, so that the number of population remains constant in the steady-state.

2.1. Production structure of final good

A country produces a homogeneous final good Y, using effective labor force L_Y and a range of capital good x_i. The number of capital goods that workers can use is limited by their average skill level h_s.[6] As mentioned before, we call this effect the SDTC. This formulation means that a worker with a high skill level can use more capital goods than a worker with a low skill level. For example, a highly skilled

[6] This formulation is also used in the following literatures, Easterly *et al*. (1994), Jones (1996, 1998), and

worker may be able to use computerized machine tools unavailable to workers below a certain skill level. Specifically, let the average skill level or human capital, defined by

$$h_s \equiv \frac{\int_0^\infty hL_w(h)dh}{\int_0^\infty L_w(h)dh},$$

where $\int_0^\infty L_w(h)dh$ represents the size of total labor force with health level g. We call this h_s effect external, because though all benefit from it, no individual human capital accumulation decision can have an appreciable effect on h_s. Therefore, the technology for final good production is specified as

$$Y = L_Y^{1-\alpha}\int_0^{h_s^\varepsilon} x_i^\alpha di,$$

where $0<\alpha<1$, $0\le\varepsilon\le 1$.[7] Note that the parameter ε corresponds to the degree of SDTC, and therefore the process of steadily increases of ε represents a phase of economic development. Because of the supply of labor measured in efficiency units equals $hgnA$, the effective labor force employed in the good production is just $L_Y = (1-u-v)hgnA$. $1-u-v$ is the fraction of labor allocated to the good production, and the remaining fractions u and v are spent on human capital and health service production, respectively.

If we define aggregate physical capital K as $K \equiv \int_0^{h_s^\varepsilon} x_i di$ and assume symmetric $x_i = x$ for all i, one can get the following production function:

$$Y = \left[(1-u-v)gnA\right]^{1-\alpha} K^\alpha h^{1-\alpha} h_s^{\varepsilon(1-\alpha)}.$$

In the decentralized case, each household takes the time sequences of external effect

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Hosoya (2000).

[7] As for the case of existing the external effects, Romer (1986) actually carries out the study of the fixed-point problem in a space of $h(t)$, $t\ge 0$, paths. Therefore, we follow Romer and concentrate on explicit analysis to the steady-state situation.

$\left\{h_s^{\varepsilon(1-\alpha)}(t)\right\}_{t=0}^{\infty}$, as given. On the other hand, in the command optimum case, a social planner will take this effect into account, perfectly. Since we study here the latter case, substituting $h_s = h$ into the production function and rearranging to obtain[8]

$$Y = \left[\left(1-u-v\right)gnA\right]^{1-\alpha} K^{\alpha} h^{(1-\alpha)(1+\varepsilon)} . \tag{2}$$

2.2. Health and human capital generation[9]

In the present model, the specification for health service production is the same with van Zon and Muysken (2001). They assumed that the health production takes place under conditions of decreasing returns to scale. Consequentry,

$$\dot{g} = \left[\psi\left(\frac{A}{\mu}\right)^{\beta} \pi^{1-\beta} v^{\beta} - \eta\pi g\right] h , \tag{3}$$

where ψ and π are constant productivity parameters in health generation. As mentioned before, v represents the share of effective labor employed in the health sector. Moreover, η is a constant depreciation rate. $0 < \beta \leq 1$ reflects the assumption of decreasing returns.

In the long-run, we assume that the health level g will converge to g^*.[10] As a result, Eq. (3) reduces to the following expression:

$$g^* = \frac{\psi}{\eta}\left(\frac{A}{\pi\mu}\right)^{\beta} v^{\beta} = \Gamma v^{\beta} , \tag{4}$$

where Γ is implicitly defined by $\Gamma \equiv (\psi/\eta)(A/\pi\mu)^{\beta}$. From Eq. (4), a higher share of employment in the health sector will result in a higher equilibrium health level g^*.

[8] More detailed discussion on the differences between decentralized and social optimum case, see Lucas (1988).

[9] van Zon and Muysken (2001) gives more detailed discussion for the health production.

As for the human capital production, the Lucas's (1988) framework can be extended in a straightforward manner. Therefore, we have

$$\dot{h} = \delta ugh \,, \tag{5}$$

where δ is a constant productivity parameter. The only difference with Lucas model is that taking health g explicitly into account.

2.3. Command optimum solutions

We follow Grossman (1972) and incorporate health into the utility function. This means that a good health may be also expected to influence utility, directly. The intertemporal utility function is defined as

$$U = \int_0^\infty e^{-\rho\tau} \left(g^\gamma \left(\frac{C}{L} \right)^{1-\gamma} \right)^{1-\theta} \frac{L}{1-\theta} d\tau \,, \qquad 0 < \theta < 1 \,, \tag{6}$$

where ρ is the rate of time preference, and $1/\theta$ is the intertemporal elasticity of substitution, $0 \le \gamma \le 1$ measures the relative contribution of health to intertemporal utility compared with per capita consumption. Moreover, $L = nT$ is the size of the total population, and C is the total consumption.

The present studies concentrate on the command optimum economy. A social planner should maximize the intertemporal utility Eq. (6) under the conditions, Eqs. (2), (3), (5), and the physical capital dynamics $\dot{K} = Y - C$. To obtain a closed form solution, we assume a constant steady-state allocation of effective labor force as well as Lucas model. This implies that the health capital accumulation is inherently stable in the long-run: i.e., the health level g will always converge to g^* defined Eq. (4). Thus, let us replace the constraint of Eq. (3) by that of $g = g^*$ defined in Eq. (4).

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[10] An asterisk (*) denotes the steady-state value.

However, the revised system still does not allow us to obtain a closed form solution. For this difficulty, as in van Zon and Muysken (2001), we can reduce the revised system and employ a graphical groping method instead.

To solve the corresponding optimization problem, we set up the present value Hamiltonian:

$$H \equiv \frac{C^{\gamma_1}(n\mu)^{\gamma_2}(g^*)^{\gamma_3}}{1-\theta}e^{-\rho t} + \lambda\left[\left\{(1-u-v)\,g^* nA\right\}^{1-\alpha} K^{\alpha} h^{(1-\alpha)(1+\varepsilon)} - C\right] + \xi\delta u g^* h\,,$$

where λ and ξ are the co-state variables for K and h. C, u, and v are the control or choice variables, and K and h are the state variables. Note that $g^* = \Gamma v^{\beta}$ must be constant in the steady-state. Moreover, we define $\gamma_1 \equiv (1-\gamma)(1-\theta)$, $\gamma_2 \equiv 1-\gamma_1$, and $\gamma_3 \equiv 1-(1-2\gamma)(1-\theta)$.

The first-order necessary conditions for an interior solution are listed below:

$$\frac{\partial H}{\partial C} = (1-\gamma)e^{-\rho t}C^{\gamma_1 - 1}(n\mu)^{\gamma_2}(g^*)^{\gamma_3} - \lambda = 0\,,$$

$$\frac{\partial H}{\partial u} = -\frac{\lambda(1-\alpha)Y}{1-u-v} + \xi\delta g^* h = 0\,,$$

$$\frac{\partial H}{\partial v} = \frac{\gamma_3 \beta e^{-\rho t}C^{\gamma_1}(n\mu)^{\gamma_2}(g^*)^{\gamma_3}}{(1-\theta)v} - \frac{\lambda(1-\alpha)Y}{1-u-v} + \frac{\lambda\beta(1-\alpha)Y}{v} + \frac{\beta\xi\delta u g^* h}{v} = 0\,,$$

$$\dot{\lambda} = -\frac{\partial H}{\partial K} = -\left[\lambda\alpha\left\{(1-u-v)g^* nA\right\}^{1-\alpha} K^{\alpha-1} h^{(1-\alpha)(1+\varepsilon)}\right],$$

$$\dot{\xi} = -\frac{\partial H}{\partial h} = -\lambda(1-\alpha)(1+\varepsilon)\left\{(1-u-v)g^* nA\right\}^{1-\alpha} K^{\alpha} h^{\varepsilon-\alpha-\alpha\varepsilon} - \xi\delta u g^*\,,$$

plus the usual two transversality conditions,

$$\lim_{t\to\infty}\lambda(t)K(t) = 0\,,\quad \lim_{t\to\infty}\xi(t)h(t) = 0\,.$$ [11]

We can obtain many results by using the above conditions. In particular, the

[11] A sufficient condition for a solution of the first-order conditions to solve the maximization problem is that the Hamiltonian function be jointly concave in (K , h). However, social planner cannot ignore the external effects h_s , therefore the relevant Hamiltonian is not concave for the planner and the sufficient conditions are not met in this case.

steady-state growth rates are calculated

$$R = \hat{C} = \hat{K} = \hat{Y} = (1+\varepsilon)\hat{h} = \frac{\delta g^*(1-v)(1+\varepsilon)-\rho}{\theta+\gamma(1-\theta)}, \tag{7}$$

where the growth rate of variables C, K, Y, and h are denoted by $\hat{C}$, $\hat{K}$, $\hat{Y}$, and $\hat{h}$, and these are collected by denoting R.[12]

2.4. Reduced dynamical system

What we want to do next is to reduce the above revised system. As a result, the reduced dynamical system is expressed by the following system of simultaneous equations:

$$f = c\left[(1-c)(1+\varepsilon)-\alpha\right]D, \tag{8}$$

$$v = \frac{f-\alpha\beta(1-\alpha)(1-\theta)(1-\gamma)}{f-\alpha(1+\beta)(1-\alpha)(1-\theta)(1-\gamma)}, \tag{9}$$

$$c = 1-s = 1-\frac{\alpha R}{R\left[\theta+\gamma(1-\theta)\right]+\rho}, \tag{10}$$

$$R = \frac{\delta g^*(1-v)(1+\varepsilon)-\rho}{\theta+\gamma(1-\theta)}, \tag{11}$$

$$u = \frac{(1-c)(1-v)(1+\varepsilon)}{\alpha}, \tag{12}$$

where s is the saving rate, and c is the average propensity to consume. Moreover, we define $D \equiv \beta\left[\theta+2\gamma(1-\theta)\right]$.[13]

From Eq. (11), it follows that the rate of growth (R) rises with the productivity parameters in health (implied Γ) and human capital production (δ). The effects of

[12] Full derivation of the model is given in Appendix A.
[13] As well as the previous subsection, the derivations of the reduced dynamical system are given in Appendix A.

preference parameters in this model are similar to the standard Cass-Koopmans models. To ensure $1-u-v \geq 0$, as for Eq. (12), we need $c \geq 1-[\alpha/(1+\varepsilon)]$ and therefore the steady-state saving rate needs to be smaller than $\alpha/(1+\varepsilon)$.

2.5. Graphical analysis

Eqs. (8)-(11) need to be solved simultaneously and u (Eq. (12)) would then follow the simultaneous solution of Eqs. (8)-(11). To solve the reduced system, we employ the van Zon and Muysken's graphical analysis.[14] Observations of Eqs. (8)-(10) define a relation between v and R, while Eq. (11) also represents a same relation with respect to v and R. Combining these two relations in the (v, R)-plane, we can confirm that the effects of changes in the system parameters to the steady-state growth solution.

A four-quadrant diagram of Figure 1 represents a relationship between v and R that follows from Eqs. (8)-(11). Eq. (8) is first presented in the 1st and the 4th quadrant as a relation between c and f, where we concentrate on the range $1 \geq c \geq 1-[\alpha/(1+\varepsilon)]$. It decreases from $f=0$ at $c=1-[\alpha/(1+\varepsilon)]$ to $f=-\alpha\beta[\theta+2\gamma(1-\theta)]$ at $c=1$. In the same way, Eq. (10) is only represented in the 1st quadrant as a relationship between c and R, which decreases from $R=\rho/[\varepsilon+(1-\theta)(1-\gamma)]$ at $c=1-[\alpha/(1+\varepsilon)]$ to $R=0$ at $c=1$. Finally, in the 2nd and the 3rd quadrant, Eq. (9) is depicted as a relationship between v and f. It increases from $v=\beta/(1+\beta)$ at $f=0$ to $v=v'$ at $f=-\alpha\beta[\theta+2\gamma(1-\theta)]$. If a value of f goes to negative infinity, v would asymptotically approach a value of 1. Note that

[14] See van Zon and Muysken (1997, 2001).

$$v' = \frac{\beta\left[\theta + 2\gamma(1-\theta)\right] + \beta(1-\alpha)(1-\theta)(1-\gamma)}{\beta\left[\theta + 2\gamma(1-\theta)\right] + (1+\beta)(1-\alpha)(1-\theta)(1-\gamma)} \leq 1,$$

where v' denotes the maximum value for v. The relevant range for v is therefore $\beta/(1+\beta) \leq v \leq v'$, while the relevant range for R is given by $0 \leq R \leq \rho/\left[\varepsilon + (1-\theta)(1-\gamma)\right]$. Mapping processes R onto c, c onto f, and f onto v lead to the new curve $R'v'$. The resulting curve $R'v'$ in the 2nd quadrant of Figure 1 represents the summarized system of Eqs. (8)-(10). To obtain the simultaneous solution of Eqs. (8)-(11), we draw Eq. (11) and the curve $R'v'$ in a (v, R)-space of Figure 2.

The curve $R'v'$ in Figure 2 has the inverse orientation as in Figure 1. Eq. (11) is a concave function that decreases from the maximum rate R^{**} for $v = \beta/(1+\beta)$ to $R = 0$ at $v^* < 1$.[15] The solution of the model is obtained at the point of intersection E of Eq. (11) and the curve $R'v'$. A unique equilibrium exists if the curve $R'v'$ has a convex property and if $R^{**} < \rho/\left[\varepsilon + (1-\theta)(1-\gamma)\right]$, $v^* > v'$.[16] In the steady-state, we confirm that Y, C, and K will grow at the equilibrium rate R_E, while health and longevity are constant at g^* and T_E, respectively.[17]

3. Implications

3.1. Two types of trade-off

There are two types of trade-off relation in the model. One is concerning labor

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[15] Setting $R = 0$ (in addition, set to $\beta = 1$ for simplicity) for Eq. (11) and calculating with respect to v, we obtain the following two roots: $v = (1/2) \pm \left[\sqrt{\delta\Gamma(1+\varepsilon)\left\{\delta\Gamma(1+\varepsilon) - 4\rho\right\}}\right] / 2\delta\Gamma(1+\varepsilon)$.

[16] In van Zon and Muysken (1997), they show that for plausible values of the parameters of the model, these constraints are likely to be satisfied. We assume this to be the case in the remainder of the analysis.

[17] Subscript E denotes the equilibrium value.

allocation among three sectors. In particular, the trade-off between health and human capital can be seen in Eq. (12). The presence of the term $1-v$ implies the fact that a fraction v of the labor force is not available for the production of output or human capital. The role of health investment v is to maintain the average health level of the population at its steady-state level g^*. Another trade-off concerns the relation between consumption and health. Disregarding the contribution of health to welfare by setting $\gamma = 0$, this leads to an individual's growth maximizing choice of $v = \beta/(1+\beta)$.[18] On the other hand, if we take into account the direct effects of health to welfare, Figure 2 shows that the growth rate R^* at the point of intersection between two curves is lower than R^{**}, while in that case $v > \beta/(1+\beta)$. As a consequence, the incorporation of the direct contribution of health to individual's welfare increases the level of health services at the expense of economic growth, ceteris paribus.

3.2. The role of health for economic development

Our concern in this subsection is to analyze how changes in the degree of external effects ε, which captures the skill driven technological change (SDTC) of the economy, lead to changes not only in economic performances but also in health level and longevity of the population. The economic impacts of changes in other parameters are very similar to the analysis of van Zon and Muysken (2001), and we therefore limit the discussion to the effect of changes in ε on the model.

When an increase in ε, it will be efficient to more distribute labor force to the final good sector by the efficiency of good production increases. Then, the number of persons who provide a health service will decrease (v falls). While as we have seen

[18] This case implies that the impact of health to longevity is a pure external effect for agent. Appendix B gives more detailed discussion.

in Eq. (2), the productivity increases in the final good production, due to rising ε, have a great impact on skills of labor force used in that sector. Individuals will therefore more invest in human capital accumulation to improve their skill level since the importance rises of human capital used in the final good production (u rises).[19] As a consequence, an increase in ε yields a decline of relative importance of health capital production, so that it causes a decline of average health level (g^* falls). Hence, we found that ε and g^* are negatively correlated and therefore the SDTC leads to a decline of individuals' health status. In this model, the growth performance of the economy can be divided into three cases with the magnitude of technology (Γ, δ, ε) and taste (ρ) parameters.

Case 1: If $\delta\Gamma(1+\varepsilon) > 4\rho$ is satisfied, the growth rate of the economy increases.[20] This case requires a higher level of the productivity parameters in both health production and human capital accumulation (higher level of Γ and δ), ceteris paribus. Another aspect for this growth-enhancing condition is that the more the agent values future consumption and health relative to current consumption and health, because of the lower is ρ. As has been pointed out in the earlier section, we assumed that the process of steadily increases of ε represents a phase of economic development. Consider the health production, in particular, sustainable development needs for a higher level of social basis, such as the improved public health environment, that makes health capital generation smooth. Therefore, a good health environment has an important role for long-term development because that environment (higher level of Γ) directly contributes the improvement of health level of the population and the

[19] This means that the profitability increases from human capital investment.
[20] For detailed discussion of this condition, see Appendix C.

growth performances. Assuming that the level of health investment as given, the country which has the improved public health environment enjoys the better growth performances. In this case, a reduction g^* leads to a contraction of population's longevity T. To maintain a higher growth rate, the saving rate s must increase and therefore it leads to a decline of the average propensity to consume c. As a consequence, we can suppose that the case corresponds to the situation of *growth taking-off*. Figure 3 depicts in this case.

Proposition 1. *If there exists the SDTC and the inequality* $\delta\Gamma(1+\varepsilon) > 4\rho$ *is satisfied, the economy will be the state with a higher growth rate and a lower health level. Therefore, the SDTC leads to growth at the expense of average health level of the population.*

Proof. See Figure 3.

Case 2: If $\delta\Gamma(1+\varepsilon) < 4\rho$ is satisfied, changes in the growth rate are not uniform.[21] There is a possibility of arising three-different types of equilibrium. Case 2 emerges when the value of productivity parameters in both health and human capital production are relatively low (lower level of Γ and δ). This case also implies that the less the agent values future consumption and health relative to current consumption and health, because of the higher is ρ. Since the improved public health environment is indispensable for nurturing a healthy labor force, we can consider that the present case corresponds to the unimproved environment for health production. In a worst development case of three possible cases, we can confirm that the economy falls into underdevelopment trap. Concerning longevity, a reduction of g^* also leads to a contraction of T, as in Case 1. Moreover, it depends on change of equilibrium growth rate whether saving rate increases. For example, when an increase (decrease) in the growth rate, the saving rate s increases (decreases). Hence, average propensity to consume c decreases (increases). Case 2 is shown in Figure 4.

Proposition 2. *If there exists the SDTC and the inequality* $\delta\Gamma(1+\varepsilon) < 4\rho$ *is satisfied, change of equilibrium growth rate is not uniform. However, in a worst development case of three-distinct cases, the economy may fall into underdevelopment trap. Moreover, in Case 2, individuals' average health level surely falls as well as Case 1.*

Proof. See Figure 4.

Let us summarize that the equilibrium relations between two cases (Case 1 and 2): R_E (Case1) $>$ R_E (Case 2), while v_E (Case 2) $>$ v_E (Case 1).

In both Case 1 and 2, the level of health investment surely falls. However, there is a difference with respect to the degree of changes. That is to say, in a case of the improved environment on public health (Case 1), the necessary investment level for health to maintain a health level g^* is relatively low. Therefore, in this case, individual will more invest in human capital accumulation suppressing health capital production. By this change, the economic growth rate increases. On the other hand, in a case of the relatively unimproved environment on public health (Case 2), it is indispensable for more than health investment level needed in Case 1. According to

[21] As for the condition, see Appendix C.

this fact, an increase in the investment for human capital accumulation becomes restrictive. Even if the SDTC arises, there is a possibility that the case where an economic growth rate does not increase. The situation, which is characterized by ‘low growth’ and ‘poor health’, corresponds to a phase of underdevelopment trap in developing countries.

4. Productivity slowdown in advanced economy

We have mainly focused on developing economy and analyzed theoretically it so far. In this section, we apply the previous model to the study of advanced economy (for example OECD countries). By this application, we can discuss on the phenomena of productivity slowdown in Western countries in terms of the preference changes and the population increases through rising longevity. In recent years, the total expenditures of GDP of Western countries have shown a tendency to rise due to the aging of the population as in Figure 5. We will therefore examine a relation between the aging problem and the productivity slowdown in these countries.

The recent slowdown in the growth of productivity has been attracted considerable attention. In many literatures, for example Griliches (1980), Nadiri and Schankerman (1981), Baumol (1986), and Hamilton and Monteagudo (1998), the deceleration has been generally attributed to many factors: e.g. slowdown in the growth of capital intensity, and the stock of R&D. The former studies including Griliches (1980) have been mainly shed light on the technology side, because the rate of growth of total factor productivity (TFP) determines the rate of economic growth in neo-classical frameworks. In contrast with them, our model presents the distinct explanations for the phenomena of productivity slowdown.

4.1. Preference and productivity slowdown

Let us assume the situation where preference of the population for a good health strengthens with the improvements of living standard. This phenomenon corresponds to the case where parameter γ rises with output per capita in our model. From Eq. (11)

$$\frac{\delta g^*(1-\nu)(1+\varepsilon)-\rho}{\theta+\gamma'(1-\theta)}<\frac{\delta g^*(1-\nu)(1+\varepsilon)-\rho}{\theta+\gamma(1-\theta)},$$

where we assume $\gamma' > \gamma$. This implies that growth of the economy will be slowdown in the process of preference changes, ceteris paribus. Such a phenomenon may be an inevitable one for advanced economy.

4.2. Population, longevity, and productivity slowdown

In advanced economy, for example Western economy, average age of the population has shown a tendency to rise during the last decades. If we incorporate longevity of individuals to the model, this affects the two aspects of the population. The active population determines labor supply and therefore the scale of all economic activities. On the other hand, the total population determines the scale of the demand for health services. Therefore, the factor that rises in longevity may shrink an economic activity. For example, technological progress in the health sector (e.g. ψ increases in Eq. (3) and (4)) could be expected not only to boost overall productivity, but also to break productivity growth

When integrating the discussion between Subsection 4.1 and 4.2, we can present the alternative and the comprehensive explanation on productivity slowdown. That is, an increase in health service with improving the living standard extends individuals' longevity. The extension increases non-active population in the economy. Via such a process, the phenomena of productivity slowdown occur in advanced countries. This is our *certain* conjecture.

4.3. A simple test for productivity slowdown through rises in longevity

Using a simple econometric framework, we will test for the conjecture. The idea based on the conjecture is summarized as follows: if a country which has a higher health level (relatively long life expectancy at initial point in time) tends to grow slower than a country which has a lower health level. This property is similar to the concept of β convergence in empirical growth fields (see for example Barro and Sala-i-Martin, 1991, 1992, 1995).

In order to make a relation between productivity growth and average health level of the population more precise, we consider the following equation predicted by the above conjecture. As a proxy of health level, we employ the life expectancy. Eq. (13) relates the growth rate of income per capita between two points in time to the initial level of life expectancy:

$$GROWTH_{i,t,t-1} = a + bLIFEE_{i,t-1} + \varepsilon_{i,t}\ , \tag{13}$$

where $GROWTH$ is the growth rate of per capita income level, a is the constant term, $LIFEE$ is the life expectancy at birth, and ε is the random disturbance. Moreover, the subscript i denotes the country, and the subscript t denotes the year. Our main objective is to estimate the unknown parameter b. From the above discussion, we expect a negative coefficient on the initial life expectancy ($LIFEE$). The data we use here is the Barro and Sala-i-Martin's cross-country data sets (1995, pp.353-358). This is shown in Table 1. The sample period is 1960-1985, and therefore the initial point is 1960. Table 2 reports the results of ordinary least square estimation (the method of OLS) using White's heteroskedasticity-consistent covariance estimation method.

We first present the estimation using 24 OECD countries (Estimation 1 in Table 2). The coefficient on the initial life expectancy (longevity), $LIFEE60$, enters with expected negative coefficient, while the coefficient estimate appears to be low and the variable rarely enters significantly at the 5% confidence level. Although the initial life expectancy enters insignificantly, the negative coefficient may be interpreted as a consequence of productivity slowdown through rises in longevity.

Figure 6 represents the data plots on 24 OECD countries used in the previous regression. When we look carefully at Figure 6, it is likely that the 3 plots, including Korea, Mexico, and Turkey, are outliers with respect to the life expectancy at birth at 1960. Considering the sample problem, let us exclude the data of these 3 countries in the following estimation.

Therefore, we only use the data for 21 OECD countries and estimate for Eq. (13) once more. The sample period is also 1960-1985. In Table 2, Estimation 2 reports the result of ordinary least square estimation using White's heteroskedasticity correction method. The coefficient on the initial life expectancy, $LIFEE60$, enters with the negatively and significantly at the 5% confidence level. Although we use here the extremely simple estimation method, it is reasonable to suppose that our conjecture on productivity slowdown in advanced economy is supported by this estimation. The result of Estimation 2 asserts the validity of our conjecture.

Moreover, we now proceed to the additional estimation. Estimation 3 represents the estimation result using 22 OECD countries' data (21 OECD in Estimation 2 plus Korea). Returning to Figure 6, we can find that the plot of Korea is not influential point to the plots of other countries'. Regarding this fact, we will re-estimate after including Korea. As well as the previous estimation, let us take notice of the coefficient on $LIFEE60$. From Estimation 3, the coefficient on the initial life expectancy enters with the negatively and significantly at the 1% confidence level. By this result, our conjecture based on the theoretical model will be more strongly supported.

5. Concluding remarks

We have presented in this paper three-sector endogenous growth model that integrates the SDTC, human capital accumulation, and health capital generation, and have investigated its implications for macroeconomics including economic growth, average health level of the population, and their longevity.

With its emphasis on the role of SDTC and health capital, our model is clearly part of the rapidly growing literature that associates the human capital based growth model. What differentiates this analysis from the previous works is that we presented clearly relationships between health factors (health investment, public health environment) and economic growth through social technological change. This specification allows us to obtain necessary conditions for growth taking-off. Under the present situation, we have been shown that the improved public health is indispensable for sustainable developments (Case 1). This case says that a good health becomes a necessary condition for growth taking-off. On the other hand, in a case of the unimproved public health environment, any reallocation of labor force caused by the SDTC yields the three-distinct types of growth pattern (Case 2). In a worst development case, we proved that the economy falls into underdevelopment trap. In these connections, we have arrived at the conclusion that an aid meant to improve the productivity of health service generation in the poorer developing economies, could actually contribute growth taking-off on its own. Consequently, a healthy body that is supported by the improved state of public health has a crucial role as a basic device of economic development.

In addition to the principal implications, we have arrived at the interesting implications on productivity slowdown in Western economy. Our conjecture based on the theoretical analysis was as follows: aging of the population through rises in their longevity causes productivity slowdown. This has been supported by the simple econometric tests for OECD countries. The empirical results represent that the possibility to suffer from continuously slowdown in advanced economies is suggestive in the future, since these countries have already achieved a higher health level characterized longer life expectancy.

Through the whole analysis, our results depend fundamentally on the contrasting assumptions about the technologies employed in health generation and human capital production: diminishing returns in the former but constant returns in the latter. To us, these assumptions are eminently plausible and may be justified on various grounds, e.g. Baumol (1967). Others may be rather less convinced, however, and may wish to reserve judgment until more compelling evidence becomes available. Obviously, the validity of each assumption is ultimately an empirical question, the resolution of which ought to be a high priority for further research.

Appendices

Appendix A.

First, we present the following first-order conditions, again (except for the transversality conditions):

$$\frac{\partial H}{\partial C} = (1-\gamma)e^{-\rho t}C^{\gamma_1 - 1}(n\mu)^{\gamma_2}(g^*)^{\gamma_3} - \lambda = 0\,, \tag{A1}$$

$$\frac{\partial H}{\partial u} = -\frac{\lambda(1-\alpha)Y}{1-u-v} + \xi\delta g^* h = 0\,, \tag{A2}$$

$$\frac{\partial H}{\partial v} = \frac{\gamma_3 \beta e^{-\rho t}C^{\gamma_1}(n\mu)^{\gamma_2}(g^*)^{\gamma_3}}{(1-\theta)v} - \frac{\lambda(1-\alpha)Y}{1-u-v} + \frac{\lambda\beta(1-\alpha)Y}{v} + \frac{\beta\xi\delta u g^* h}{v} = 0\,, \tag{A3}$$

$$\dot{\lambda} = -\frac{\partial H}{\partial K} = -\left[\lambda\alpha\left\{(1-u-v)g^* nA\right\}^{1-\alpha} K^{\alpha-1}h^{(1-\alpha)(1+\varepsilon)}\right], \tag{A4}$$

$$\dot{\xi} = -\frac{\partial H}{\partial h} = -\lambda(1-\alpha)(1+\varepsilon)\left\{(1-u-v)g^* nA\right\}^{1-\alpha} K^{\alpha}h^{\varepsilon-\alpha-\alpha\varepsilon} - \xi\delta u g^*\,. \tag{A5}$$

Second step is to find the growth rate, we start by obtaining the rate of growth of consumption from Eqs. (A1) and (A4). That is

$$\hat{C} = \frac{\dot{C}}{C} = \frac{\alpha\left\{(1-u-v)g^* nA\right\}^{1-\alpha} K^{\alpha-1}h^{(1-\alpha)(1+\varepsilon)} - \rho}{1-\gamma_1}\,. \tag{A6}$$

Substitution of (A2) into (A5) leads to

$$\hat{\xi} = -\delta g^*\left[1-v+\varepsilon(1-u-v)\right]. \tag{A7}$$

Next, substituting for Y in $\dot{K} = Y - C$, we rearrange to get

$$\hat{C} = \alpha\left(\frac{1}{1-\gamma_1}\right)\left(\hat{K} + \frac{C}{K}\right) - \rho\,.$$

Since $\hat{C}$, $\hat{K}$, and other parameters are constant, then C/K must be constant, which implies that C and K grow at the same rate. Moreover, from Eq. (A6), taking logarithms on both sides and differentiating with respect to time to get $\hat{K} = (1+\varepsilon)\hat{h}$, and thus the relations $\hat{C} = \hat{K} = (1+\varepsilon)\hat{h}$ are satisfied.

From Eq. (A2), we take logarithms on both sides and differentiating with respect to time, and using the relation $\hat{K} = (1+\varepsilon)\hat{h}$ to obtain

$$\hat{\lambda} - \hat{\xi} = -\varepsilon\hat{h}. \tag{A8}$$

Here, substituting $\hat{\lambda} = (\gamma_1 - 1)\hat{C} - \rho$ (from Eq. (A1)) and Eq. (A7) into (A8), we obtain

$$(\gamma_1 - 1)\hat{C} - \rho + \delta g^* \left[1 - v + \varepsilon(1 - u - v)\right] = -\varepsilon\hat{h},$$

and substitution of $u = \hat{h}/\delta g^*$ (from $\hat{h} = \delta u g^*$) and $\hat{C} = (1+\varepsilon)\hat{h}$ into the above equation leads to the following result,

$$\hat{h} = \frac{\delta g^*(1-v)(1+\varepsilon) - \rho}{(1-\gamma_1)(1+\varepsilon)}. \tag{A9}$$

Now, for the good production function (Eq. (2)), taking logarithms on both sides and differentiating with respect to time to get, $\hat{Y} = (1+\varepsilon)\hat{h}$. According to the relations among $\hat{C} = \hat{K} = (1+\varepsilon)\hat{h}$, $\hat{Y} = (1+\varepsilon)\hat{h}$, and Eq. (A9), we can obtain the following expressions:

$$\begin{aligned} R = \hat{Y} = \hat{C} = \hat{K} = (1+\varepsilon)\hat{h} &= \frac{\delta g^*(1-v)(1+\varepsilon) - \rho}{1-\gamma_1} \\ &= \frac{\delta g^*(1-v)(1+\varepsilon) - \rho}{\theta + \gamma(1-\theta)}, \end{aligned} \tag{A10}$$

where $\gamma_1 \equiv (1-\theta)(1-\gamma)$. This is the same as Eq. (7) or (11).

Third step, let us find the saving rate. The definition of s is the following:

$$s \equiv \frac{\dot{K}}{Y} = \hat{K}\left(\frac{K}{Y}\right) = \hat{C}\left(\frac{K}{Y}\right), \tag{A11}$$

where we use the relation $\hat{C} = \hat{K}$. We substitute Eq. (A6) and the good production function (from Eq. (2)) into Eq. (A11) to obtain

$$s=\frac{\alpha}{1-\gamma_1}-\frac{\rho}{1-\gamma_1}\frac{1}{\left\{(1-u-v)g^*nA\right\}^{1-\alpha}K^{\alpha-1}h^{(1-\alpha)(1+\varepsilon)}}. \tag{A12}$$

Again from Eq. (A6),

$$(1-\gamma_1)\hat{C}+\rho=\alpha\left\{(1-u-v)g^*nA\right\}^{1-\alpha}K^{\alpha-1}h^{(1-\alpha)(1+\varepsilon)}. \tag{A13}$$

Substituting Eq. (A13) into (A12), and we apply the relation $R=\hat{C}$ to get

$$s=1-c=\frac{\alpha R}{R\left[\theta+\gamma(1-\theta)\right]+\rho}, \tag{A14}$$

where $c+s=1$. In this equation, c is the average propensity to consume. This equation is the same as Eq. (10).

Fourth step, we should find the value of u which is a fraction of the labor supply in human capital production. Here, we substitute $R=\hat{h}=\delta ug^*$ into Eq. (A10) to obtain

$$u=\frac{(1-c)(1-v)(1+\varepsilon)}{\alpha}. \tag{A15}$$

This is the same as Eq. (12).

Final step, we will find the value of v which represents a fraction of the labor supply in health capital generation. Eqs. (A1), (A2), and (A3) can be combined to obtain

$$\frac{(1-s)\gamma_3\beta}{(1-\gamma)(1-\theta)v}-\frac{1-\alpha}{1-u-v}+\frac{(1-\alpha)\beta}{v}+\frac{(1-\alpha)u\beta}{(1-u-v)v}=0. \tag{A16}$$

Accordingly, substituting $c=1-s$, $\gamma_3\equiv 1-(1-2\gamma)(1-\theta)$, and Eq. (A15) into (A16) and rearranging gives the value of v as

$$v=\frac{c\left[(1+\varepsilon)-c(1+\varepsilon)-\alpha\right]D-\alpha\beta(1-\alpha)(1-\theta)(1-\gamma)}{c\left[(1+\varepsilon)-c(1+\varepsilon)-\alpha\right]D-\alpha(1+\beta)(1-\alpha)(1-\theta)(1-\gamma)}, \tag{A17}$$

where $D\equiv\beta\left[\theta+2\gamma(1-\theta)\right]$. Substituting $f=c\left[(1+\varepsilon)-c(1+\varepsilon)-\alpha\right]D$ (Eq. (8))

into Eq. (A17), we get

$$v=\frac{f-\alpha\beta(1-\alpha)(1-\theta)(1-\gamma)}{f-\alpha(1+\beta)(1-\alpha)(1-\theta)(1-\gamma)}. \tag{A18}$$

This is the same as Eq. (9).

Appendix B.

If we ignore the direct influence of health on welfare as well as the influence through longevity, that is to say, we treat L as given in the utility function, and not substituting Eq. (1) in the utility function while setting $\gamma=0$, Eq. (A3) is reduced to

$$\frac{\partial H}{\partial v}=-\frac{\lambda(1-\alpha)Y}{1-u-v}+\frac{\lambda\beta(1-\alpha)Y}{v}+\frac{\beta\xi\delta ug^{*}h}{v}=0. \tag{A19}$$

Substitution of Eq. (A2) into (A19) and then solving for v, gives us

$$v=\frac{\beta}{1+\beta}. \tag{A20}$$

Appendix C.

From the footnote 15, we obtained the two roots. We first investigate Case 1 (in a case of the improved public health). Since we are interested in a larger value of v (see Figure 2), the relevant value for the time fraction v^{*} is

$$v^{*}=\frac{1}{2}+\frac{\sqrt{\delta\Gamma(1+\varepsilon)\left\{\delta\Gamma(1+\varepsilon)-4\rho\right\}}}{2\delta\Gamma(1+\varepsilon)}. \tag{A21}$$

In Eq. (A21), when $dv^{*}/d\varepsilon$ has a positive sign, then Eq. (11) shifts to upward (see Figure 3). We calculate $dv^{*}/d\varepsilon$ with respect to Eq. (A21) to obtain

$$\frac{dv^{*}}{d\varepsilon}=\frac{\delta\Gamma(1+\varepsilon)\left[2(\delta\Gamma)^{2}(1+\varepsilon)-4\rho\delta\Gamma\right]-2\delta\Gamma\left[\left\{\delta\Gamma(1+\varepsilon)\right\}^{2}-4\rho\delta\Gamma(1+\varepsilon)\right]}{4\left\{\delta\Gamma(1+\varepsilon)\right\}^{2}\left[\left\{\delta\Gamma(1+\varepsilon)\right\}^{2}-4\rho\delta\Gamma(1+\varepsilon)\right]^{1/2}},$$

$$= \frac{\rho}{(1+\varepsilon)\left[\delta\Gamma(1+\varepsilon)\left\{\delta\Gamma(1+\varepsilon)-4\rho\right\}\right]^{1/2}} . \tag{A22}$$

where $\rho > 0$. For $dv^* / d\varepsilon$ takes a positive sign, the RHS of Eq. (A22) must be a positive. This yields the following inequality condition:

$$\delta\Gamma(1+\varepsilon) > 4\rho .$$

In the same way, we next investigate Case 2 (in a case of the unimproved public health). As for Eq. (A22), when $dv^* / d\varepsilon$ has a negative sign, then Eq. (11) shifts to downward (see Figure 4). For $dv^* / d\varepsilon$ takes a negative sign, we need for the following inequality condition:

$$\delta\Gamma(1+\varepsilon) < 4\rho .$$

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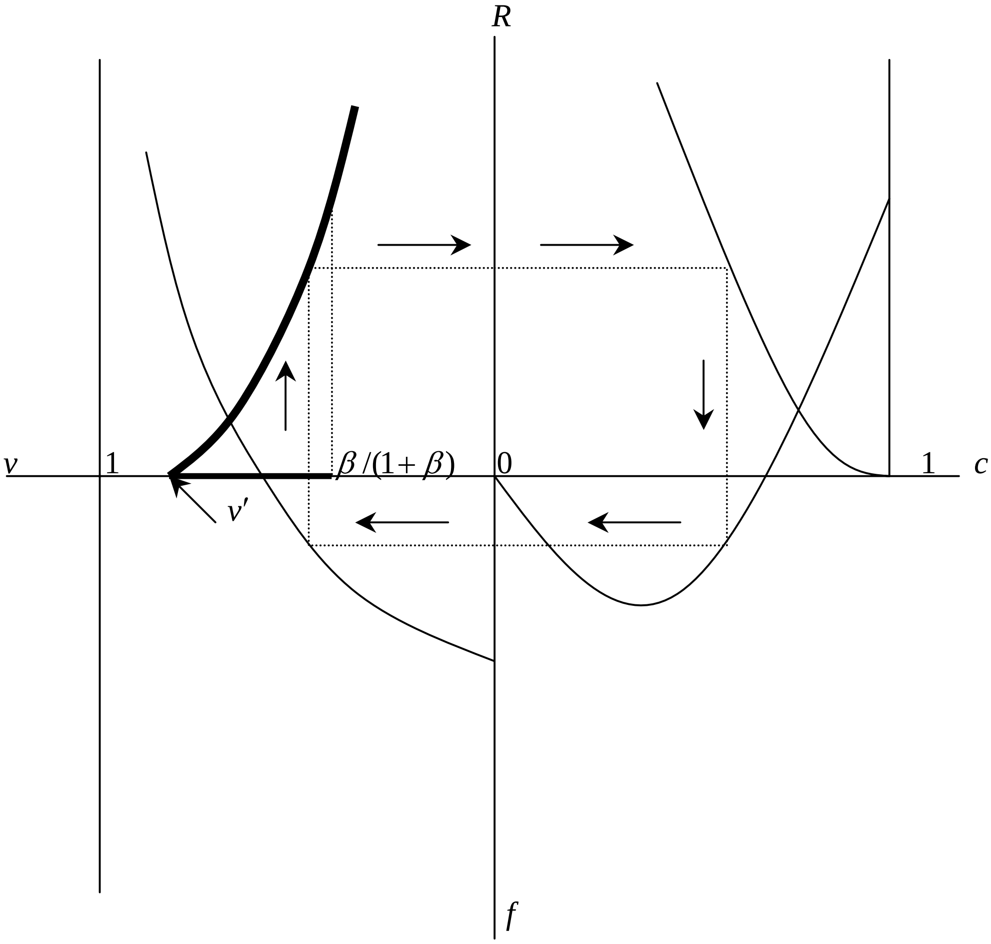

Fig. 1. *A four quadrant diagram.*

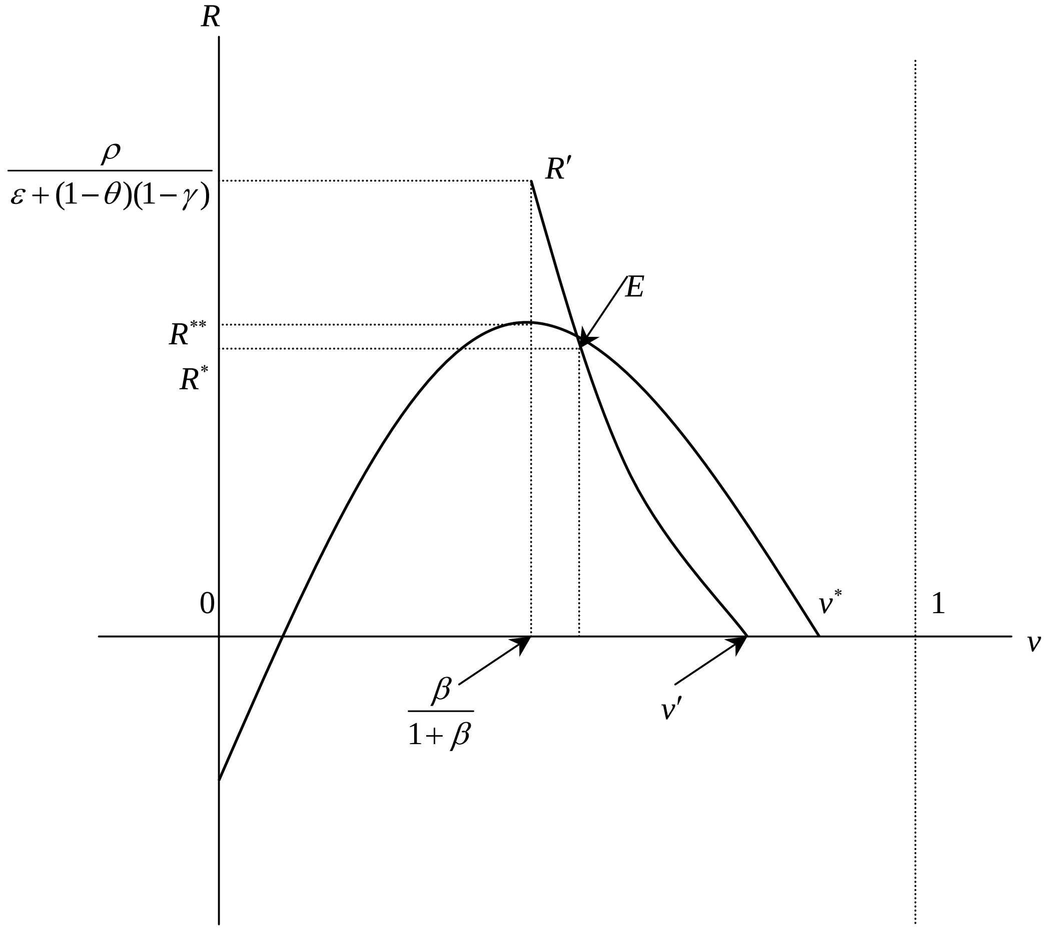

Fig. 2. *The north – west quadrant again.*

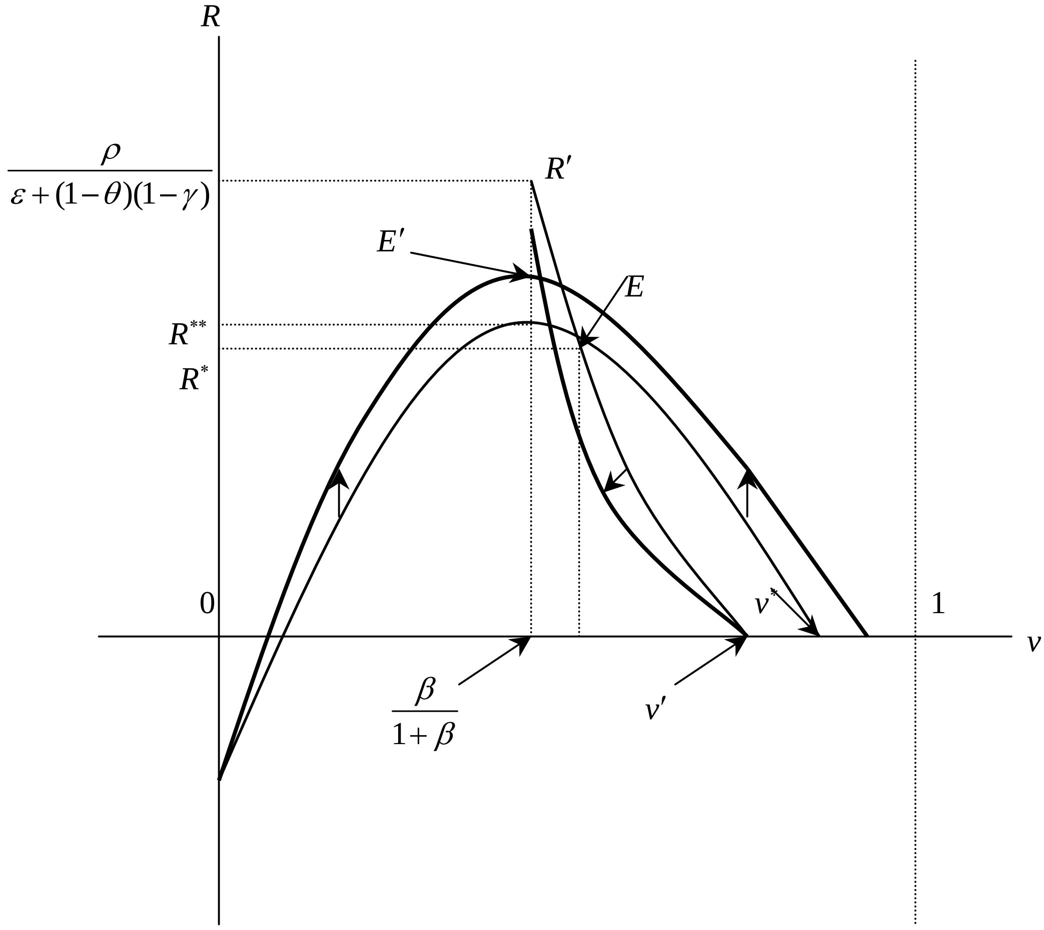

Fig. 3. *A rise in* ε *(in a case of growth taking-off).*

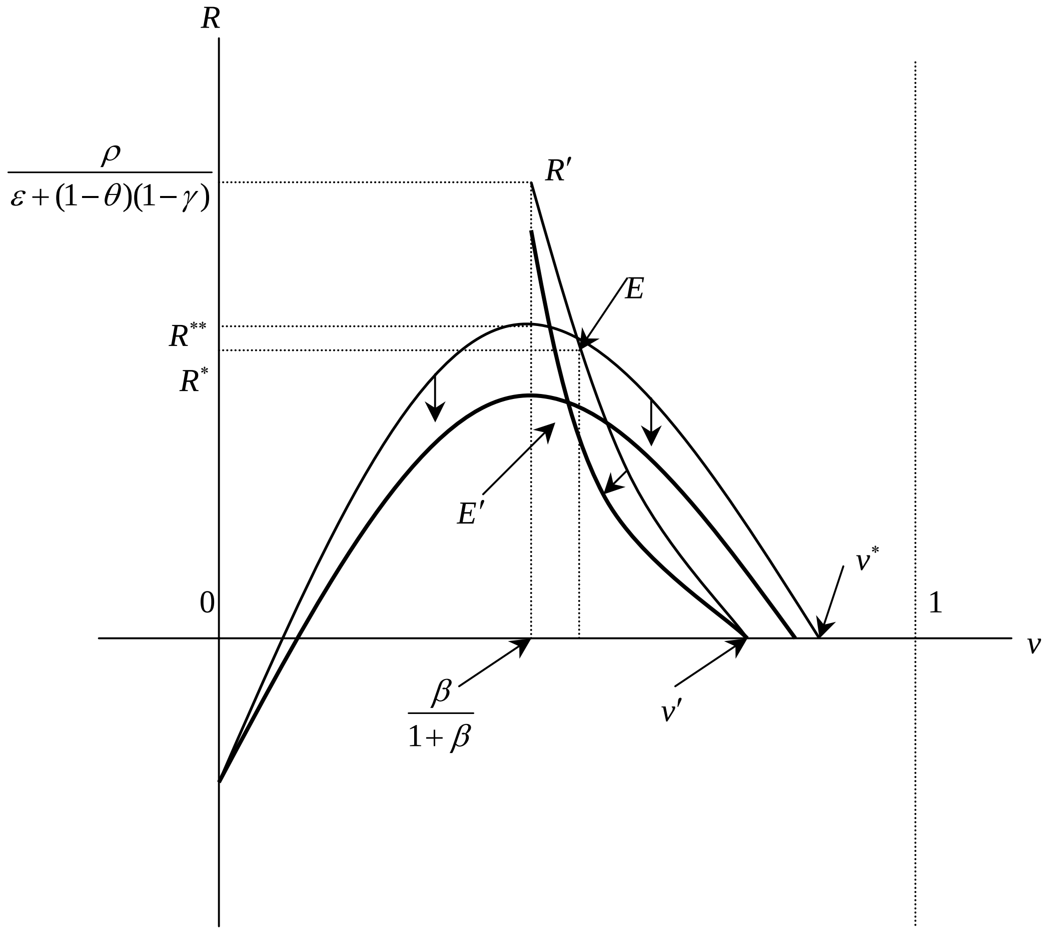

Fig. 4. *A rise in* ε *(in a case of underdevelopment trap).*

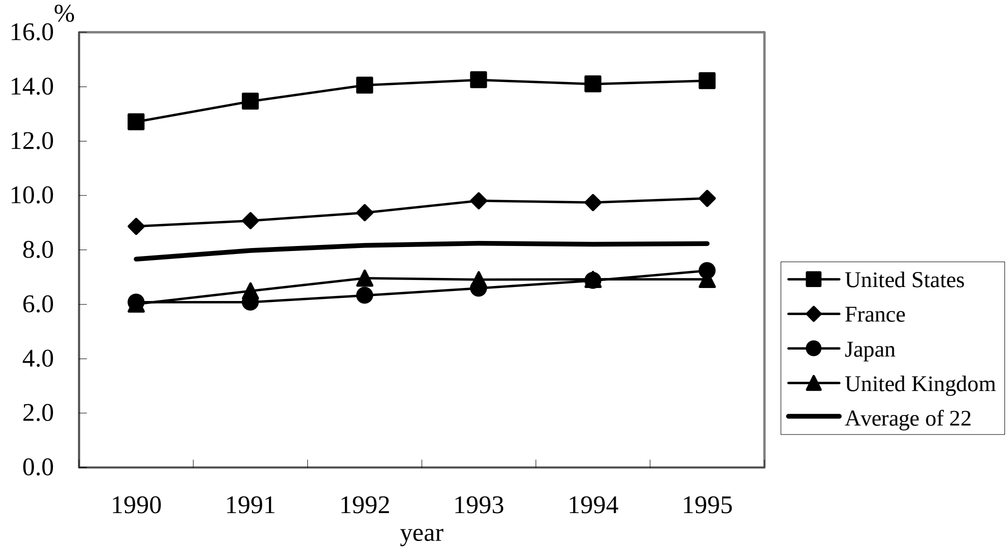

Fig. 5. *Total health expenditure of GDP* .
Source : The World Bank (1998) *World Development Indicators* CD-ROM edition.

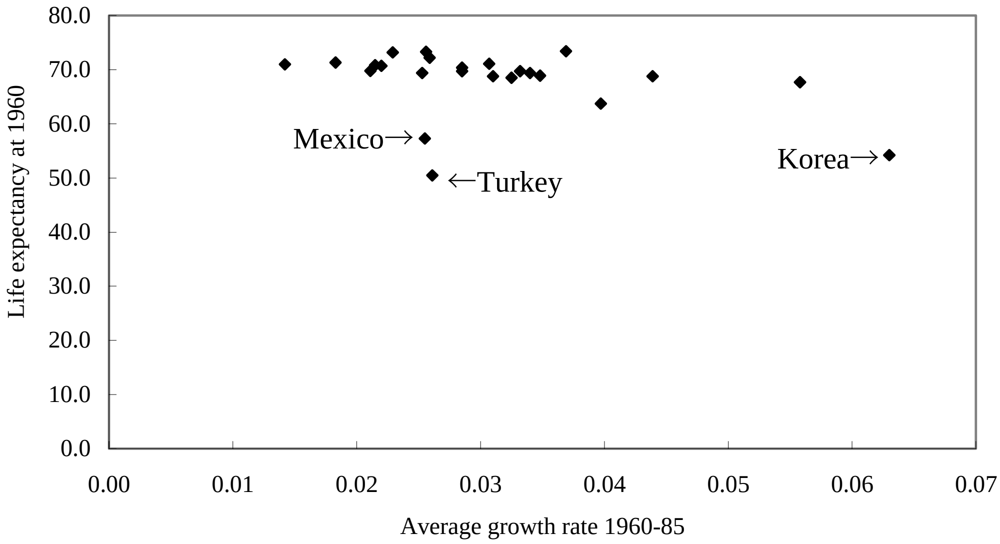

Fig. 6. *Growth rate and life expectancy* .
Source : Barro and Sala-i-Martin (1995).

Table 1. *Average growth rate and life expectancy in 24 OECD countries*

Country	Growth rate 1960-1985	Growth rate of life expectancy 1960-1985	Life expectancy 1960	Life expectancy 1985
Canada	0.0307	0.0717	71.1	76.2
Mexico	0.0255	0.1885	57.3	68.1
United States	0.0211	0.0731	69.8	74.9
Japan	0.0558	0.1418	67.7	77.3
Korea	0.0630	0.2675	54.2	68.7
Austria	0.0310	0.0712	68.8	73.7
Belgium	0.0285	0.0660	69.7	74.3
Denmark	0.0259	0.0374	72.2	74.9
Finland	0.0325	0.0949	68.5	75.0
France	0.0285	0.0881	70.4	76.6
Germany	0.0253	0.0706	69.4	74.3
Greece	0.0439	0.1032	68.8	75.9
Ireland	0.0332	0.0545	69.7	73.5
Italy	0.0340	0.0994	69.4	76.3
Netherlands	0.0256	0.0437	73.3	76.5
Norway	0.0369	0.0422	73.4	76.5
Portugal	0.0397	0.1444	63.7	72.9
Spain	0.0348	0.1074	68.9	76.3
Sweden	0.0229	0.0437	73.2	76.4
Switzerland	0.0183	0.0757	71.3	76.7
Turkey	0.0261	0.2495	50.5	63.1
United Kingdom	0.0215	0.0551	70.8	74.7
Australia	0.0220	0.0721	70.7	75.8
New Zealand	0.0142	0.0479	71.0	74.4

Source : Barro and Sala-i-Martin (1995).
Note : Because of the data availability, we exclude 5 OECD countries in the present analysis; Czech, Hungary, Iceland, Luxembourg, and Poland are excluded.

Table 2. *Cross-country regressions in OECD countries*
Sample period: 1960-1985
Dependent variable: $GROWTH6085$

Variable	Estimation 1	Estimation 2	Estimation 3
Constant	0.0787	0.1861*	0.1790*
	(0.0501)	(0.0650)	(0.0169)
$LIFEE60$	-0.0007	-0.0022**	-0.0021*
	(0.0007)	(0.0009)	(0.0002)
Sample country	24OECD	21OECD	22OECD
R2	0.1365	0.2660	0.5387

Notes : White heteroskedasticity-robust standard errors are reported in parentheses. *, ** indicate that the coefficient is significantly different from 0 at the 1, 5 percent significance level, respectively.