

## **Optimal Portfolio of Knowledge and Human Capital Investment\***

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We address the optimal combination of the subsidies to the R&D investment, the educational investment, and the job training to attain the optimal portfolio of the knowledge investment and the human capital investment. The policy simulations, using a general equilibrium model, which reflects the characteristics of the Korean economy and the knowledge production and the human capital accumulation process, show that: (1) the subsidy to the R&D investment is more effective to improve the productivity and the welfare of the future generations than that to the educational investment (or to the job training); (2) compared with the difference in the impact of the subsidy schemes on the productivity, the difference in the increase in the tax burden due to the provision of the subsidy is smaller, which indicates the differential effects on the welfare; and (3) the optimal combination of the subsidy schemes, taking into account the differential impact on the productivity, the tax burden, the welfare across generations, is shown 50-65% subsidy to the R&D investment, 65-80% subsidy to the educational investment, and no subsidy to the job training.

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## 1. INTRODUCTION

The population aging is one of the most serious problems in many countries including Korea, where the speed of the population aging is among the highest in the world.<sup>1)</sup> More old-age dependents relative to workers resulting from the population aging suggest the likelihood of more consumption relative to income and, therefore, less national saving. And the reduction of the labor force due to the population aging and population reduction will be another obstacle to the economic growth.<sup>2)</sup>

The population aging will increase the social welfare expenditure in the future. The government of many countries tends to provide more generous social welfare benefits to the elderly than to any other age groups. This tendency of the policy revision, accompanied by the population aging, will raise the tax burden ratio, the ratio of the tax burden to GDP, which will further reduce the labor supply, and the savings, and the growth rate.<sup>3)</sup>

In addition to the delay of the quantitative economic growth due to the reduction of the labor and the capital inputs, the population aging may also delay the technological progress. The population size reduction due to the fall in the fertility rate implies the market size reduction, and will decrease the return from the research and development (R&D). The decrease in the

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<sup>1)</sup> The current proportion of the population aged 65 and older in Korea is much lower than most of the developed countries, 11.3% as of 2010. However, it is projected to increase to 23.1% in 2030, almost the same as the projected OECD average at that time.

<sup>2)</sup> Many previous studies, including Auerbach and Kotlikoff (1987b) and Kotlikoff *et al.* (1996) (for the US), and Chun (2007) (for Korea), presented very pessimistic pictures of the aged society. They presented the possibility of the reduction of the national savings and the labor supply. Bloom *et al.* (2011) showed the possibility of the previous researches' exaggerating the risk of population aging. The study showed that the magnitude of the loss of the production in OECD countries due to the population aging is not large. In addition, it presented that in the case of the developing countries, the increase in the proportion of the economically active population will be able to compensate for the loss of production due to the population aging.

<sup>3)</sup> The examples of these studies include Gruber *et al.* (1998), Auerbach and Kotlikoff (1987c). Gruber *et al.* (1998) showed that the US social security system induces the early retirement and lowers the old age groups' proportion of the economically active population. Auerbach and Kotlikoff (1987c) showed that the US social security system reduces the labor supply, the savings, and the GDP.

R&D investment due to the reduction of its return will delay the technological progress.<sup>4)</sup>

There is also a bright side of the population aging. If the main source of the population aging is the fall of the fertility rate, it may increase the educational expenditure per child.<sup>5)</sup> The fall in the fertility rate implies the reduction of the number of the children, and makes it possible for their parents to increase the educational expenditure per child, which will promote the human capital investment.

Despite the co-existence of the dark side and the bright side of the population aging, it is highly likely that the effects of the delay in the quantitative growth and the technological progress will dominate those of the increasing educational expenditure. Chun (2012) showed that the population aging will eventually reduce the GDP growth rate, because the former effects dominate the latter effects, using a general equilibrium model.

Then, how do we overcome the impact of the population aging? This is the issue we address in this paper. A convincing approach is to improve the labor productivity of the future generations. The most common ways to improve the productivity are: the knowledge investment (research and development (R&D) investment); and human capital investment through the educational investment for the children and the job training. The first issue we address is which investment the most effective to improve the productivity is. For this purpose, we construct a simulation model, which reflects the characteristics of the knowledge creation process through R&D investment, and human capital accumulation process through the educational

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<sup>4)</sup> This issue was addressed by the researches on the endogenous growth theory. Aghion and Howitt (1992) and Grossman and Helpman (1991) presented the results that the population growth will promote the economic growth, because of the non-rivalry of the technology. Arrow (1962), Romer (1990), and Jones (1998) also show that the population growth will facilitate the economic growth, by assigning a constant proportion of the resources to the R&D investment. The technological progress is accelerated because the R&D cost does not depend on the population size and the population growth will increase the magnitude of the resource allocated to the R&D.

<sup>5)</sup> This aspect of the population aging is related with the argument of Becker (1973) and Becker *et al.* (1990) which addressed the trade-off between the quantity and the quality of the children faced by the parents.

investment and the job training.

The second issue is regarding the policy schemes to improve the productivity. The characteristic of the non-rivalry of the technology and human capital induces the private agents' decision-making, which causes the inefficient resource allocation: i.e., they do not take into account the spillover effects of the improvement of the firm's technology over the efficiency of the human capital investment, and vice versa. More important source of the inefficient knowledge and human capital investment is the finite horizon of the economic agents. They do not fully take into account the future generations' welfare, when they make economic decisions on the savings, and the human capital investment through the education and the job training. The firm's decision on the R&D investment is to maximize the wealth of the equity holders, who are composed of those with a finite horizon. This indicates that the economic agents under-evaluate the return from the knowledge investment and the human capital investment. Therefore, the government subsidy to the knowledge investment and human capital investment needs to be implemented.

The final issue is the identification of the optimal policy combination to attain the optimal portfolio of the knowledge investment in the form of the R&D investment and the human capital investment in the form of the educational investment and the job training. The optimal combination is affected by the effectiveness of each investment in improving the productivity, the spillover effects over the other forms of investment, and the differential intergenerational redistribution effects due to the different incidence of the tax burden and the different timing of the productivity improvement.

We address these issues using a general equilibrium model, which incorporates the firm's R&D investment decision-making, the intergenerational transfers through the educational expenditure for the children, workers' decision-making on the on-the-job training (OJT), and the finite horizon of the economic agents.

The policy simulations, using the model and its calibration, which reflect

the characteristics of the Korean economy and the knowledge production and the human capital investment process, show that: (1) the subsidy to the R&D investment is more effective to improve the productivity and the welfare of the future generations than that to the educational investment (or to the job training); (2) compared with the difference in the impact of the subsidy schemes on the productivity, the difference in the increase in the tax burden due to the provision of the subsidy is smaller, which indicates the differential effects on the welfare; and (3) the optimal combination of the subsidy schemes, taking into account differential impact on the productivity, the tax burden, and the welfare across generations, is shown 50-65% subsidy to the R&D investment, 65-80% subsidy to the educational investment, and no subsidy to the job training.

The remainder of this paper is organized as follows. The section 2 introduces the simulation model, explain the theoretical predictions, and define the competitive equilibrium. The section 3 calibrates the simulation model. After the results of the policy simulations are explained in the section 4, we conclude our discussion in the section 5.

## 2. THE MODEL

The economy in the model employed for the simulation consists of three sectors: households; firms; and the government. The households consist of the parents' generation aged 25-90 and the children's generation aged 0-24. The parents' generation makes decisions on their own consumption, time allocation among leisure, labor supply, and on-the-job training (OJT), the children's consumption, and the educational expenditure for the children. The children do not make economic decisions but accept the decision-makings by their parents.

The firms are owned by the individuals, and the equity share of each owner is the same as the share of his/her asset-holdings. The managers of the firms try to maximize the value of the firms in order to maximize the

wealth of the equity holders. The managers of the firms make decisions on the level of production, the input of the production factors, and the R&D investment to improve the production efficiency.

The government provides the subsidy to the R&D and the educational expenditure, and social welfare benefits to households, and imposes taxes to finance the government expenditure.

## 2.1. Households

The individuals live up to the age of 90 and do not face any mortality risk during the lifetime. Each individual becomes an adult, when he/she becomes 25 years old. The individual gets married as soon as he/she becomes an adult, and has children. We assume that the number of the children is determined exogenously. The parents make decisions on their children's consumption, until the children become adults, i.e., until the parents become 50 years old and the children becomes 25 years old. When the children become 6 years old, the parents start to make decisions on the educational expenditure for their children and continue the decision-makings until the children become adults. The parents also make decisions on their own consumption, labor supply, and human capital investment in the form of the on-the-job training.

The decision-makings of the individuals are based on the life-cycle preference with a finite horizon, therefore, they neither receive any inheritance from their parents nor leave any bequest to their children. The only way of intergenerational transfer is through the support for the consumption and the education.<sup>6)</sup> The preference of the parents born at  $p$  is represented by the discounted lifetime utility,  $V(p)$ .

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<sup>6)</sup> We assume that the educational expenditure for the children is determined by the preference for the intergenerational transfer. Parents transfer resources to the children, in the form of the bequest and the educational expenditure. The "joy of giving" bequest motive was represented by the bequest in the utility in many previous researches including Altig *et al.* (2001). In this paper, we assume that the parents feel the "joy of giving" to children through the educational expenditure.

$$V(p) = \sum_{a=25}^{90} \left( \frac{1}{1+\beta} \right)^{a-25} u \left( c_{a,p+a-1}, l_{a,p+a-1}, n_p c f_{a-25,p+a-1}, E_{a-25,p+a-1}^{g(n_p)} \right),$$

$$l_a = 1 - h_a - J_a,$$

$$u(c, l, cf, E) = \frac{1}{1-\gamma} \left( c^{1-\alpha-\psi_a-\varepsilon_a} l^\alpha (ncf)^{\psi_a} (E^{g(n)})^{\varepsilon_a} \right)^{1-\gamma}, \quad (1)$$

$$\psi_a = \begin{cases} \psi > 0, & a = 0, \dots, 24 \\ 0, & \text{otherwise} \end{cases},$$

$$\varepsilon_a = \begin{cases} \varepsilon > 0, & a = 6, \dots, 24 \\ 0, & \text{otherwise} \end{cases},$$

where  $a$ ,  $\beta$ ,  $c$ ,  $l$ ,  $h$ ,  $J$ ,  $cf$ ,  $E$ ,  $n$  represent the age, the discount rate, the parents' consumption, the leisure, the labor hour, and the time devoted to the on-the-job training, the consumption per child, and the educational expenditure per child, and the number of children, respectively.  $g(n)$  is the scale factor for the educational expenditure, which reflects the diminishing marginal increase in educational expenditure in response to the increase in the number of children<sup>7)</sup> ( $g'(n) > 0$ ,  $g''(n) < 0$ ). The diminishing marginal increase reflects the trade-off between the number of the children and their quality: the larger the number of children, the less educational expenditure per child. The intensity parameter of the preference for the children's consumption and the education ( $\psi$ ,  $\varepsilon$ ) takes a positive value, when the parents make decisions on them, and 0 values for the other periods of their lives.

The constraint for the parents' generation is that the present value of the labor income and the transfer income for themselves and their children from

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<sup>7)</sup> The educational expenditure for the second child tends to be smaller than that of the first child. For the empirical study for Korean case, see Kang and Hyun (2012) and Lee (2008).

the government for the lifetime is not less than that of the consumption and the on-the-job training cost for themselves, the consumption and the educational expenditure for the children, and tax payment. The lifetime resource constraint is represented by the equation (2) below.

$$\begin{aligned}
& \sum_{a=25}^{90} \prod_{s=25}^{p+a-1} (1+r_s(1-\tau_{ks}))^{-1} (w_{p+a-1} H_{a,p+a-1} (1-l_{a,p+a-1} J_{a,p+a-1} (1-\zeta_J)) (1-\tau_{l,p+a-1})) \\
& \quad + tr_{a,p+a-1} - c_{a,p+a-1} (1+\tau_{c,p+a-1})) \\
& + \sum_{a=25}^{50} \prod_{s=25}^{p+a-1} (1+r_s(1-\tau_{ks}))^{-1} n_p (trf_{a-25,p+a-1} - cf_{a-25,p+a-1} (1+\tau_{c,p+a-1})) \\
& - \sum_{a=31}^{50} \prod_{s=25}^{p+a-1} (1+r_s(1-\tau_{ks}))^{-1} n_p (1-\rho) E_{a-25,p+a-1} \geq 0.
\end{aligned} \tag{2}$$

$$H_{a+1,p+a} = \varphi_H H_{25,p+24}^{\alpha_J} J_{a,p+a-1}^{\alpha_H} H_{a,p+a-1}^{\beta_H} \Omega_{p+a-1}^{\gamma_H} + (1-\delta_H) H_{a,p+a-1}, \tag{3}$$

$$a = 25, \dots, 90.$$

$$H_{25,p+24} = \left( \sum_{j=6}^{24} E_j^P \right)^{\alpha_E}, \tag{4}$$

where  $w$ ,  $r$ ,  $\tau_l$ ,  $\tau_k$ ,  $\tau_c$ ,  $tr$ ,  $trf$ ,  $\rho$ ,  $\zeta_J$  represent the wage rate, the interest rate, the labor income tax rate, the capital income tax rate, the consumption tax rate, the government transfer to the parents and the children, and the government subsidy rate to the educational expenditure and the on-the-job training, respectively. The labor income of the household depends on the overall level of wage rate ( $w$ ), their labor supply ( $1-l-J$ ), and the efficiency of their labor service ( $H$ ). The efficiency of the labor service,  $H_a$ , measured by the human capital accumulated until the age  $a$ , is determined by their parents' educational expenditure for them in their childhood ( $E^P$ ), the parameters reflecting the rate of return to the educational expenditure,  $\alpha_E$ ,  $\alpha_J$ , the worker's human capital investment

in the form of the on-the-job training ( $J$ ), the aggregate human capital ( $\Omega$ ), and the parameter reflecting the externality of human capital accumulation ( $\gamma_H$ ): i.e. the parents' educational expenditure determines the productivity of labor when the children start working at the age of 25 ( $H_{25}$ ), and the efficiency of the human capital accumulation,  $\varphi_H H_{25}^{\alpha_J}$ , and the human capital is accumulated by the worker's on-the-job training, and the efficiency is affected by the aggregate human capital,  $\Omega^{\gamma_H}$  (equation (3)).

The optimization conditions consist of the following equations and the constraint (equations (2)-(4)).

$$l_{a,p+a-1} = \frac{\alpha}{1 - \alpha - \psi_{a-25} - \varepsilon_{a-25}} \frac{1 + \tau_{c,p+a-1}}{w_{p+a-1} H_{a,p+a-1} (1 - \tau_{l,p+a-1})} c_{a,p+a-1}, \quad (5)$$

$$c_{f_{a-25,p+a-1}} = \frac{\psi_{a-25}}{1 - \alpha - \psi_{a-25} - \varepsilon_{a-25}} c_{a,p+a-1}, \quad (6)$$

$$E_{a-25,p+a-1} = \frac{\varepsilon_{a-25}}{1 - \alpha - \psi_{a-25} - \varepsilon_{a-25}} \frac{g(n_p)(1 + \tau_{c,p+a-1})}{n_p(1 - \rho)} c_{a,p+a-1}, \quad (7)$$

$$\frac{c_{a+1,p+1}}{c_{a,p+a-1}} = \left( \frac{1 + r(1 - \tau_{k,p+a})}{1 + \beta} \right)^{\frac{1}{\gamma}} \left( \frac{1 + \tau_{c,p+a}}{1 + \tau_{c,p+a-1}} \right)^{\frac{(\alpha + \psi_{a-25} + \varepsilon_{a-25})^{1-\gamma}}{\gamma}} \cdot \left( \frac{w_{p+a-1} H_{a,p+a-1} (1 - \tau_{l,p+a-1})}{w_{p+a} H_{a+1,p+a} (1 - \tau_{l,p+a})} \right)^{\frac{1-\gamma}{\gamma}}, \quad (8)$$

$$w_{p+a-1} H_{a,p+a-1} (1 - \tau_{l,p+a-1}) (1 - \zeta_J) \frac{\beta^{a-25} u_{ca,p+a-1}}{1 + \tau_{c,p+a-1}} = \lambda_a \varphi_H \alpha_H H_{25,p+24}^{\alpha_J} J_{a,p+a-1}^{\alpha_H-1} H_{a,p+a-1}^{\beta_H} \Omega_{p+a-1}^{\gamma_H}, \quad (9)$$

$$\begin{aligned}
u_{ca, p+a-1} &= (1 - \alpha - \psi_{a-25} - \varepsilon_{a-25}) c_{a, p+a-1}^{-\gamma} \\
&\cdot \left( \frac{\alpha}{1 - \alpha - \psi_{a-25} - \varepsilon_{a-25}} \frac{1 + \tau_{c, p+a-1}}{w_{p+a-1} H_{a, p+a-1} (1 - \tau_{l, p+a-1})} \right)^{\alpha(1-\gamma)} \\
&\cdot \left( \frac{\psi_{a-25}}{1 - \alpha - \psi_{a-25} - \varepsilon_{a-25}} n_p \right)^{\psi_{a-25}(1-\gamma)} \\
&\cdot \left( \frac{\varepsilon_{a-25}}{1 - \alpha - \psi_{a-25} - \varepsilon_{a-25}} \frac{g(n_p)(1 + \tau_{c, p+a-1})}{n_p (1 - \rho)} \right)^{g(n)\varepsilon_{a-25}(1-\gamma)}.
\end{aligned} \tag{10}$$

$$\begin{aligned}
\lambda_{a-1, p+a-2} &= (1 + r_{p+a-1} (1 - \tau_{k, p+a-1}))^{-1} \\
&\cdot (w_{p+a-1} H_{a, p+a-1} (1 - l_{a, p+a-1} - J_{a, p+a-1} (1 - \zeta_J)) (1 - \tau_{l, p+a-1}) u_{ca, p+a-1}) \\
&+ \lambda_{a, p+a-1} (1 - \delta_H + \varphi_H \beta_H H_{25, p+24}^{\alpha_J} J_{a, p+a-1}^{\alpha_H} H_{a, p+a-1}^{\beta_H^{-1}} \Omega_{p+a-1}^{\gamma_H}).
\end{aligned} \tag{11}$$

The optimization conditions indicate the following features of the household decision-making. The parents and children are altruistically linked, and the resource allocation within the household is decided based on the maximization of the weighted average of the parents' welfare and the children's welfare. Therefore, given the total amount of the transfer income for the household, the resource allocation is not affected by the distribution of the transfer income from the government between the parents and the children. The decrease in the number of the children increases the educational expenditure per child, because we assume that  $g'(n) > 0$ ,  $g''(n) < 0$ , while the magnitude of the consumption for each child is not affected by the number of children. This reflects the fact that the parents assign larger resource to the children's education to improve the quality of the children, when the constraint of the resource is mitigated by the decrease in the number of children. The allocations of the parents' consumption and labor supply are the same as those in the standard life-cycle models. The

on-the-job training hour is determined by its marginal cost,  $wH_a(1-\tau_{la})(1-\zeta_J)$ , and its marginal benefit,  $\lambda_a\varphi_H\alpha_H H_{25}^{\alpha_J} J_a^{\alpha_H-1} H_a^{\beta_H} \Omega_a^{\gamma_H}$ . The marginal cost of the on-the-job training is the after-tax wage rate less the government subsidy per hour. The marginal benefit is the marginal effect of the on-the-job training on the human capital,  $\varphi_H\alpha_H H_{25}^{\alpha_J} J_a^{\alpha_H-1} H_a^{\beta_H} \Omega_a^{\gamma_H}$ , multiplied by the rate of return of the human capital increase,  $\lambda_a$ . The rate of return of the human capital investment consists of 2 components: the human capital investment increases the wage income in the future; and it also facilitates the human capital accumulation in the future.

## 2.2. Firms

The firms maximize their value ( $V$ ), which is defined as the present value of their profits, by choosing the input of the labor ( $L$ ) and the capital ( $K$ ), the physical investment ( $I$ ) and the expenditure for the R&D ( $y_R$ ). The profit is the revenue minus the labor cost, the capital cost, the physical investment, and the cost of R&D investment,  $(1-\zeta)y_{Rs}$ . The technology of the firms is represented by the Cobb-Douglas production function of the labor and the capital, with the labor-augmenting technological progress.

$$V_t = \sum_{s=t}^{\infty} \left( \prod_{j=t}^s (1+r_j)^{-1} \right) (Y_s - w_s L_s - r_s K_s - I_s - (1-\zeta)y_{Rs}), \quad (12)$$

$$Y_s = K_s^{1-\theta} (A_s L_s)^{\theta}, \quad (13)$$

where  $Y$ ,  $A$ ,  $\theta$ ,  $\zeta$  represent the output, the firm's technology level, the labor income share, and the government subsidy rate for the R&D. The labor productivity is determined by the overall level of productivity of the society,  $A$ , and the human capital embodied in the individual's labor service,  $H$  (see equation (3)), which affects the labor input measured in efficiency unit ( $L$ ).

The evolutions of the physical capital and the technological level are

determined following equations (14) and (15).

$$K_{s+1} = I_s + (1 - \delta_K)K_s, \quad (14)$$

$$A_{s+1} = A_s(1 - \delta_A) + \phi A_s^\sigma y_{R_s}^\nu, \quad (15)$$

where  $\delta_K$  and  $\delta_A$  are the depreciation rates of physical capital and the technology, and  $\phi$ ,  $\sigma$ ,  $\nu$  are the R&D technology parameters reflecting the efficiency of R&D in new technology production, the contributions of the existing technology and the contribution of the R&D investment to the new technology production, respectively.

The firm's maximization problem is represented by the following equation (12).

$$\begin{aligned} Z = & \sum_{s=t}^{\infty} \left( \prod_{j=t}^s (1+r_j)^{-1} \right) \left( K_s^{1-\theta} (A_s L_s)^\theta - w_s L_s - r_s K_s - I_s - (1-\zeta) y_{R_s} \right) \\ & + \sum_{s=t}^{\infty} \eta_s (I_s + (1-\delta_K)K_s - K_{s+1}) \\ & + \sum_{s=t}^{\infty} \xi_s (A_s(1-\delta_A) + \phi A_s^\sigma y_{R_s}^\nu - A_{s+1}), \end{aligned} \quad (16)$$

where  $\eta$  and  $\xi$  are the shadow values of the physical capital accumulation equation and the technological evolution equation.

The optimization conditions consist of the equations (14), (15), and the following equations (17)-(20).

$$\theta K_s^{1-\theta} (A_s L_s)^{\theta-1} A_s = w_s, \quad (17)$$

$$(1-\theta) K_s^{-\theta} (A_s L_s)^\theta = r_s + \delta_K, \quad (18)$$

$$\sum_{s=t}^{\infty} \left( \prod_{j=t}^s (1+r_j)^{-1} \right) \left( K_s^{1-\theta} (A_s L_s)^{\theta-1} \theta L_s \right) - \xi_{s-1} + \xi_s (1 - \delta_A + \phi A_s^{\sigma-1} \sigma y_{R_s}^\nu) = 0, \quad (19)$$

$$\sum_{s=t}^{\infty} \left( \prod_{j=t}^s (1+r_j)^{-1} \right) (1-\zeta) = \xi_s (\varphi A_s^\sigma \nu y_{R_s}^{\nu-1}). \quad (20)$$

The equations (17)-(20) are the first order conditions for the labor input, the capital input, the technological level, and the R&D investment.

Defining  $\xi_s = \xi_s' \left( \prod_j (1+r_j)^{-1} \right)$ , we get the following equation (19a).

$$\begin{aligned} \xi_s' &= (1+r_{s+1})^{-1} \left( K_{s+1}^{1-\theta} (A_{s+1} L_{s+1})^{\theta-1} \theta L_{s+1} \right) \\ &+ (1+r_{s+1})^{-1} \xi_{s+1}' (1-\delta_A + \varphi A_{s+1}^{\sigma-1} \sigma y_{R_{s+1}}^\nu). \end{aligned} \quad (19a)$$

The equation (17) shows the equalization of the marginal productivity of labor and the wage rate, and the equation (18) that of the marginal productivity of capital and the rental rate. The equation (19a) shows the optimal condition of the evolution of the technological level. The present value ( $\xi_s'$ ) of the shadow value  $\xi_s$ , which is the marginal value of mitigating the constraint for technology level, can be interpreted as the marginal return from the improvement of the technology. The marginal return can be divided into 2 parts. The improvement of the technology raises the production level in the future, represented by the first term of the right hand side of the equation (19a), and it facilitates the technological progress, represented by the second term.

The following equation (20a) is derived from the equation (20). The equation (20a) shows the decision making process on the R&D investment.

$$(1-\zeta) = \xi_s' (\varphi A_s^\sigma \nu y_{R_s}^{\nu-1}). \quad (20a)$$

The left hand side of (20a) represents the marginal cost of the R&D investment. The effective marginal cost is the difference of the R&D investment and the subsidy from the government. The right hand side is the rate of return of the R&D investment, which is the multiplication of the term,

reflecting the effect of the R&D investment on the technological progress  $(\varphi A_s^\sigma \nu y_{Rs}^{\nu-1})$ , by the marginal return from the technological progress  $(\xi_s')$ .

The equation (19a) indicates that the marginal return of the technological progress is positively related with  $K$  and  $L$ . The decrease in the market size resulting from the declining population, which reduces the labor input and the capital accumulation, lowers the return of the technological progress and the rate of return of the R&D investment, and reduces the R&D investment. As a result, the technological progress will be delayed.

### 2.3. Government

The roles of government are the provision of the subsidy to the R&D investment, the educational investment for the children and on-the-job training, the provision of transfer payment to the households, and the imposition of taxes to finance the expenditure. We assume that the government maintains the balanced budget every period (see equation (21)).

$$\begin{aligned} & \sum_{a=6}^{24} \rho E_{at} \mu_{at} + \sum_{a=25}^{90} \zeta_J w_t H_{a,t} (1 - \tau_{l,t}) J_{a,t} \mu_{a,t} + \zeta y_{Rt} + \sum_{a=0}^{24} trf_{at} \mu_{at} + \sum_{a=25}^{90} tr_{at} \mu_{at} \\ & = \tau_l w_t N_t + \tau_k r_t W_t + \tau_c C_t, \end{aligned} \quad (21)$$

$$N_t = \sum_{a=25}^{90} H_{at} (1 - l_{at} - J_{at}) \mu_{at}, \quad (22)$$

$$W_t = \sum_{a=25}^{90} a_{at} \mu_{at}, \quad (23)$$

$$C_t = \sum_{a=25}^{90} c_{at} \mu_{at} + \sum_{a=0}^{24} cf_{at} \mu_{at}, \quad (24)$$

where  $\mu_a$ ,  $a_a$ ,  $N$ ,  $W$ ,  $C$  represent the population and the asset-holding of the aged  $a$ , the aggregate values of the labor supply, the asset-holdings, and the consumption.

## 2.4. Competitive Equilibrium

The competitive equilibrium is defined as the resource allocations in the competitive output and factor markets, which satisfy the conditions 1)-6), given the policy parameters  $\{\rho, \zeta, \zeta_J, tr, trf\}$ .

- 1) Individuals maximize the lifetime expected utility.  
- Equations (2)-(4), (5)-(11) hold.
- 2) Firms maximize their value.  
- Equations (14), (15), (17), (18), (19a), (20a) hold.
- 3) The law of motions for macroeconomic variables is consistent with the decision making of individuals  
- Equations (22)-(24) hold.
- 4) The budget of the government is balanced  
- Equation (21) holds.
- 5) The factor markets clear  
- Equations (25), (26) hold.

$$W_s^{1-\theta} (A_s N_s)^{\theta-1} \theta A_s = w_s, \quad (25)$$

$$(1-\theta)W_s^{-\theta} (A_s N_s)^{\theta} = r_s + \delta_K. \quad (26)$$

- 6) The output market clears.  
- Equation (27) holds.

$$K_s^{1-\theta} (A_s L_s)^{\theta} = \sum_{a=25}^{90} c_a \mu_{a,s} + \sum_{a=0}^{24} c f_{a,s} \mu_{a,s} + \sum_{a=6}^{24} E_{a-25,s} \mu_{a-25,s} + I_s. \quad (27)$$

## 3. CALIBRATION

The parameterization for the policy simulation model is summarized in

**Table 1 Parameterization**

Fertility Rate	Total fertility rate is 2 in 1980, falls gradually to 1.2 until 2010, and thereafter rises to 1.4 until 2050.
Preference Parameters	Share of leisure in utility ( $\alpha$ ): 0.55 Share of children's consumption in the utility ( $\psi$ ): 0.126 Share of education in the utility ( $\varepsilon$ ): 0.035 Scale factor for educational expenditure: $g(n) = n^{0.492}$ Risk aversion parameter ( $\gamma$ ): 1.5 Discount rate ( $\beta$ ): 2% per annum
Technology Parameters	Labor income share ( $\theta$ ): 60% Depreciation rate of physical capital ( $\delta$ ): 5% per annum Return-from-education parameter ( $\alpha_E$ ): 0.1265
R&D Technology Parameters	Depreciation rate of technology ( $\delta_A$ ): 0% Efficiency of R&D ( $\phi$ ): 0.0237 Share of existing technology in technology improvement ( $\sigma$ ): 0.5 Share of R&D investment in technology improvement ( $\nu$ ): 0.1
Human Capital Parameters	Depreciation rate of technology ( $\delta_H$ ): 0% Efficiency of human capital investment ( $\phi_H$ ): 0.0106 Contribution of education to efficiency of human capital accumulation ( $\alpha_J$ ): 0 at benchmark economy, assumed 0.2 for sensitivity analysis Share of existing human capital ( $\beta_H$ ): 0.5 Share of the on-the-job training hour ( $\alpha_H$ ): 0.1 Externality parameter ( $\gamma_H$ ): 0 at benchmark economy, assumed 0.2 for sensitivity analysis.
Social Welfare Function	Utilitarian social welfare function assumed (equation (30)) Discount rate ( $\beta_s$ ): 2%, 1.5%, 1% per annum
Government Policy	Net transfer income from government by age and year: computed using Auerbach and Chun (2006) Tax proportion: 40% (consumption tax), 31% (wage income tax), 29% (capital income tax) government subsidy rates for the R&D and the educational expenditure ( $\zeta_J, \zeta, \rho$ ) are 0's in the benchmark economy and assume alternative level for policy simulation

table 1. We adopt the values for  $\gamma$  and  $\beta$ , 1.5 and 0.02, to produce the reasonable values for the aggregate wealth and the consumption profile.<sup>8)</sup> We set 0.55 for  $\alpha$ , because the Ministry of Labor (2005) reported that the proportion of labor hour out of the substitutable time is about 45%.<sup>9)</sup> We assume the parameters for shares of the children's consumption and educational expenditure as follows, reflecting that: (1) the proportion of the expenditure for the children, including the consumption and the educational expenditure, is estimated 35% of the baby boom generations in Korea (Son, 2011); and Kang and Hyun (2012) showed that the proportion of the educational expenditure in the household consumption is 7%.

$$\psi_a = \begin{cases} 0.28 \times (1 - \alpha) = 0.126, & a = 0, \dots, 24 \\ 0, & \text{otherwise} \end{cases}$$

$$\varepsilon_a = \begin{cases} 0.07 \times (1 - \alpha) = 0.0315, & a = 6, \dots, 24 \\ 0, & \text{otherwise} \end{cases}$$

The scale factor function of the educational expenditure is assumed  $g(n) = n^{0.492}$ , based on the empirical findings of Lee (2008).

The demographic structure in the model is determined by the fertility rate, because the model does not assume the mortality risk. We assume that the total fertility rate has fallen from 2 (as of 1980) to the current level (1.2 as of 2010), and will rise to 1.4 until 2050, based on the projection of National Statistics Office (2005).

The labor income share in the production function is assumed 60%, based on the value reported in National Account. The depreciation rate of the

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<sup>8)</sup> The previous empirical research showed a wide range of the estimate for the risk aversion parameter  $\gamma$ , and there is scant evidence of the appropriate value for  $\beta$ . For the extensive literature survey on the parameter estimates, see Auerbach and Kotlikoff (1987a).

<sup>9)</sup> According to the Ministry of Labor (2005), the average labor hour per week of the representative worker is 45 hours. Assuming that the time per week under the individual discretion, excluding the time for sleeping, eating, and commuting, is about 97 hours, the proportion of the labor is about 48%.

physical capital is assumed 5% per annum, based on its estimated value reported in Pyo (2003).

We set 0% for the depreciation rate of the technology, following Jones (1995). We choose the values for the parameters reflecting the contribution of the existing technology and the R&D investment in technology production function using the equation (15). The equation (15) can be rewritten as the following equation (15a).

$$\frac{A_{s+1} - A_s}{A_s} = \phi A_s^{\sigma-1} y_{R_s}^\nu. \quad (15a)$$

On the balanced growth path, the left hand side of the equation (15a) is constant. Taking the natural log function and taking derivatives both sides of the equation, we get the equation (28), which shows the long-run relationship between  $\nu$  and  $\sigma$ .

$$\frac{\Delta A / A}{\Delta y_R / y_R} = \frac{\nu}{1 - \sigma}. \quad (28)$$

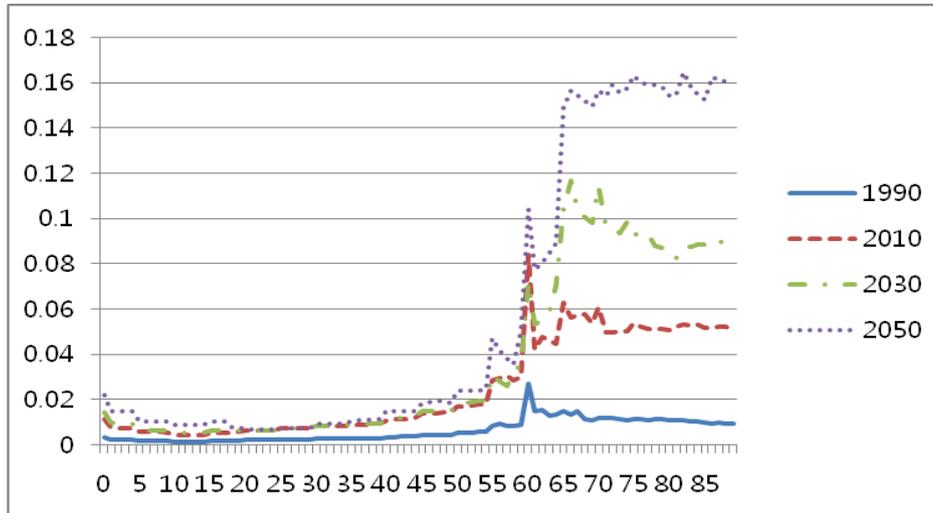
The left hand side of the equation (28) is the elasticity of productivity growth with respect to R&D investment. Lee *et al.* (2010) reported its estimated value around 0.2 for several OECD countries.<sup>10)</sup> We cannot solve for both  $\nu$  and  $\sigma$  using the estimated value using the equation (28) only. We choose 0.1 and 0.5 for the value of  $\nu$  and  $\sigma$  in the benchmark economy and assume different combination for the sensitivity analysis,<sup>11)</sup> and choose 0.0237 for the values of  $\phi$  in order to reproduce the average productivity growth for the period 2000-2005, which was estimated by Kwack (2007).<sup>12)</sup>

<sup>10)</sup> Lee *et al.* (2010) also reported the estimated elasticity for several OECD countries: 0.220 (for US), 0.288 (Japan), 0.116 (Canada), 0.147 (Italy), and 0.182 (Korea).

<sup>11)</sup> We try the sensitivity analysis assuming alternative values satisfying equation (28):  $(\nu, \sigma) = (0.25, 0.15)$  or  $(0.75, 0.05)$ .

<sup>12)</sup> Kwack (2007) reported that the productivity growth due to the total factor productivity is

**Figure 1 Transfer Income from Government ([1])**



We choose 0.1265 for  $\alpha_E$ , based on the estimate for the elasticity of income of the children with respect to the educational expenditure by An and Jeon (2008). We assume that the human capital accumulation function is the same as that of technology production through the R&D,  $\alpha_H = \nu$ ,  $\beta_H = \sigma$ , except for  $\varphi_H$  (0.0106), so that we can produce a reasonable value for the time devoted to the on-the-job training. We set 0's for the parameters for the contribution of the education to the efficiency of human capital accumulation,  $\alpha_J$ , and the externality of the aggregate human capital,  $\gamma_H$ , at benchmark economy and assume the alternative values for the sensitivity analysis. We also assume that  $\delta_H = 0$ , following Hechman and Taber (1998).

We assume the government subsidy rates for the R&D and the educational expenditure ( $\zeta_J, \zeta, \rho$ ) are 0's in the benchmark economy, and investigate the effect of the government subsidy by assuming alternative levels. We compute the transfer income from the government by age and year, shown in

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1.48% and 0.82% due to the human capital accumulation for the period 2000-2005. We choose the value of  $\phi$  that reproduces 2.30% for the labor productivity for that period.

figure 1, using the method of Auerbach and Chun (2006).<sup>13)</sup> The proportion of the tax revenue by the tax base is assumed 40% (consumption tax), 31% (wage income tax), 29% (capital income tax) based on the records in recent years.

## 4. FINDINGS

We simulate 4 economies. The economy [1] is our benchmark economy where the government does not provide the subsidy for the R&D investment, that for the educational expenditure, or that for the on-the-job training. In this economy, we assume the fertility rate estimates by the NSO (2005) and reflect the current public transfer program.<sup>14)</sup> The economy [2] simulates the provision of the subsidy to the R&D of the firms, the economy [3] that to the educational expenditure of the households, and the economy [4] that to the on-the-job training of the workers. In all three economies, we assume that the subsidy rate is 40% ( $\zeta_j = \zeta = \rho = 0.4$ ).

### 4.1. Benchmark Economy

The resource allocations in our benchmark economy ([1]) are summarized in table 2 and figure 2. As of the year 2000 of the benchmark economy, the capital-output ratio is 3.65, the average of workers' share of the labor hour out of total substitutable time is 34.9%, and the savings rate is 19.4%. Even though the share of the labor hour is lower than that reported in the Ministry of Labor (2005) (0.48), which surveyed on the labor conditions of the regular workers, the value is a reasonable compromise, considering the existence of

<sup>13)</sup> In order to incorporate the generational accounts into our general equilibrium model, we adjusted the absolute level of the public transfers for each age in each year considering the overall change in the wage level.

<sup>14)</sup> Under the current public transfer programs, the government transfer expenditure is projected to increase up to 22% of GDP until around 2060, due to the maturing of the social welfare system including the National Pension and the Public Long-Term Care Insurance, and the population aging.

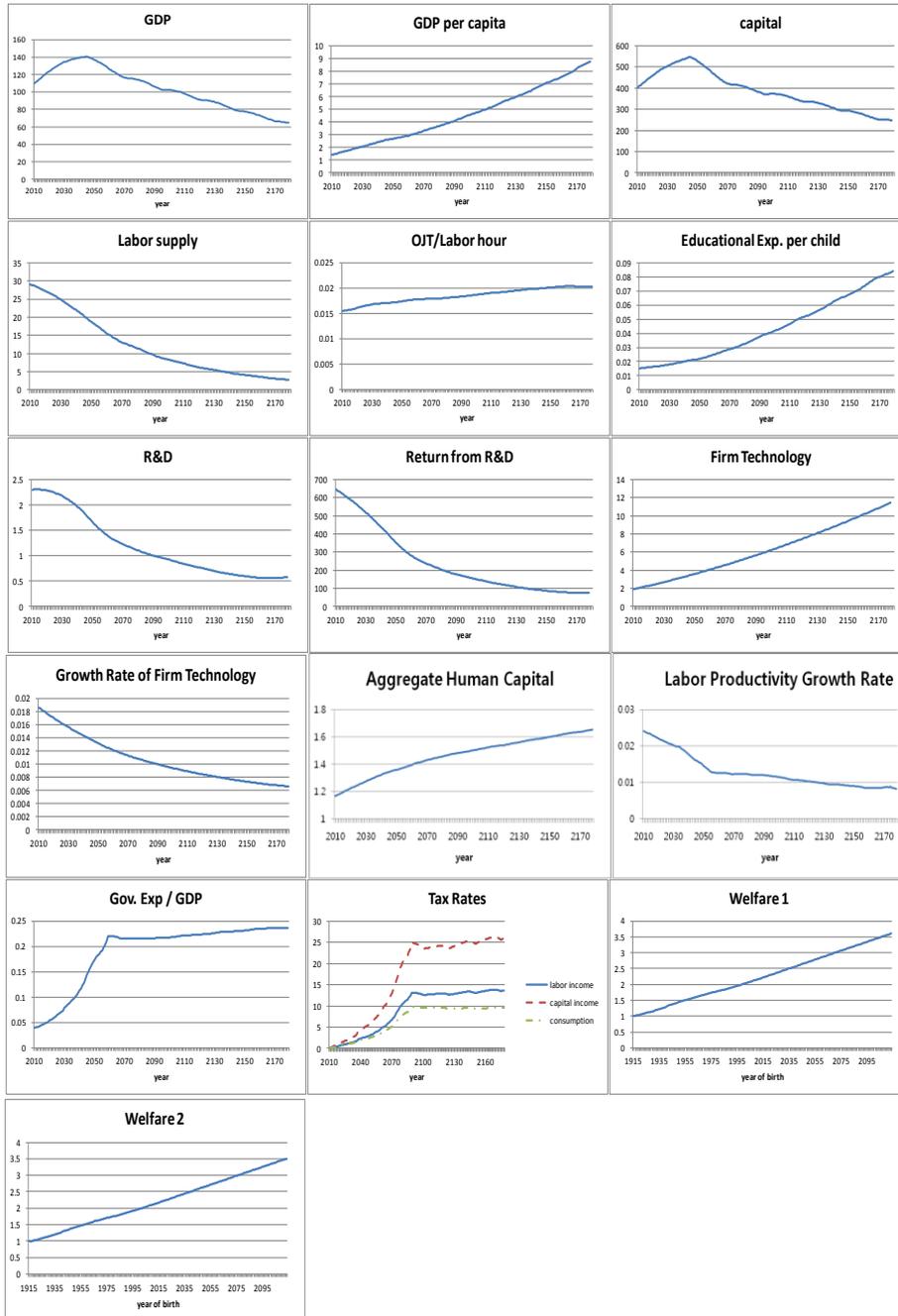
**Table 2 Resource Allocation (for the year 2000)**

Capital-Output Ratio	3.65
Labor Hour (worker)	0.349
Ratio of OJT Hour to Labor Hour (%)	1.5
Savings Rate (%)	19.4
Ratio of Consumption (except for educational exp) to GDP (%)	79.3
Ratio of Educational Expenditure to GDP (%)	1.1
Ratio of Educational Expenditure to Household Consumption (for households with children %)	4.8
Ratio of Educational Expenditure to Household Consumption (for the whole household, %)	1.4
R&D Investment / GDP (%)	2.3

the daily workers, the temporary workers, and other non-regular workers, whose labor hour is much shorter than the regular workers, and their large proportion in the labor force in Korea. The low level of the net savings rate generated, 1.15% ( $=19.4\% - 3.65(K/GDP) \times 5\%$ ), well reflects the low rate of the savings rates and their downward trend of the recent years.

The educational expenditure computed in the model is 1.1% of GDP, 1.4% of the consumption of the whole household, 4.8% of the consumption of the household with children, 6.3% of the consumption of the household with the children aged 6-24, which is close to the estimate by Kang and Hyun (2008), 7% of household consumption with children. The ratio of the R&D to GDP in the initial year computed is 2.3%, which is close to its actual magnitude of the recent years (2.3%, OECD (2011)). The ratio of the time devoted to the on-the-job training to the labor hour is 1.5%, which is close to the estimate by the Kim *et al.* (2011). They showed that the average time devoted to the job training by the wage workers, who have participated into the job training, is 37 hours a year. This is about 1.5% of the annual working hour, taking into account: the average labor hour per week of the regular workers is 48 hours (the Ministry of Labor, 2005); and a year is about 52 weeks.

**Figure 2 Base Case Economy**



The resource allocations after the initial period are reported figure 2. The GDP is projected to increase until 2040s, and to decrease thereafter because of the decrease in the capital stock and the labor supply due to the population aging. However, the GDP per capita will continue to increase because of the technological progress. The technological progress results from the educational expenditure, the on-the-job training, and the R&D investment. The educational expenditure is projected to increase because of the decrease in the number of the children per parent, due to the low fertility rate. The increase in the educational expenditure will improve the labor productivity and the marginal benefit of the OJT, (equations (4), (9)), which will increase the time devoted to the OJT. The R&D investment is projected to gradually decrease, because of the decrease in the return from the R&D. The decrease in the return from the R&D is due to the decrease in the market size and the production level (see equation (19a)), resulting from the population decrease. The aggregate human capital is projected to rise up to the level 1.65 times as high as that at the initial period, while the firm's technology to rise up to the level 11.3 times as high as that at the initial period. These results indicate that the future labor productivity will be more dependent upon the R&D investment than on the human capital investment, because the population decrease in the future will restrict the growth of the aggregate human capital. The model produces the annual rate of the firm's technological progress for the recent 10 (30) years is 2.0% (2.2%), which belongs to the range of the estimates of the total factor productivity by the previous empirical studies.<sup>15)</sup>

To compute the welfare across generations, we use the following equation (29). We solve for  $x_p$ , the proportional change in the adult consumption, the leisure, the children's consumption, and the educational expenditure of the generation born in the initial year ( $p=0$ , i.e. the year 1980), required to equalize the lifetime expected utility of each generation to that of the cohort born in the initial year.

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<sup>15)</sup> These studies include Pilat (1995), Young (1995), Kwack (1997), and Yoon and Lee (1998). The estimates for the total factor productivity growth rate belong to the range 2-4% per annum.

$$\begin{aligned}
& \sum_{a=25}^{90} \left( \frac{1}{1+\beta} \right)^{a-25} u \left( c_{a,p+a-1}, l_{a,p+a-1}, n_p c f_{a-25,p+a-1}, E_{a-25,p+a-1}^{g(n_p)} \right) \\
& = \sum_{a=25}^{90} \left( \frac{1}{1+\beta} \right)^{a-25} u \left( c_{a,0+a-1} x_p, l_{a,0+a-1} x_p, n_0 c f_{a-25,0+a-1} x_p, \left( E_{a-25,0+a-1} x_p \right)^{g(n_p)} \right). \tag{29}
\end{aligned}$$

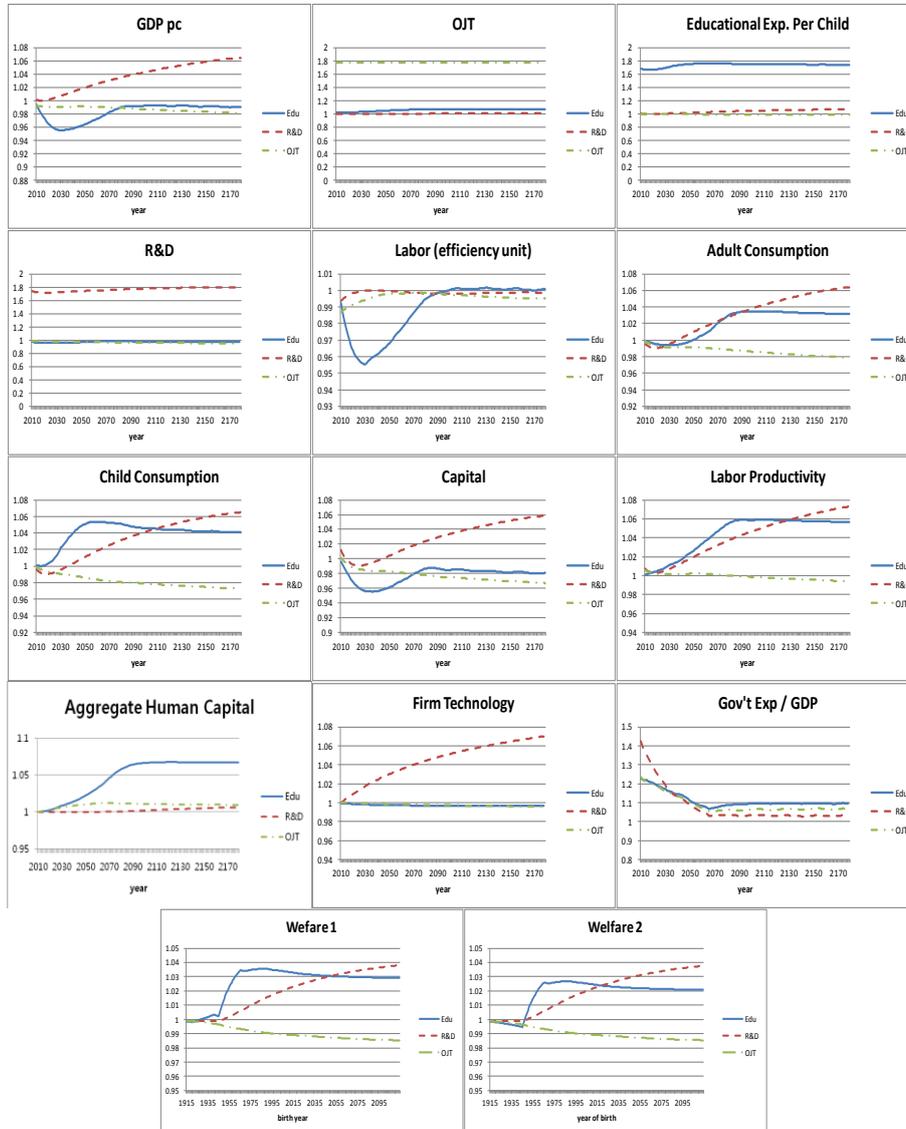
The labor productivity growth will improve the welfare of the future generations. The welfare level of the future generations born in 2100 is 3.4 times as high as the level of the welfare of the current generations, and the welfare level for the cohorts born after 2100 will rise continuously because of continuous growth.

#### 4.2. Policy Simulations

The provision of the subsidy to the R&D investment is shown to improve the GDP per capita and the welfare of the future generations more than that to the educational expenditure or to the on-the-job training. The provision of the subsidy which covers the 40% of the R&D investment cost will improve the GDP per capita by up to 6%, while that which covers the same proportion of the educational expenditure will not raise the GDP per capita. Moreover, the provision of the subsidy to the OJT will lower the GDP level, even though the magnitude of the GDP reduction is small.<sup>16)</sup> The differential effect of these 3 subsidy schemes, despite almost the same impact on the R&D investment, the educational expenditure, and the time devoted to the job training, is due to difference in the effect on the capital accumulation and the labor supply. The subsidy to the educational expenditure will reduce the savings and the wealth accumulation because of the increase in the educational expenditure by up to 80%, even though it will raise the labor productivity by 6% in the long run. The subsidy to the job training will

<sup>16)</sup> The figure 3 shows that the provision of the subsidy to the on-the-job training lowers the GDP per capita for some period after its introduction. It is because its provision increases the time allocated to the on-the-job training and decreases the labor hour. The human capital accumulation through the on-the-job training is shown to offset the loss of production due to the decrease in the labor hour in the long run.

Figure 3 Policy Simulations<sup>17)</sup>



<sup>17)</sup> We reported the ratio of the value of each variable to that in the benchmark economy ([1]).

reduce the savings, the wealth accumulation, and the labor supply due to the increase in the time for the job training, even though it will raise the aggregate human capital by 1%. Moreover, the subsidy has little impact on the labor productivity, because the decrease in the capital accumulation resulting from the provision of the subsidy will lower the productivity of the labor. On the other hand, the subsidy to the R&D is projected to improve the firm's technology by up to 6%, without negative impacts on the wealth accumulation or the labor supply.<sup>18)</sup>

Another important factor affecting the improvement of the firm's technology and the human capital investment and the economic growth is the increase in the tax burden. The ratio of the government expenditure to GDP increases most in the case of the subsidy to the R&D in the first year of the policy implementation, followed by that to the educational expenditure and that to the on-the-job training. In future periods, the ratio increases most in the case of the subsidy to the educational expenditure, followed by that to the on-the-job training and that to the R&D. The ratio is lowest in the future in the case of the subsidy to the R&D, due to the fact that it raises the GDP most. The proportional increase in the tax burden will decrease overtime, because the tax burden has a rising trend in the benchmark economy. In the future period, the difference in the proportional increase in the tax burden is not large, while they have differential effect on the efficiency of labor, which indicates the differential effects of these policies on the welfare of the future generations.

The effects on the welfare of the three policies are quite different. The implementation of the education subsidy improves the welfare of the cohorts

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<sup>18)</sup> The differential effects of the subsidies to the R&D, the educational expenditure, and the OJT, are consistent with the findings of the previous empirical researches: the R&D investment and the human capital investment contributed significantly to the economic growth, while the job training programs did not have significant effects on the job finding rate or the wage level. Acevedo (2008) presented that the private and public R&D stocks accounted for 16% and 19% of the economic growth respectively during the period 1976-2009. Kim (2011) showed that the human capital accumulation accounted for 1.3%p of the economic growth rate during the period 1980-2004. Lee (2005) showed that the job training programs did not raise the job finding rate or the wage level when the workers are reemployed after the job training.

who will be born relatively early, while that of the R&D subsidy the welfare of those who will be born in later years, because the productivity improvement is realized earlier in the case of the former than in the case of the latter policy implementation. In the case of the subsidy to the on-the-job-training does not improve the welfare because of the limited improvement of the labor productivity, the decrease in the GDP per capita and the consumptions, and the increase in tax burden.

Despite its little impact on the GDP per capita, the subsidy to the education improve the overall level of the welfare because it raises the labor productivity, increases the consumption for the adults and the children. We report two measures of the welfare effect: one taking into account the “joy of giving,” the increase in the utility due to the increase in the educational expenditure for the children (“welfare 1”); and one without consideration of the joy of giving (“welfare 2”). Comparison of the two measures shows that about 30% of the welfare improvement due to the education subsidy is accounted for by the increase in the joy of giving.

### **4.3. Optimal Combination of the Subsidies**

In this section, we search for the optimal combination of the three subsidies. We have shown the differential effects of the subsidies to the R&D, the educational investment, and the on-the-job training on the improvement of the productivity, and tax burden across generations. Despite the differential impacts on productivity, all three subsidy schemes improve the productivity. However, the subsidy schemes may cause the intergenerational redistribution. The provision of the subsidy to the R&D investment will improve the welfare of the future generations, who are alive in the periods when the improvement of the productivity due to the subsidy is realized. Because of the time lag between the provision of the subsidy and the realization of the efficiency gain, and the increase in the tax burden to finance the subsidy program, the current generations’ welfare improvement may be very limited. The optimal level of the subsidy rates is also an

important issue, because there is a trade-off regarding its level. The increase in the subsidy rate improves the productivity in larger scale, while it causes larger increase in the tax rates.

Taking into account these effects, we search for the optimal policy mix, which a hypothetical social planner chooses based on the utilitarian social welfare function, which is defined as the weighted average of the lifetime expected utility of each generation. The utilitarian social welfare function used to evaluate the social welfare is shown in the following equation (30).

$$\begin{aligned}
 SW_0 &= \sum_{p=-90}^{\infty} \left( \frac{1}{1 + \beta_s} \right)^{\max(0, p)} V_0(p), \\
 V_0(p) &= \sum_{a=\max(25, -p)}^{90} \left( \frac{1}{1 + \beta} \right)^{a - \max(25, -p)} \\
 &\quad \cdot u(c_{a, p+a-1}, l_{a, p+a-1}, n_p c f_{a-25, p+a-1}, E_{a-25, p+a-1}^{g(n_p)}).
 \end{aligned} \tag{30}$$

The social welfare is evaluated from the forward-looking perspective, in the sense that the utility from the consumption, the leisure, and the educational expenditure of the current generations, who are alive in the initial year, of the period before the initial year is not reflected. The social welfare takes into account the resource allocations of the present and future periods. The weight is given based on the social discount rate ( $\beta_s$ ), with which the social planner discounts the welfare of the future generations. There is no consensus on the value of the social discount rate. But, most of the researchers agree that the social discount rate is not more than the discount rate of the individuals ( $\beta$ ). Rosen and Gayer (2009) state that the social discount rate should be set at lower level than the individuals' discount rate, because the finite life expectancy makes the current generations myopic. We search for the optimal policy mix under the social discount rates (0.02, 0.015, 0.01 per annum), which is lower than or equal to the individuals' discount rate (0.02 per annum).

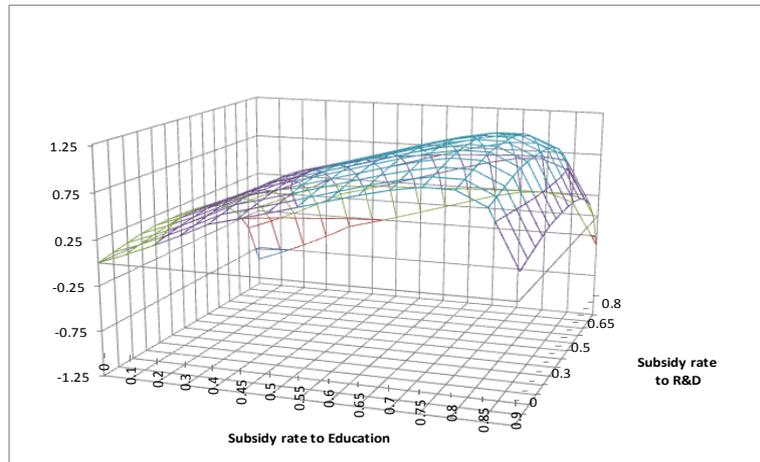
**Table 3 Optimal Combination of Subsidy Rates (%)**

$(\zeta_J, \zeta, \rho)$		<1>	<2>	<3>	<4>	<5>
	$\sigma=0.5^{1)}$	$\sigma=0.25$	$\sigma=0.75$	$\sigma=0.5$	$\sigma=0.5$	$\sigma=0.5$
	$\nu=0.1^{1)}$	$\nu=0.15$	$\nu=0.05$	$\nu=0.1$	$\nu=0.1$	$\nu=0.1$
	$\alpha_J=0.0^{1)}$	$\alpha_J=0.0$	$\alpha_J=0.0$	$\alpha_J=0.2$	$\alpha_J=0.0$	$\alpha_J=0.2$
$\gamma_H=0.0^{1)}$	$\gamma_H=0.0$	$\gamma_H=0.0$	$\gamma_H=0.0$	$\gamma_H=0.2$	$\gamma_H=0.2$	
Based on Welfare 1 <sup>2)</sup>						
$\beta_s=0.020$	(0, 50, 75)	(0, 50, 75)	(0, 55, 80)	(0, 50, 80)	(0, 50, 80)	(0, 50, 80)
$\beta_s=0.015$	(0, 60, 80)	(0, 55, 80)	(0, 60, 80)	(0, 60, 80)	(0, 60, 80)	(0, 60, 80)
$\beta_s=0.010$	(0, 65, 80)	(0, 60, 80)	(0, 70, 80)	(0, 70, 80)	(0, 60, 80)	(0, 70, 80)
Based on Welfare 2 <sup>3)</sup>						
$\beta_s=0.020$	(0, 50, 65)	(0, 45, 65)	(0, 55, 70)	(0, 50, 70)	(0, 50, 70)	(0, 50, 70)
$\beta_s=0.015$	(0, 55, 70)	(0, 55, 70)	(0, 60, 70)	(0, 60, 70)	(0, 60, 70)	(0, 60, 70)
$\beta_s=0.010$	(0, 65, 75)	(0, 60, 70)	(0, 65, 75)	(0, 60, 70)	(0, 60, 70)	(0, 70, 80)

Notes: 1) Benchmark case. 2) Welfare 1 takes account of the welfare from the “job of giving”. 3) Welfare 2 disregards the welfare from the “job of giving”.

The numbers in table 3 are the optimal subsidy rates to the job training, the R&D, and the education. The optimal policy combination under the assumption of 2% social discount rate consists of: 50% subsidy to the R&D investment, 75% subsidy to the educational investment, and 0% subsidy to the on-the-job training.<sup>19)</sup> The welfare gain of the subsidies to the R&D and the educational investment is quite large. Figure 4 shows that the welfare gain under the optimal combination of the subsidies at the benchmark case is about 1.2% of the welfare at the base-case economy without any subsidy. Assuming lower discount rates raises the optimal subsidy rate to the R&D investment up to 65% and the optimal subsidy rate to the educational investment up to 80%. Using the welfare 2 as the welfare measure lowers the optimal subsidy rate to the education a little to 65-75%.

<sup>19)</sup> The optimal subsidy rate to the OJT is 0, because the provision of the subsidy to the OJT does not improve the welfare, as shown in section 4.2.

**Figure 4 Welfare Gain (% of Welfare Benchmark)**

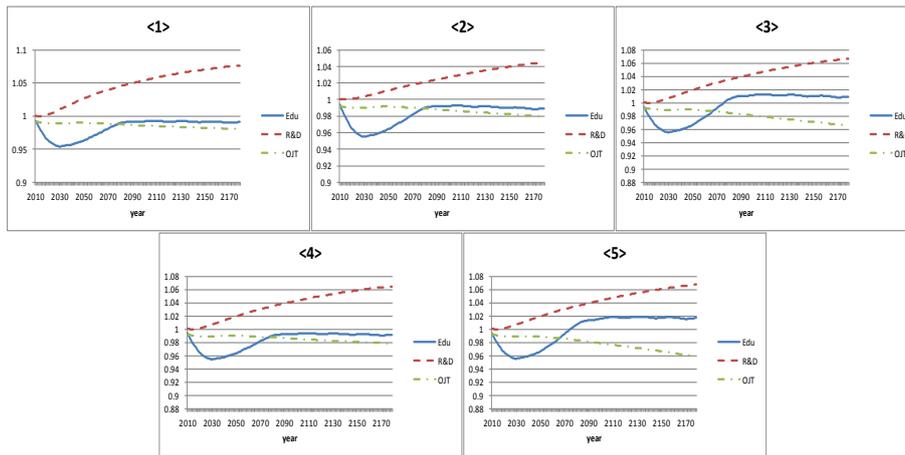
#### 4.4. Sensitivity Analysis

We try the sensitivity analyses assuming alternative values of parameters,  $\sigma$ ,  $\nu$ ,  $\alpha_J$ ,  $\gamma_H$ . We compute 5 additional economies assuming: <1>  $(\sigma, \nu) = (0.25, 0.15)$ ; <2>  $(\sigma, \nu) = (0.75, 0.05)$ ; <3>  $(\sigma, \nu, \alpha_J) = (0.5, 0.1, 0.2)$ ; <4>  $(\sigma, \nu, \gamma_H) = (0.5, 0.1, 0.2)$ ; and <5>  $(\sigma, \nu, \alpha_J, \gamma_H) = (0.5, 0.1, 0.2, 0.2)$ . Assumptions <1> and <2> are for the sensitivity analysis for the variation of  $\sigma$ ,  $\nu$ , which produces the same elasticity of the firm's technological progress with respect to the R&D investment as that in the benchmark economy where  $(\sigma, \nu) = (0.5, 0.1)$ . Assumptions <3>, <4>, <5> are to check the sensitivity of the results due to the change in the human capital accumulation process: <3> assumes the existence of the contribution of the education to the efficiency of the human capital accumulation; <4> assumes the existence of the externality of the aggregate human capital; and <5> assumes both the factors.

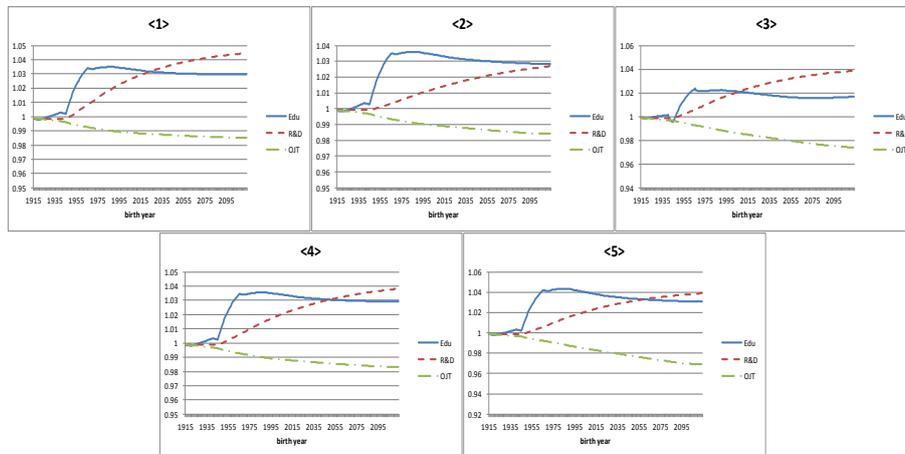
Figure 5 shows that the alternative assumptions on the firm's technological process and the human capital accumulation process do not produce the qualitatively different results. The subsidy to the R&D is more effective to raise the GDP per capita than that to the education, and that to the job training

Figure 5 Sensitivity Analysis<sup>20)</sup>

[GDP per Capita]



[Welfare 1]



Notes: <1>:  $(\sigma, \nu)=(0.25, 0.15)$  <2>:  $(\sigma, \nu)=(0.75, 0.05)$ ; <3>:  $(\sigma, \nu, \alpha_J)=(0.5, 0.1, 0.2)$ ; <4>:  $(\sigma, \nu, \gamma_H)=(0.5, 0.1, 0.2)$ ; <5>:  $(\sigma, \nu, \alpha_J, \gamma_H)=(0.5, 0.1, 0.2, 0.2)$ .

<sup>20)</sup> We reported the ratio of the value of each variable to that in the benchmark economy.

is not effective to raise GDP per capita. The subsidies to the R&D and the education improve the welfare of the future generations, while that to the job training does not improve the welfare, because of the decrease in the labor supply, the resulting decrease in the labor income and the wealth accumulation. Table 3 also shows that the alternative assumption on the parameters does not change the optimal combination of the subsidy rates to the R&D, the education, and the job training much.

The results of the sensitivity analysis indicate the potential importance of the role of education in improving efficiency of the human capital accumulation through the job training and the externality of the human capital accumulation. In the economies <3> and <5>, the effects of the subsidy to the education on the GDP per capita level are amplified by incorporating the roles, i.e. by assuming positive numbers for  $\alpha_J$ ,  $\gamma_H$ . There is little empirical findings regarding the values for  $\alpha_J$ ,  $\gamma_H$  for Korea. However, it is not likely that  $\alpha_J$  and  $\gamma_H$  are as high as 0.2, because the estimates for these parameters for other countries, are not so high.<sup>21)</sup>

## 5. CONCLUSION

We have searched for the optimal combination of the firm's technology and human capital accumulation through the education and the job training, using a general equilibrium model. The characteristic of the non-rivalry of the technology and human capital induces the private agents' decision-making, which causes the inefficient resource allocation: i.e. they do not take into account the spillover effects of the improvement of the firm's technology over the efficiency of the human capital investment, and vice versa. More importantly, the finite-horizon economic agents do not fully take account of the externality of the improvement of the technology and the

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<sup>21)</sup> For example, Ciccone and Peri (2006) showed a very low value of the education externality: the point estimates of the external return to a 1-year increase in average schooling are around 0 at the city level and around 2% at the state level in US, which indicates 0 or 0.02 for  $\gamma_H$ .

human capital accumulation. Therefore, the optimal portfolio of the knowledge investment in the form of the R&D investment and the human capital investment in the form of the educational investment and the job training should be attained by the optimal subsidy combination, which enables the internalization of the benefits of the spillover effects of the improvement of the firm's knowledge (or the worker's knowledge).

The policy simulations, using a general equilibrium model, which incorporates these aspects of the knowledge investment and human capital investment, the characteristics of the Korean economy and the knowledge production and the human capital investment process, show that: (1) the subsidy to the R&D investment is more effective to improve the productivity and the welfare of the future generations than that to the educational investment (or to the job training); (2) compared with the difference in the impact of the subsidy schemes on the productivity, the difference in the increase in the tax burden due to the provision of the subsidy is smaller, which indicates the differential effects on the welfare; and (3) the optimal combination of the subsidy schemes, taking into account differential impact on the productivity, the tax burden, and the welfare across generations, is shown to be 50-65% subsidy to the R&D investment, 65-80% subsidy to the educational investment, and no subsidy to the job training.

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