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The Growth Effects of Population Aging in an Economy with Endogenous Technological Progress*

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We address the effects of population aging on economic growth, taking account of its growth-delaying effects, through the reduction of capital accumulation and labor force, and the R&D investment reduction due to its lowered return resulting from reduced market size, as well as its growth-promoting effects, through the increase in educational investment due to decrease in the number of child per parent. The policy simulations with a general equilibrium model and its calibration, reflecting the Korean economy, show that: (1) the population aging delays technological progress as well as quantitative economic growth; (2) the government subsidies to R&D and educational investment can partly compensate for the loss in economic growth due to the population aging, but they cannot deal with the problem fundamentally; and (3) the optimal subsidy rates to R&D and education are quite high, ranging from 50 to 70% to R&D and from 70 to 80% to education.

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I. Introduction

Population aging is one of the most serious problems in many countries. Korea is not an exception. Even though the proportion of the population aged 65 and older was 11.3 percent as of 2010, much lower than most of the developed countries, the proportion is projected to increase to 23.1 percent in 2030, almost the same as the projected OECD average at that time (UN (1998)). More elderly dependents relative to workers resulting from the population aging suggest the likelihood of

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more consumption relative to income and, less saving. And the reduction of the labor force due to the population aging and population reduction will be another obstacle to economic growth.[1]

Another risk related with the population aging is the increase in the social welfare expenditure. The government of many countries tends to provide more generous social welfare benefits to the elderly than to any other age groups. Korean government has introduced many transfer payments to the elderly and reinforced the protection of this age group. The examples include the introduction of the public long-term care insurance, the universal pension, and the extension of the coverage of the public medical insurance and reduction of out-of-pocket money for treatment of the diseases since 2007. This tendency of the policy revision, accompanied by the population aging, will increase the tax burden, which will further reduce the labor supply, savings, and growth rates.[2]

In addition to the delay of the quantitative economic growth due to the reduction of the labor and the capital inputs, the population aging, accompanied by the increase in the transfer payment to the elderly, may also delay the technological progress. The population size reduction due to the fall in the fertility rate implies the market size reduction,[3] and will decrease the return from the research and development (R&D). The decrease in the R&D investment due to the reduction of its return will delay the technological progress.[4]

[1] Many previous studies addressed this issue. Most of the studies presented very pessimistic pictures of the aged society. They presented the possibility of the reduction of the national savings and the labor supply due to the population aging. They include Auerbach and Kotlikoff (1987b) and Kotlikoff et al. (1996) (for the US), and Chun (2007) (for Korea). Bloom et al. (2011) showed the possibility that the previous research exaggerated the risk of population aging. They tried a quantitative analysis on the effect of the population aging on the economic growth. The study showed that the population aging in OECD countries will cause the delay of the economic growth by reducing in the labor force and the national savings rate. However, it also showed that the magnitude of the loss of the production due to the population aging is not large. In addition, it presented that in the case of the developing countries, the increase in the economically active population proportion will be able to compensate for the loss of production due to the population aging.

[2] The examples of these studies include Gruber and Wise (1998), Auerbach and Kotlikoff (1987c). Gruber and Wise (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.

[3] The fertility rate reduction does not always decrease total population. If the fertility rate is not so low and the life expectancy increases fast enough, an increase in the population may happen even at the low fertility rate. However, at the current low fertility rate of Korea, the population will eventually decrease. Moreover, the population decrease will happen in the near future. The National Statistics Office (NSO)'s 2010 population projection showed that the total population of Korea would decrease from around 2030 under the assumption that the fertility rate is at the current level.

[4] The studies on the endogenous growth theory, including 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

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 investment per child.[5] 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 investment per child. This will promote the productivity of the children in their working ages.

We address the effects of the population aging and the resulting population size reduction on economic growth and welfare by using a general equilibrium model. Unlike previous studies that focused on a specific aspect of the population aging, we investigate this issue, taking explicit account of the growth-promoting effects as well as the growth-delaying effects of the population aging in a unified framework. The special features of the simulation model are as follows. First, the model explicitly takes into account resource allocation between parents and children. In the household sector, the parents and the children coexist, and the parents make decisions on the consumption of the parents and the children, the labor supply of the parents and the educational investment for the children. This specification enables the analysis of the effects of the population aging, which changes the age structure of the family, on the resource allocation within the family. Second, the model reflects the decision-making of the firms on the R&D investment to maximize the value of the firm. Third, the model endogenizes the process of the technological progress, by introducing the production function of the new technology. The technological progress is determined by the firm's decision-making on the R&D investment and the household's decision making on the educational investment. Finally, we reflect the characteristics of the Korean policies of the transfer payment,[6] using the method of the generational accounting.

The policy simulations with the model and its calibration, reflecting the Korean economy and its government transfer payment policies, show that: (1) the population aging and the resulting population size reduction will delay the technological progress as well as the quantitative economic growth; (2) government subsidies to the R&D and the educational investment, which improve the

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.

[5] 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.

[6] Even though the model has a general setting, which can be applied to a variety of economies, we apply this model to the Korean economy, because Korea is a very special case in the aspect of the population aging and the extension of the social welfare policies, especially to the elderly, in the sense that: (1) the speed of the population aging is the highest in OECD countries; and the growth rate of the government transfer expenditure to the elderly is expected to be very high because of the rapid expansion of welfare programs for the elderly in recent years.

technology and the labor productivity, can partly compensate for the loss in economic growth due to the population aging, but they cannot deal with the problem fundamentally; and (3) optimal subsidy rates to the R&D and the education are quite high, ranging from 50 to 70% to the R&D and from 70 to 80% to the education.

The remainder of this paper is organized as follows. Section II introduces the simulation model, explain the theoretical predictions, and define the competitive equilibrium. Section III calibrates the simulation model. After the results of the policy simulations are explained in Section IV, we conclude our discussion in Section V.

II. 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 and older and the children's generation aged 0-24. The parents' generation makes decisions on their own consumption and labor supply, the children's consumption, and the educational investment 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 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 subsidies to the R&D and the educational investment, and social welfare benefits to households. It imposes taxes to finance the government expenditure.

II.1. Households

The individuals live up to the age of D, and do not face any mortality risk until the age of 50. But they do face the mortality risk after the age 50.[7] The mortality risk is represented by the mortality rate, which is 1-survival rate. The survival rate, $S_{p,i,i+1}$, is the probability that the aged i born at p survive until next year. Each individual becomes an adult, when she becomes 25 years old. The individual gets

[7] Assuming the mortality risks before the age 50 causes the problem of the orphanage, which make the analysis complicated. In order to avoid the technical problem, we assume that people do not face the mortality risk until the age 50.

married and has children as soon as she becomes an adult. We assume that the number of the children is determined exogenously. The law of motion of the population distribution is expressed by the following equation (1).

$$\begin{aligned} \mu_{i,p+i} &= n_p \mu_{25,p+i-1} && (i=0) \\ &= \mu_{i-1,p+i-1} && (0<i\le 50) \\ &= S_{p,i-1,i}\mu_{i-1,p+i-1} && (50<i\le D) \\ &= 0 && (i>D) \end{aligned} \tag{1}$$

where i and p represent the age and the year of birth of each generation. Thus $\mu_{i,t}$ is the population of the aged i at period t, and n_p is the fertility rate of the parents, who were born at $p-25$ and are 25 years older than their children. In this model, the fertility rate is the same as the number of children per parent.

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 investment for their children and continue the decision-makings until the children become adults. The parents also make decisions on their own consumption and labor supply.

The decision-makings of the individuals are based on the life-cycle preference, 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.[8] The preference of the parents, who were born at period p, is represented by the discounted lifetime utility.

$$\sum_{i=25}^{D}\left(\frac{1}{1+\beta}\right)^{i-25} S_{p,i}u\left(c_{i,p+i}, l_{i,p+i}, n_p cf_{i-25,p+i}, E_{i-25,p+i}{}^{g(n_p)}\right),\quad S_{p,i}=\prod_{j=1}^{i} S_{p,j-1,j} \tag{2}$$

$$u(c,l,cf,E)=\frac{1}{1-\gamma}\left(c^{1-\omega_i-\psi_i-\varepsilon_i} l^{\alpha}\left(ncf\right)^{\psi_i}\left(E^{g(n)}\right)^{\varepsilon_i}\right)^{1-\gamma},\quad \omega_i+\psi_i+\varepsilon_i=\alpha \tag{2'}$$

$$\psi_i=\begin{cases}\psi>0, & i=25,\cdots,50\\ 0, & \text{otherwise}\end{cases}$$

[8] We assume that the educational investment for the children is determined by the preference for the intergenerational transfer. In reality, parents transfer resources to the children, in the form of the bequest and the educational investment. The 'joy of giving' bequest motive was represented by the bequest in the utility in many previous studies including Altig et al. (2001). In this paper, we assume that the parents feel the 'joy of giving' to children through the educational investment.

$$\varepsilon_i = \begin{cases} \varepsilon > 0, & i = 31, \cdots, 50 \\ 0, & \text{otherwise} \end{cases}$$

where β is the discount rate, $c_{i,t}$, $l_{i,t}$, $cf_{i-25,t}$, $E_{i-25,t}$ represent the consumption and the leisure of the parents of the aged i, the consumption per child, and the educational investment per child of the aged $i-25$ at t. $S_{p,i}$ is the probability of those born at p surviving until the age i. $g(n)$ is the scale factor for the educational investment, which reflect the diminishing marginal increase in educational investment in response to the increase in the number of children[9] ($g'(n) > 0$, $g''(n) < 0$). 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 investment per child.[10] The intensity parameter of the preference for the children's consumption and the education (ψ, ε) takes a positive value, when the parents make decisions on them, and 0 values for the other periods of their lives.

The sources of fund for the household expenditure are the labor income and the transfer income for the parents and the children from the government. The parents spend on the consumption for themselves and the children, the educational investment for the children, and tax payment. We assume an annuity market, where the survivors of a cohort share the wealth or the debt of the deceased of the same cohort, in order to prevent the accidental bequest. The constraint for the parents' generation is represented by the equation (3) and (3-1).

For $i = 25, \cdots, D-1$

$$\begin{aligned} a_{i+1,p+i+1} = {} & a_{i,p+i}\left(1 + r_{p+i}\left(1 - \tau_{k,p+i}\right)\right) / S_{p,i,i+1} + w_{i,p+i} e_{i,p+i}\left(1 - l_{i,p+i}\right)\left(1 - \tau_{l,p+i}\right) + tr_{i,p+i} - c_{i,p+i}\left(1 + \tau_{c,p+i}\right) \\ & + n_p\left(trf_{i-25,p+i} - cf_{i-25,p+i}\left(1 + \tau_{c,p+i}\right)\right) \cdot 1\left(i \le 50\right) - n_p\left(1 - \rho\right) E_{i-25,p+i} \cdot 1\left(i \ge 31\right) \cdot 1\left(i \le 50\right) \end{aligned}$$

with the probability of $S_{p,i,i+1}$ (3)

$a_{i+1,p+i+1} = 0$ with the probability of $1 - S_{p,i,i+1}$

[9] The educational investment 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).

[10] Other forms of the consumption for the children than the educational investment may affect the quality of the children. For example, the consumption expenditure to improve the health state, such as those to prevent the obesity and nutrition imbalance may improve the quality of the children. In this paper, we focus on the effect of the educational investment on the labor productivity.

$$a_{D+1,p+D+1} = 0 \tag{3-1}$$

$$e_{25,p+25} = \left(\sum_{j=31}^{50} E^{P}_{j,p-25+j} \right)^{\alpha_E} ep_{25} \tag{4}$$

where w_t, r_t, τ_{lt}, τ_{kt}, τ_{ct} represent the wage rate, the interest rate, the labor income tax rate, the capital income tax rate, the consumption tax rate at t, $tr_{i,t}$, $trf_{i,t}$, and $a_{i,t}$ are the government transfer to the parents and the children and asset-holding of the aged i at t, and ρ is the government subsidy rate to the educational investment, respectively. $1(\cdot)$ is the indicator function which allocates 1 if the proposition in the parenthesis is true and 0 otherwise. The labor income of the household depends on the overall level of wage rate (w), their labor supply ($1-l$), and the efficiency of their labor service (e). The labor productivity of the aged 25, who have just started to work, is determined by their parents' educational investment for them in their childhood (E^P) and the parameter reflecting the rate of return to the educational investment, α_E (see equation (4)). The profile of the labor productivity (ep_i) is determined by the age. The profile is assumed based on the age profile of the wage rate reported by the Ministry of Labor (2005).

The optimization problem of the parents is represented by the following value function.

$$\begin{aligned} &V_{i,p+i}\left(a_{i,p+i}, tr_{i,p+i}, trf_{i-25,p+i}, \rho\right) \\ &= \max_{c,l,cf,E} \frac{1}{1-\gamma}\left(c^{1-\omega_i-\psi_i-\varepsilon_i} l^{\alpha} \left(n_p \cdot cf\right)^{\psi_i} \left(E^{g(n_p)}\right)^{\varepsilon_i}\right)^{1-\gamma} \\ &+ \frac{1}{1+\beta} S_{p,i,i+1} V_{i+1,p+i+1}\left(a_{i+1,p+i+1}, tr_{i+1,p+i+1}, trf_{i+1-25,p+i+1}, \rho\right) \end{aligned} \tag{5}$$

subject to (3) and, (3-1).

The optimization conditions consist of the following equations and the constraints represented by equation (3) and (3-1).[11]

$$l_{i,p+i} = \frac{\omega_i}{1-\omega_i-\psi_i-\varepsilon_i} \frac{1+\tau_{c,p+i}}{w_{p+i} e_{i,p+1}\left(1-\tau_{l,p+i}\right)} c_{i,p+i} \tag{6}$$

[11] The existence of the annuity market arrangement in this model makes the optimization conditions the same as those in the case where there is no mortality risks.

$$cf_{i-25,p+i}=\frac{\psi_i}{1-\omega_i-\psi_i-\varepsilon_i}c_{i,p+i} \tag{7}$$

$$E_{i-25.p+i}=\frac{\varepsilon_i}{1-\omega_i-\psi_i-\varepsilon_i}\frac{g(n_p)\left(1+\tau_{c,p+i}\right)}{n_p\left(1-\rho\right)}c_{i,p+i} \tag{8}$$

$$\frac{c_{i+1,p+i+1}}{c_{i,p+i}}=\left(\frac{1+r\left(1-\tau_{k,p+i+1}\right)}{1+\beta}\right)^{\frac{1}{\gamma}}\left(\frac{1+\tau_{c,p+i+1}}{1+\tau_{c,p+i}}\right)^{\omega_i\frac{1-\gamma}{\gamma}}\left(\frac{w_{p+i}e_{i,p+i}\left(1-\tau_{l,p+i}\right)}{w_{p+i+1}e_{i+1,p+i+1}\left(1-\tau_{l,p+i+1}\right)}\right)^{\omega_i\frac{1-\gamma}{\gamma}} \tag{9}$$

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 investment per child, because we assume that $g'(n)>0$, $g''(n)<0$. On the other hand, the magnitude of the consumption for each child is not affected by the number of children per parent. 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.

II.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 (wL), the capital cost (rK), the physical investment (I), 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.

$$V_t=\sum_{s=t}^{\infty}\left(\prod_{j=t}^{s}\left(1+r_j\right)^{-1}\right)\left(Y_s-w_sL_s-r_sK_s-I_s-\left(1-\zeta\right)y_{Rs}\right) \tag{10}$$

$$Y_t=K_t^{1-\theta}\left(A_tL_t\right)^{\theta} \tag{11}$$

where Y_s, A_s, θ, ζ represent the output, the firm 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, e (see equation (4)), which affects the labor input measured in efficiency unit (L).

The evolutions of the physical capital and the technological level are determined following equations (12) and (13).

$$K_{t+1} = I_t + (1-\delta_K)K_t \tag{12}$$

$$A_{t+1} = A_t(1-\delta_A) + \phi A_t^{\sigma} y_{Rt}^{\upsilon} \tag{13}$$

where δ_K and δ_A are the depreciation rates of the physical capital and the technology, and ϕ, σ, υ 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,[12] respectively.

The firm's maximization problem is represented by the following value function (14).

$$V_t(K_t, A_t, \zeta) = \max_{L_t, I_t, y_{Rt}} \left(K_t^{1-\theta}(A_t L_t)^{\theta} - w_t L_t - r_t K_t - I_t - (1-\zeta) y_{Rt} \right) + \frac{1}{1+r_{t+1}} V_{t+1}(K_{t+1}, A_{t+1}, \zeta) \tag{14}$$

subject to (12), (13).

The optimization conditions consist of the equations (12), (13), and the following equations (15)-(18).

$$\theta K_t^{1-\theta}(A_t L_t)^{\theta-1} A_t = w_t \tag{15}$$

[12] The new technology production function is a modified version of that in Jones (1995). Jones (1995) specified that the new technology is produced with the existing technology and the number of research workers, which represents the research sector size. Under Jones (1995)'s specification, the technological progress in the long run is not possible without population increase. We adopt the R&D investment as an index for the research sector size, in order to overcome this problem. Similar specification is found in Trostel (1993), even though it is for the human capital production. Trostel (1993) assumed that the human capital production is a function of the existing human capital, the time devoted to human capital production, and the human capital investment in the physical form.

$$\left(1-\theta\right)K_t^{-\theta}\left(A_tL_t\right)^{\theta}=r_t+\delta_K \tag{16}$$

$$\left(1+r_{t+1}\right)^{-1}\left(K_{t+1}^{1-\theta}\left(A_{t+1}L_{t+1}\right)^{\theta-1}\theta L_{t+1}\right)-\xi_t$$
$$+\left(1+r_{t+1}\right)^{-1}\xi_{t+1}\left(1-\delta_A+\phi A_{t+1}^{\sigma-1}\sigma y_{Rt+1}^{\upsilon}\right)=0 \tag{17}$$

$$\left(1-\zeta\right)=\xi_t\left(\phi A_t^{\sigma}\upsilon y_{Rt}^{\upsilon-1}\right) \tag{18}$$

Where ξ_t is the shadow value of the technological evolution equation (13) at *t*.

The equations (15)-(18) are the first order conditions for the labor input, the capital input, the technology level, and the R&D investment. By rearranging the equation (17), we get the following equation (17').

$$\xi_t=\left(1+r_{t+1}\right)^{-1}\left(K_{t+1}^{1-\theta}\left(A_{t+1}L_{t+1}\right)^{\theta-1}\theta L_{t+1}\right)$$
$$+\left(1+r_{t+1}\right)^{-1}\xi_{t+1}\left(1-\delta_A+\phi A_{t+1}^{\sigma-1}\sigma y_{Rt+1}^{\upsilon}\right) \tag{17'}$$

The equation (15) shows the equalization of the marginal productivity of labor and the wage rate, and the equation (16) that of the marginal productivity of capital and the rental rate. The equation (17') shows the optimal condition of the evolution of the technology level. The shadow value ξ_t, 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 (17'), and it facilitates the technological progress, represented by the second term.

The equation (18) shows the decision making process on the R&D investment. The left hand side of (18) 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 $(\phi A_t^{\sigma}\upsilon y_{Rt}^{\upsilon-1})$, by the marginal return from the technological progress (ξ_t).

The equation (17') 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.[13] As a result, the technological progress will be delayed.

II.3. Government

The roles of government are the provision of the subsidy to the R&D investment and the educational investment for the children, 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 (equation (19)).

$$\sum_{i=6}^{24}\rho E_{i,t}\mu_{i,t}+\zeta y_{Rt}+\sum_{i=0}^{24}trf_{i,t}\mu_{i,t}+\sum_{i=25}^{D}tr_{i,t}\mu_{i,t}=\tau_{l,t}w_t N_t+\tau_{k,t}r_t W_t+\tau_{c,t}C_t \qquad (19)$$

$$N_t=\sum_{i=25}^{D}e_{i,t}\left(1-l_{i,t}\right)\mu_{i,t} \qquad (20)$$

$$W_t=\sum_{i=25}^{D}a_{i,t}\mu_{i,t} \qquad (21)$$

$$C_t=\sum_{i=25}^{D}c_{i,t}\mu_{i,t}+\sum_{i=0}^{24}cf_{i,t}\mu_{i,t} \qquad (22)$$

where N_t, W_t, C_t represent the aggregate values of the labor supply, the asset-holdings, and the consumption at period *t*.

II.4. Competitive Equilibrium

The competitive equilibrium is defined as the collection of the value function of the firms (equation (14)), the value function of households (equation (5)), the decision making functions of firms, $K_{t+1}^d(K_t,A_t,\zeta)$, $L_t^d(K_t,A_t,\zeta)$, $y_{Rt}(K_t,A_t,\zeta)$, the decision making functions of households, $a_{i+1,t+1}(a_{i,t},tr_t,trf_t,\rho)$, $l_{i,t}(a_{i,t},tr_t,trf_t,\rho)$, $E_{i,t}(a_{i,t},tr_t,trf_t,\rho)$, $cf_{i,t}(a_{i,t},tr_t,trf_t,\rho)$, given the policy

[13] The market size effects on growth may be more relevant to large economies than to small economies like Korea. However, Korea is not a small open economy of textbook definition, even though it is not a very large country. The production factor mobility is not perfect due to the imperfect information of Korea (foreign countries) on the investment environment of the foreign countries (Korea). Moreover, recently the domestic market becomes more important as a buffer against the external shocks from abroad, such as the global financial crisis and the fiscal crisis of the U.S. and European countries. Therefore the market size effects on growth is still relevant for Korea.

parameters $\{tr_t, trf_t, \rho, \zeta\}_{t=0}^{\infty}$ and the law of motion of the population distribution (equation (1)), which satisfy the conditions 1) - 6).

1) Individuals maximize the lifetime expected utility.
   - Equations (3), (3-1), (6)-(9) hold.

2) Firms maximize their value.
   - Equations (12), (13), (15), (16), (17'), (18) hold.

3) The law of motions for macroeconomic variables is consistent with the decision making of individuals.
   - Equations (20)-(22) hold.

4) The budget of the government is balanced.
   - Equation (19) holds.

5) Factor markets clear.
   - Equations (23), (24) hold.

$$W_t^{1-\theta}\left(A_t N_t\right)^{\theta-1}\theta A_t = w_t \tag{23}$$

$$\left(1-\theta\right)W_t^{-\theta}\left(A_t N_t\right)^{\theta} = r_t + \delta_K \tag{24}$$

6) The output market clears.
   - Equation (25) holds.

$$K_t^{1-\theta}\left(A_t L_t\right)^{\theta} = \sum_{i=25}^{D} c_{i,t}\mu_{i,t} + \sum_{i=0}^{24} cf_{i,t}\mu_{i,t} + \sum_{i=6}^{24} E_{i,t}\mu_{i,t} + I_t + y_{Rt} \tag{25}$$

III. Calibration

The parameterization for the policy simulation model is summarized in Table 1. We adopt the values for γ and β, 2 and 0.02, to produce the reasonable values for the aggregate wealth and the consumption profile.[14] We set 0.55 for α, because the Ministry of Labor (2005) reported that the proportion of labor hour out of the

[14] The previous empirical research showed a wide range of the estimate for the risk aversion parameter γ, and there is scant evidence of the appropriate value for β. For the extensive literature survey on the parameter estimates, see Auerbach and Kotlikoff (1987a).

substitutable time is about 45%.[15] We assume the parameters for shares of the children's consumption and educational investment as follows, reflecting that: (i) the proportion of the expenditure for the children, including the consumption and the educational investment, is estimated 35% of the baby boom generations in Korea (Son (2011)); and (ii) Kang and Hyun (2012) showed that the proportion of the educational investment in the household consumption is 7%.

$$\psi_i = \begin{cases} 0.28 \times (1-\alpha) = 0.126, & i = 25, \cdots, 50 \\ 0, & \text{otherwise} \end{cases}$$

$$\varepsilon_i = \begin{cases} 0.07 \times (1-\alpha) = 0.0315, & i = 31, \cdots, 50 \\ 0, & \text{otherwise} \end{cases}$$

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

The demographic structure in the model is determined by the fertility rate and the life expectancy. 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 (2010). We also try sensitivity analyses assuming the situation where the fertility rate will rise to 1.8 or where the fertility rate will stay at the current level. We assume that the maximum age is 90, and adjusted the survival rates so that the life expectancy of the generations born from 2010 can become close to that projected by the 2010 NSO's population projection.[16]

The labor income share in the production function is assumed 60%, based on the value reported in National Account. The depreciation rate of the 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, δ_A, 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 (13). The equation (13) can be rewritten as the following equation (13').

$$\frac{A_{s+1} - A_s}{A_s} = \phi A_s^{\sigma-1} y_{Rs}^{\upsilon} \tag{13'}$$

[15] 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%.

[16] The projection of the 2010 NSO population projection on the life expectancy is: 81 years (2010 newborns), 83 years (2020 newborns), 84 years (2030 newborns), 86 years (2040 newborns), 87 years (2050 newborns), 89 years (2060 newborns), 90 years (2070 newborns).

On the balanced growth path, the left hand side of the equation (13') is constant. Taking the natural log function and taking derivatives both sides of the equation, we get the equation (26), which shows the long-run relationship between υ and σ.

$$\frac{\Delta A / A}{\Delta y_R / y_R} = \frac{\upsilon}{1-\sigma} \tag{26}$$

The left hand side of the equation (26) is the elasticity of productivity growth with respect to R&D investment. Lee et al. (2010) reported its estimated value around 0.2 for the several OECD countries.[17] We cannot solve for both υ and σ using the estimated value. We simulate 3 cases: (i) υ =0.5, σ =0.1 (case <1>); υ =0.15, σ =0.25 (case <2>), which is the case of the small value of σ, and υ =0.05, σ =0.75 (case <3>), which is the case of the large value of σ. For the value of ϕ, we choose the values that reproduces the average productivity growth for the period 2000-2005, which was estimated by Kwack (2007).[18] These values produce the annual rate of the technological progress for the past 10 (30) years is about 2.3 % (2.6 %), which belongs to the range of the estimates of the total factor productivity by the previous empirical studies.[19] We choose 0.1265 for α_E, based on the estimate for the elasticity of income of the children with respect to the educational investment by An and Jeon (2008).

The age profile of the labor productivity is estimated using the wage data reported in the Ministry of Labor (2005). The labor productivity profile estimated is as follows.

$$\exp(ep_i) = 8.625154 + 0.03467 \cdot (i-25) - 0.000591 \cdot (i-25)^2 \tag{27}$$

We assume the government subsidy rates for the R&D and the educational investment (ζ, ρ) are 0's in the benchmark economy, and investigate the effect of the government subsidy by assuming alternative levels. We compute the net transfer income from the government by age and year, using the method of Auerbach and Chun (2006).[20] The proportion of the tax revenue by the tax base is assumed 40%

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[17] Lee et al. (2010) 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).

[18] Kwack (2007) reported that the productivity growth due to the total factor productivity is 1.48% and that due to the human capital accumulation is 0.82% for the period 2000-2005. We choose the value of ϕ that reproduces 2.30% for the labor productivity for that period.

[19] 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.

[20] 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

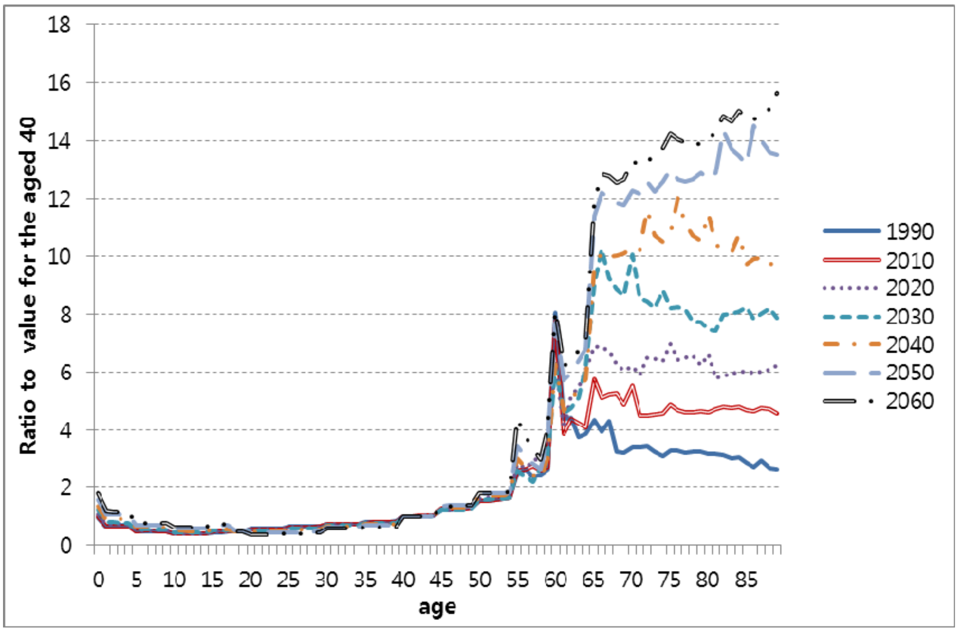
(consumption tax), 31% (wage income tax), 29% (capital income tax).

[Table 1] Parameterization

Demographic Assumption	Total fertility rate is 2 in 1980, falls gradually to 1.2 until 2010, and thereafter rises to 1.4 until 2050. The maximum surviving period is assumed 90 years. The survival rates are assumed to reflect the projection of the life expectancy by 2010 NSO population projection.
Preference parameters	Share of leisure in utility (α): 0.55, Share of children's consumption in the utility (ψ): 0.126 (=0.28 x ($1-\alpha$)) Share of education in the utility (ε): 0.0315 (=0.07 x ($1-\alpha$)) Relative risk aversion parameter (γ): 2 Discount rate (β): 2% per annum
Technology parameters	Labor income share (θ): 60% Depreciation rate of physical capital (δ): 5% per annum Return-from-education parameter (α_E): 0.1265
R&D technology parameters	Depreciation rate of technology (δ_A): 0% per annum Efficiency of R&D (ϕ): 0.284 (<1>), 0.315 (<2>), 0.260 (<3>) Share of existing technology in technology improvement (σ): 0.5 (<1>), 0.25 (<2>), 0.75 (<3>) Share of R&D investment in technology improvement (υ): 0.1 (<1>), 0.15 (<2>), 0.05 (<3>)
Social welfare function	Utilitarian social welfare function assumed. Discount rate (β_s): 2%, 1.5%, 1% per annum
Government policy	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 investment (ζ,ρ) are 0's in the benchmark economy and assume alternative level for policy simulation

change in the wage level.

[Figure 1] Age profile of transfer income by year



IV. Findings

We simulate 6 economies (see Table 2). The economy [1] is our benchmark economy where the medium fertility is assumed, and the government provides the transfer payment programs, but does not provide the subsidy for the R&D investment, or that for the educational investment. The economy [2] removes the government transfer payment programs to investigate the effects of the transfer program. The scenarios [3] and [4] simulate the high fertility and the low fertility economy with the government transfer programs, respectively. The scenarios [5] and [6] introduce the subsidy to the R&D investment and that for the educational in the medium fertility economy with the government transfer programs, respectively.

[Table 2] Policy Scenarios

Scenario	Contents
[1]	Medium fertility[1)] Transfer income from government is included. $\zeta, \rho = 0$
[2]	Medium fertility No transfer income from government $\zeta, \rho = 0$

[3]	High fertility[2)] Transfer income from government is included $\zeta, \rho = 0$
[4]	Low fertility[3)] Transfer income from government is included $\zeta, \rho = 0$
[5]	Medium fertility Transfer income from government is included $\zeta = 40\%$ [4)], $\rho = 0$
[6]	Medium fertility Transfer income from government is included $\zeta = 0$, $\rho = 40\%$ [4)]

Note: 1) Fertility rate rise from 1.2 to 1.4 until 2050.
2) Fertility rate rise from 1.2 to 1.8 until 2050.
3) Fertility rate stays at current level (1.2).
4) The subsidy is provided from 2011.

IV.1. Benchmark Economy

The resource allocations in our benchmark economy ([1]) are summarized in Table 3 and figures 2. In the recent year (2010) of the benchmark economy[21], the capital-output ratio is 3.50-3.54, the average of workers' share of the labor hour out of total substitutable time is about 38.0-38.1%, and the savings rate is 21.0-21.2%. 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. However, the value is a reasonable compromise, considering the existence of 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 well reflects the low rate of the savings rates and their downward trend of the recent years, even though it is lower than the average national savings rate in 2000's (31.5%).

The educational investment computed in the model is: 1.9-2.0% of GDP; 2.5% of the consumption of the whole household; 5.6% of the consumption of the household with children, which is lower than the estimate by Kang and Hyun (2008) (7%). However, the proportion of the educational investment among household consumption is about 7% in the case of the households with the educational investment, where the child is aged 6-24. The ratio of the R&D investment to GDP in the initial year computed is 2.4%, which is a little lower than the actual magnitude for the period 2000-2007 (about 2.8%, Kim (2011)).

[21] The economy is simulated from the year 1980. However, we calibrate model to reflect the economy of recent years (2000-2010). Therefore, we report the resource allocations as of 2010 instead of those as 1980.

[Table 3] Resource allocation (benchmark economy, 2010)

Variables	<1>	<2>	<3>
Capital-Output ratio	3.52	3.50	3.54
Labor hour (worker)	0.381	0.380	0.381
Savings Rate (%)	21.1	21.2	21.0
Ratio of consumption (except for educational exp.) to GDP (%)	76.9	76.9	77.1
Ratio of educational investment to GDP (%)	2.0	1.9	1.9
Ratio of educational investment to household consumption (for households with children %)	5.6	5.5	5.5
Ratio of educational investment to household consumption (for the whole household, %)	2.5	2.5	2.5
R&D investment / GDP (%)	2.4	3.4	1.3

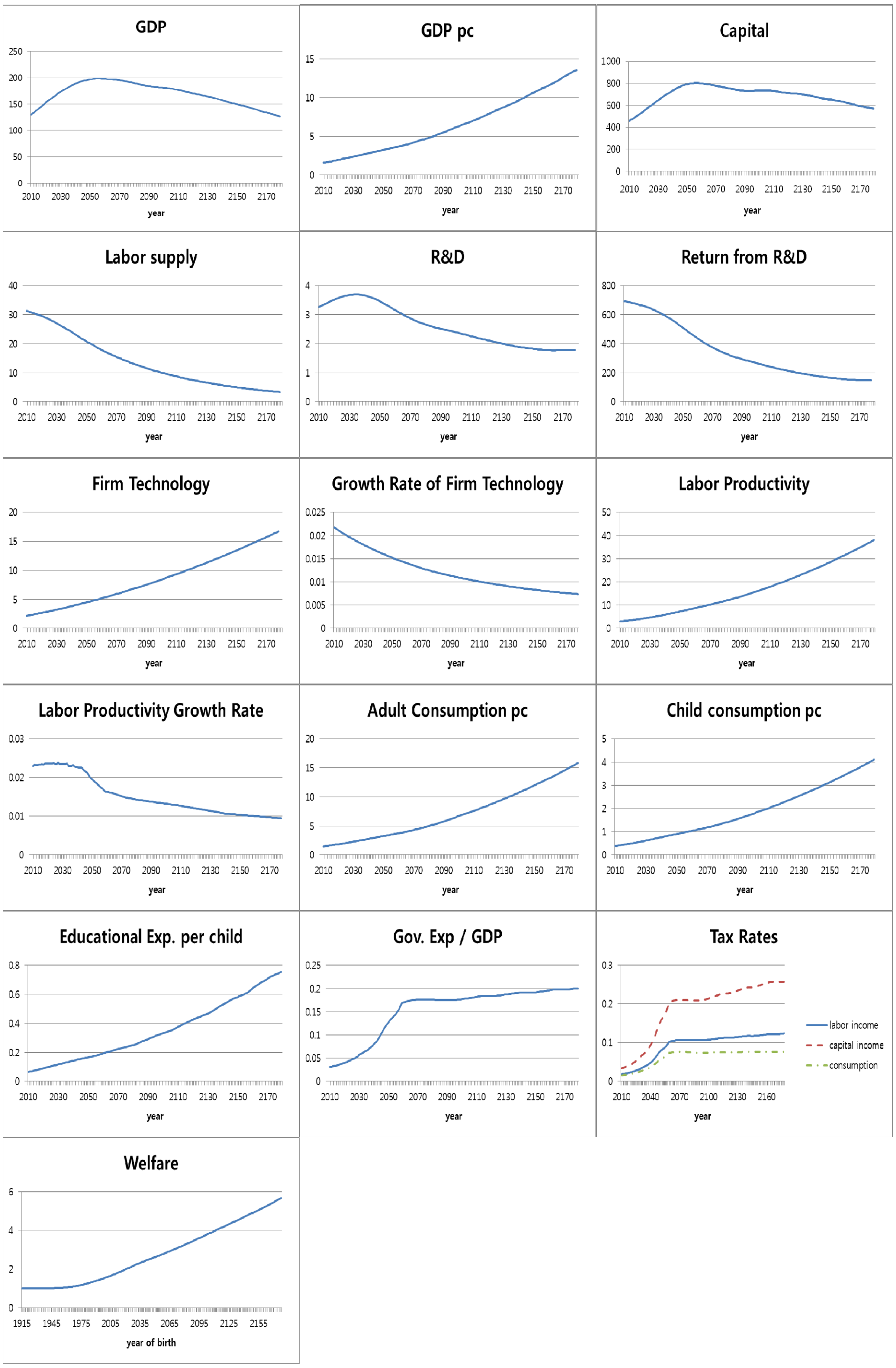
The resource allocations after the year 2010 are reported in Figure 2. The GDP is projected to increase until 2050s, and to decrease thereafter because of the decrease in the capital stock and the labor supply due to the population aging. However, the GDP per capita will continue to increase because of the technological progress. The technological progress results from the R&D investment and the educational investment. The R&D investment will gradually decrease because of the declining 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 (17')), resulting from the population decrease. The educational investment per child will increase because of the decrease in the number of child per parent (see equation (8)). The speed of the firm's technological progress and the labor productivity are shown to fall because the effect of the decreasing R&D dominates that of the increasing educational investment.

To compute the welfare across generations, we use the following equation (28). We solve for x_p, the proportional change in the adult consumption 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.

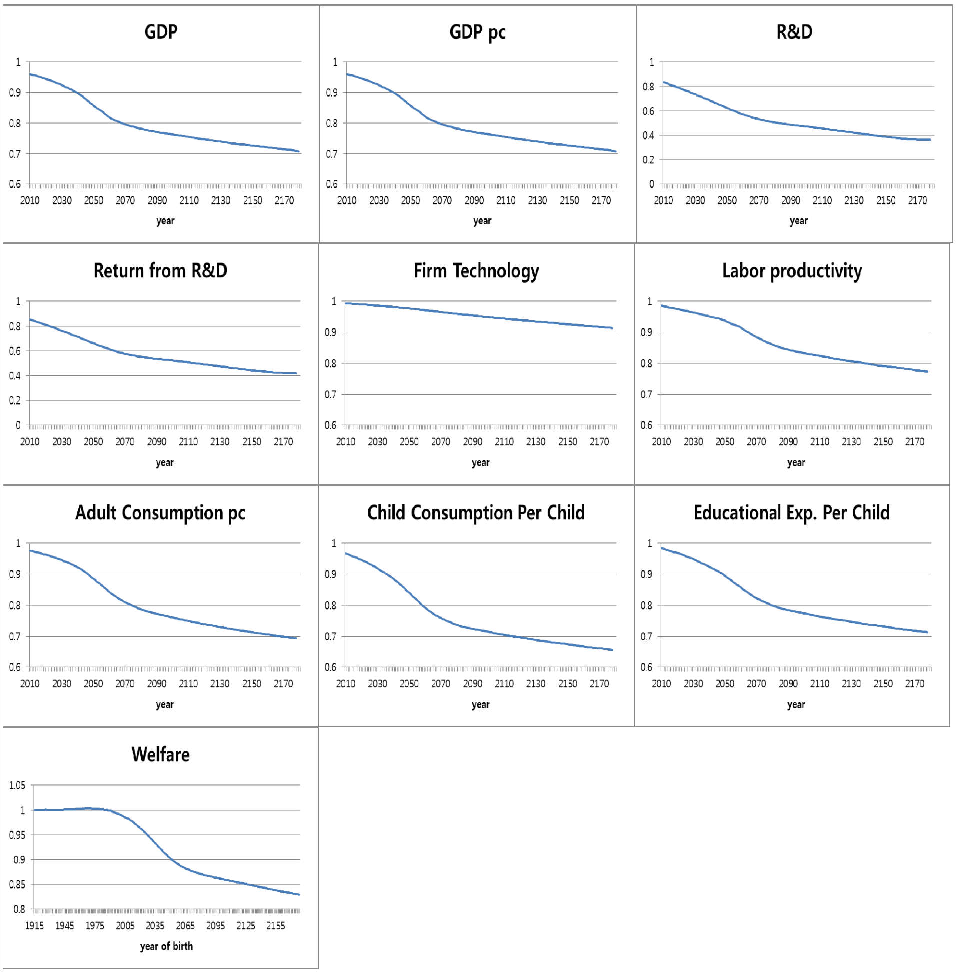
$$\sum_{i=25}^{D}\left(\frac{1}{1+\beta}\right)^{i-25} S_{p,i}u\left(c_{i,p+i}, l_{i,p+i}, n_p cf_{i-25,p+i}, E_{i-25,p+i}{}^{g(n_p)}\right)$$
$$= \sum_{i=25}^{D}\left(\frac{1}{1+\beta}\right)^{i-25} S_{0,i}u\left(c_{i,0+i}x_p, l_{i,0+i}, n_0 cf_{i-25,0+i}, E_{i-25,0+i}{}^{g(n_p)}\right) \quad (28)$$

The labor productivity growth will improve the welfare of the future generations. The welfare level of the future generations will increase by up to 5 times as much as the lifetime adult consumption of the generation born at the initial period.

[Figure 2] Base Case Economy (<1> $\sigma=0.5$, $\upsilon=0.1$)



[Figure 3] Effects of Transfer Payment ($\sigma = 0.5$, $\upsilon = 0.1$)[1)]



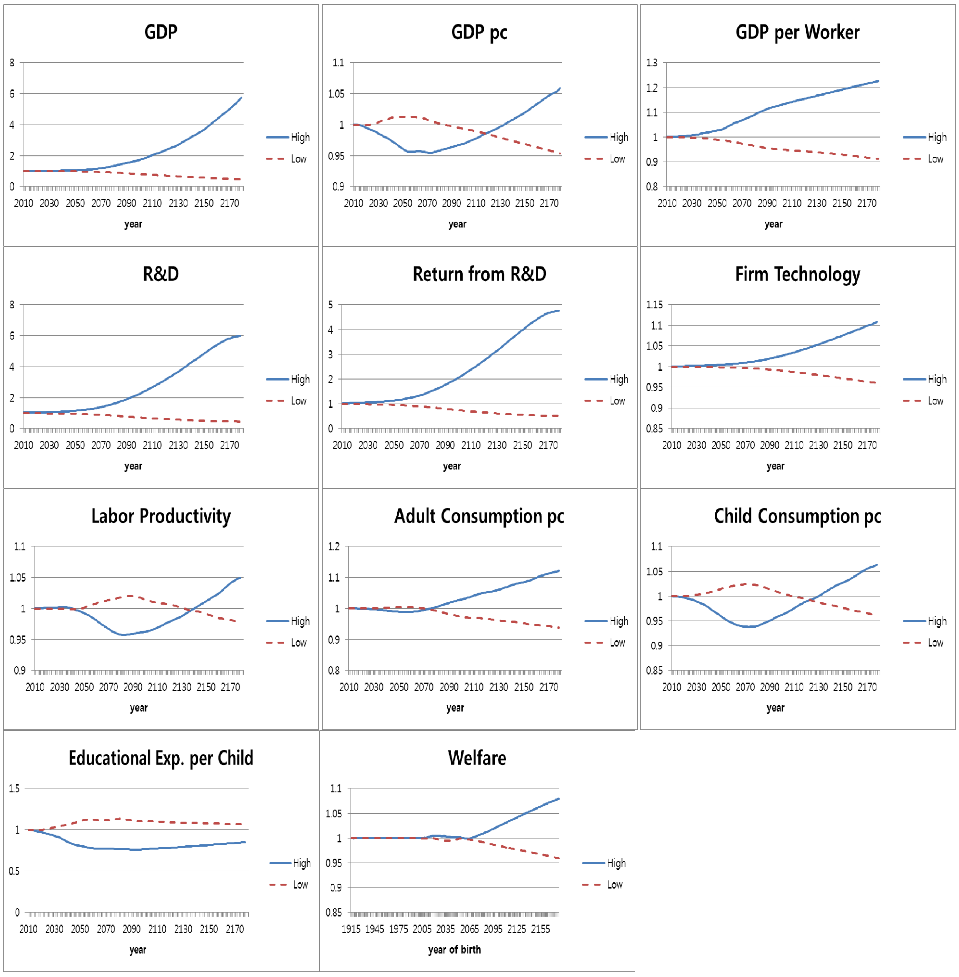
Note: 1) Reports the ratio of the value in the economy with transfer payment is provided (economy [1]) to that in the economy without transfer payment (economy [2]).

IV.2. Effects of the government transfer payment

We compare the economy [1], where the government transfer programs are introduced, and the economy [2] without the transfer programs. Figure 3 reports the ratio of the values of some macroeconomic variables in economy [1] to those in economy [2]. Figure 2 shows that the government transfer payment under the current fiscal policies will increase up to 20% of GDP, which will inevitably increase the tax burden. The increase in the aggregate government transfer payment is due to the population aging and the introduction and the reinforcement of the transfer programs for the elderly, such as introduction of the long-term care insurance and the universal old-age pension, the maturing of the public pensions, the extension of the coverage of the public medical insurance, and the decrease in its out-of-pocket medical treatment fees.

The increase in the tax burden due to the increase in the government transfer payment will lower the GDP per capita as well as GDP, because the reduction of the production will reduce the return from the R&D investment, which will reduce the R&D investment. In addition, the reduction of the disposable income will reduce the educational investment. These changes will delay the technological progress and the labor productivity growth. The welfare of the future generations will be reduced due to the decrease in the GDP per capita and the increase in the tax burden.

[Figure 4] Effect of Fertility Rate Change (σ =0.5, υ =0.1)[1)]



Note: 1) Reports the ratio of the value under the alternative fertility assumption (high fertility [3] or low fertility [4] assumpton) to that in the economy under medium fertility assumption (economy [1]).

IV.3. Effects of the fertility rate change

We compared the economy [3], which assumes the high fertility rate of NSO's 2010 population projection, and [4], which assumes its low fertility rate, with the economy [1], which assumes its medium fertility rate. Under the high (low) fertility assumption, the GDP is larger (smaller) than that under the medium fertility assumption. Even though the GDP per capita will eventually reach higher (lower) level under the high (low) fertility assumption than under the medium fertility assumption, it is lower (higher) in the transition period. This is because there is a substantial time lag between the change in the fertility rate and the change in productivity, while the increase (decrease) in the number of newborns increase (decrease) the children's consumption and the educational investment, which reduces (increases) the savings of the parents' generations in the transition period.

In addition, the increase in the number of children per parent reduces the educational investment, which will delay the labor productivity growth. However, the rise in the fertility rate will eventually raise the GDP per capita and the welfare of future generations by raising the return from the R&D, increasing the R&D investment, and improving the firm technology and the labor productivity.

Even though the GDP per capita in the high (low) fertility economy is lower (higher) for some period than that in the medium fertility economy, the GDP per worker is higher (lower) in the high (low) fertility economy in the most of the transition period except for some initial years.

IV.4. Effects of the government subsidies

We simulate the government subsidy programs to the R&D investment[22] and the educational investment. The increase in the R&D investment and the educational investment induced by these subsidies might partly compensate for the fall in the economic growth rate due to the population aging and the population size reduction. The subsidy policies are represented by the subsidy rates ζ, ρ. We assume ζ (ρ) is 40% in the economy [5] ([6]).

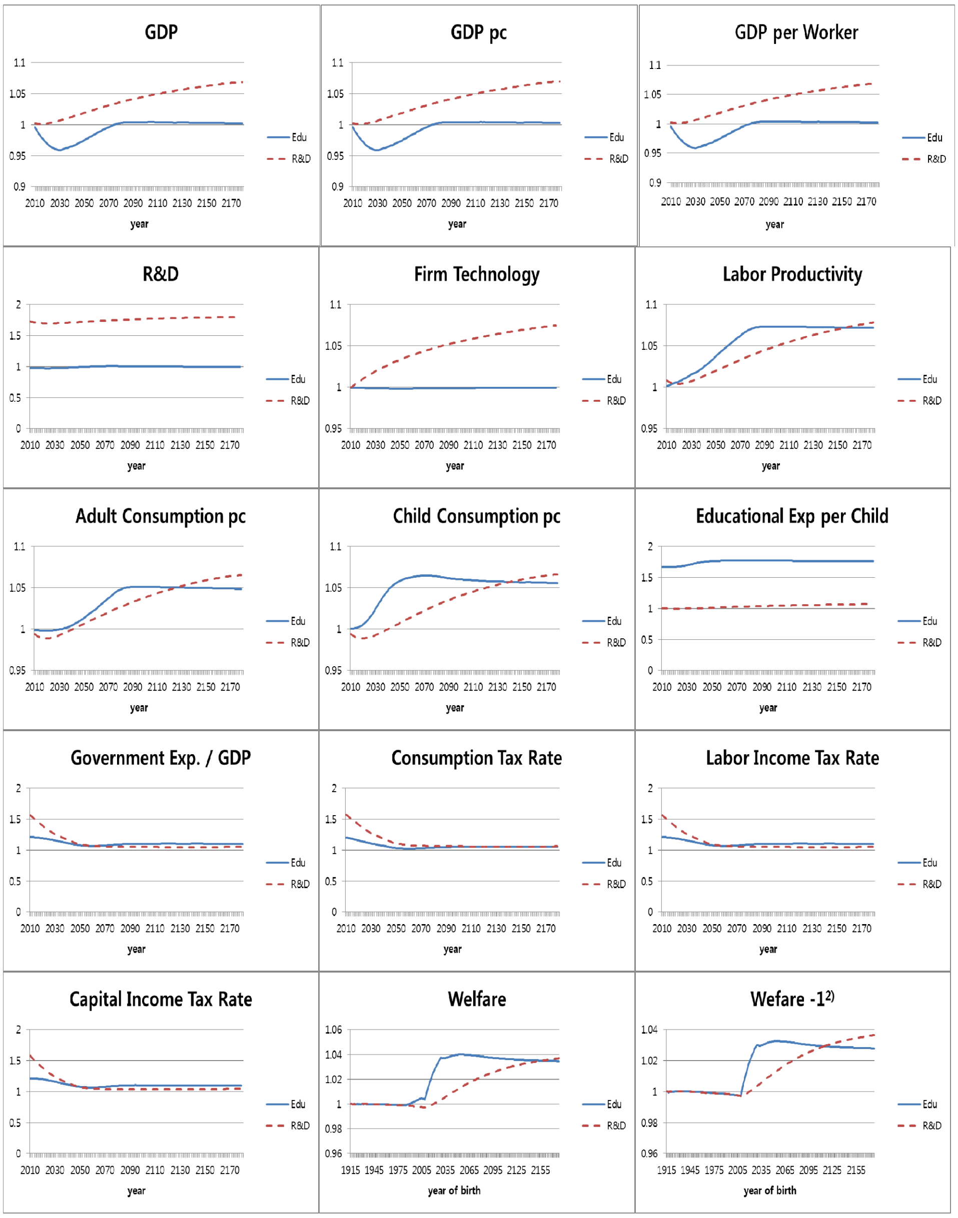
[22] The model constructed for the simulation allows the perfect non-rivalry and non-excludability of the firm technology. Under this specification, firms do not enjoy any monopoly power from the R&D investment. This specification may overstate the effects of the subsidy policy to the R&D. However, our paper addresses the long-run effect of the population aging and the subsidy policies. The time horizon in this paper is much longer than the duration of the patent right, typically 20 years. Therefore, assuming the perfect non-rivalry and non-excludability is not totally unrealistic. Moreover, there is also a factor which may cause under-evaluation of the effect of the subsidy to R&D. The firms take account of a spillover effect, which is not generally reflected in the previous literature: the R&D investment at present improves the efficiency of the new technology production of the future period (see equation (17')). Therefore, the specification of the technological progress may overstate or understate the effect of the subsidy to R&D.

The subsidies to the R&D investment and the educational investment much increase those investments. The former is shown quite effective to improve the firm technology and to raise the GDP per capita, and the latter substantially improves the labor productivity. However, it does not increase the GDP per capita much. The subsidy to the R&D raises the GDP per capita in the future period by up to 6%, while that to the education by only 0.2-0.4% even though the subsidy substantially raises the labor productivity. This is due to the heterogeneous effect of the subsidies on the consumption, the educational investment, and the saving. In the initial period of the policy implementations, the disposable income substantially decreases due to the increase in the tax burden in the case of the implementation of the subsidy to the R&D, which decreases the consumption much. On the other hand, in the case of the subsidy to the education, there is not much change in the disposable income, because the increase in the tax burden of the households is offset by the increase in the transfer payment in the form of subsidy to the education. Therefore, there is not much change in the consumption in the initial period, while the savings decrease due to the increase in the educational investment. In addition, the labor productivity improvement due to the increase in the education is realized earlier than that due to the increase in the R&D. As result, the consumption increases in the economy with the subsidy to the education much earlier than in the economy with the subsidy to the R&D. The early increase in the consumption and the net increase in the household expenditure due to the increase in the educational investment in a large scale, in the economy, where the education is subsidized, reduce the capital accumulation. This makes the effect of the subsidy on the GDP per capita limited.

The effects on the welfare of the two policies are quite different. The implementation of the education subsidy improves the welfare of the cohorts 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. 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 investment for the children ('welfare'); and one without consideration of the joy of giving ('welfare-1'). Comparison of the two measures shows that about 20% of the welfare improvement of the welfare due to the education subsidy is accounted for by the increase in the joy of giving.

Comparison of the resource allocations in the economy [3], where the high fertility assumption of the NSO (2010) is adopted, with those in the economy [5] or [6], where the medium fertility assumption is adopted, show that the subsidy policies do not solve the problem of the population aging fundamentally. The subsidies do not improve the GDP per capita growth or the GDP per worker growth as much as the rise in the fertility rate. In addition, the welfare improvement of the future generations due to the subsidy policies is not as large as that due to the rise in the fertility.

[Figure 5] Effect of Subsidy to R&D and Education ($\sigma=0.5$, $\upsilon=0.1$)[1)]



Note: 1) Reports the ratio of the value in the economy with the provision of the subsidy to R&D ([5]) or with that to the education ([6]) to the value in the economy without the subsidy programs.

2) Welfare effect without consideration of the utility from educational investment.

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, which improves the welfare of the future generations, while it causes larger increase in the tax rates. The rise in the tax rates causes large distortion of the economic decision-making, which raises the welfare cost. In addition, there might be a redistributive effect across generations: the current generations, who have to pay large taxes but enjoy little benefit of the technological progress, are likely to pay welfare cost, while the future generations, who benefit from the technological progress, will have welfare gains.

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 at the initial period 0 (SW_0). The social welfare function is defined as the weighted average of the lifetime expected utility of each generation, shown in equation (29).

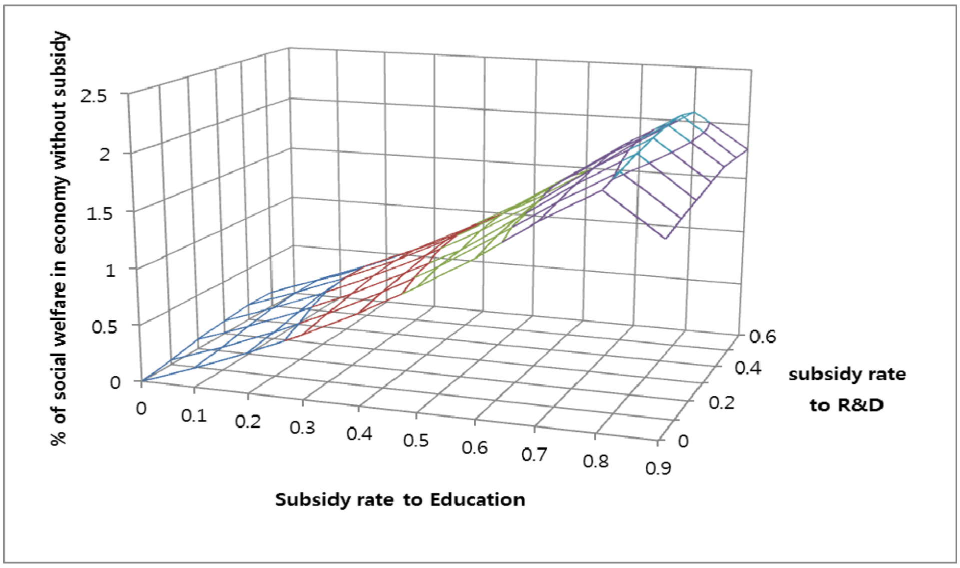
$$SW_0 = \sum_{p=-D_0^{'}}^{\infty} \left(\frac{1}{1+\beta_s}\right)^{\max(0,p)} \mu_{0,p} \sum_{i=\max(25,-p)}^{D_p} \left(\frac{1}{1+\beta}\right)^{i-\max(25,-p)} S_{p,i} u\left(c_{i,p+i}, l_{i,p+i}, n_p cf_{i-25,p+i}, E_{i-25,p+i}{}^{g(n_p)}\right) \quad (29)$$

The social welfare is evaluated from the forward-looking perspective, in the sense that it does not reflect the utility of the current generations, who are alive in the initial year, for the period before the initial year. 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 (β_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 (β). Rosen and Gayer (2009) state that the social discount rate should be set 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). We compute the welfare gain due to the combination of the subsidy to the R&D and the education by computing the proportional change in the lifetime consumption of the parents in the economy [1], required to equalize the social welfare in the economy under the alternative subsidy policies with that in our benchmark economy [1].

According to Figure 6, which reports the magnitude of the welfare gain by the subsidy rates, the welfare is improved until the subsidy rates reaches very high level of subsidy rates. In the case <1>, where σ =0.5, υ =0.1, the optimal combination of the subsidy rates is that subsidy rate for the education is about 80% of the educational investment and that for the R&D is 50%. The optimal subsidy rate to the education is higher, because the subsidy to the education improves the welfare of the cohort born relatively early, which is disounted less than that of those born later. On the other hand, the subsidy to the R&D improves the welfare of the generations born relatively later, which is discounted heavily.

Table 4 reports the optimal combination of the subsidy rates by the level of social discount rate. The table shows that the lower the social discount rate is, the higher is the optimal subsidy rate to the R&D, which improves the welfare of the future generations. The optimal subsidy rate to the education is not much affected because the subsidy improves the welfare of the cohorts born relatively early.

[Figure 6] Welfare Gain of Subsidies ($\sigma=0.5$, $\upsilon=0.1$, $\beta_s=0.02$)



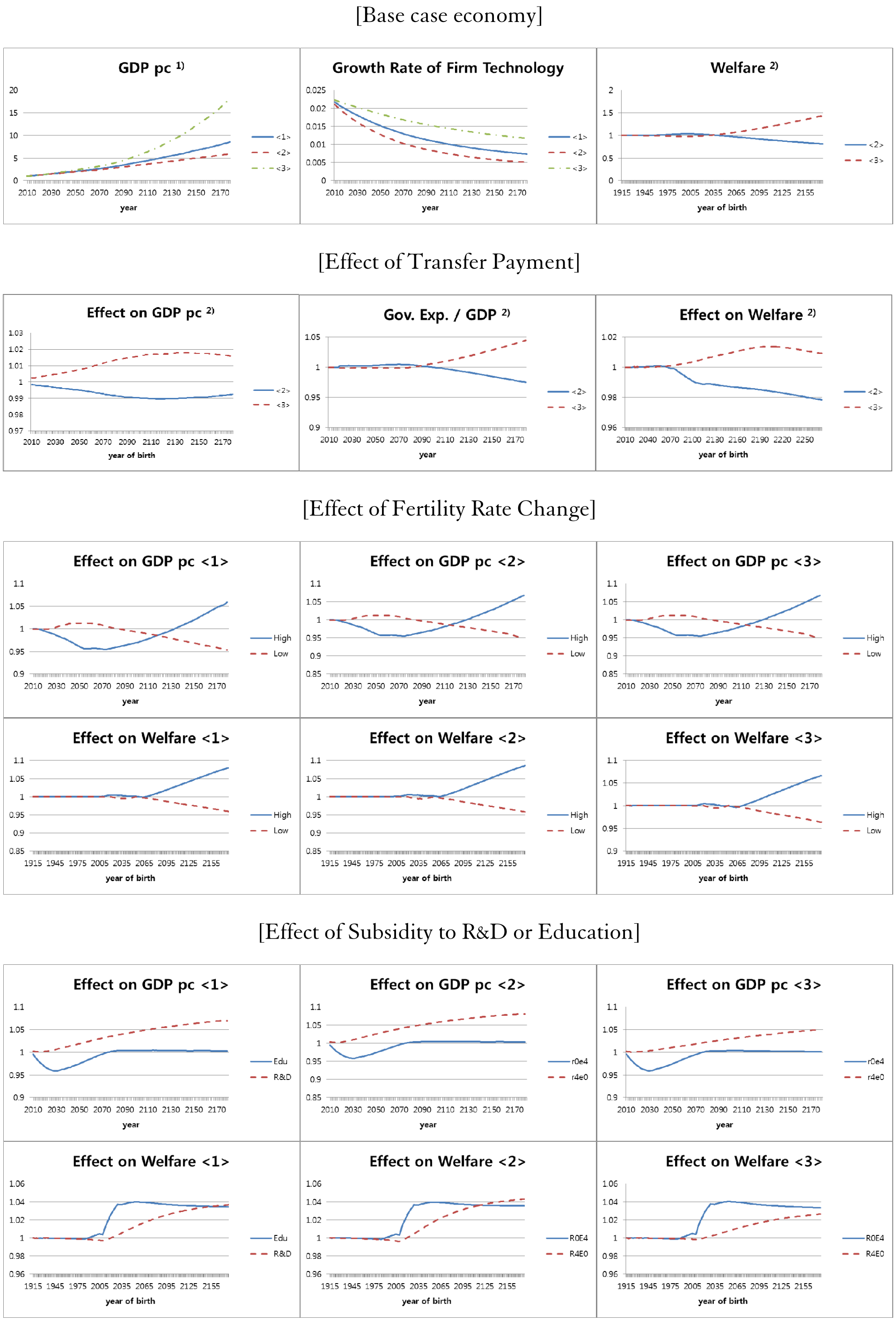
[Table 4] Optimal Combination of Subsidy Rates (%)

(ζ,ρ)	<1> $\sigma=0.5$, $\upsilon=0.1$	<2> $\sigma=0.25$, $\upsilon=0.15$	<3> $\sigma=0.75$, $\upsilon=0.05$
$\beta_s=0.020$	(50, 80)	(50, 70)	(50, 80)
$\beta_s=0.015$	(60, 70)	(60, 80)	(70, 80)
$\beta_s=0.010$	(60, 80)	(60, 80)	(70, 80)

IV.5. Sensitivity Analysis

Figure 7 and Table 4 report the results of the sensitivity analysis on the value of σ and υ. We simulated two more cases: the case <2> where $\sigma=0.25$, $\upsilon=0.15$; and the case <3> where $\sigma=0.75$, $\upsilon=0.05$. The change in the values of σ and υ do not change the qualitative aspects of the effects of the population aging and the policy changes on the resources and the welfare. The only difference

[Figure 7] Sensivivity Analysis



Note: 1) Reports the ratio of the value overtime to that as of 2010.

2) Reports the ratio of the value in case <2> or <3> to that in case <1>.

is in the absolute level of GDP and the speed of the growth: the economy with higher σ tend to grow faster, because of the larger spillover effect of the technological progress at present on that in the future.

The optimal subsidiy rates are not affected much. The optimal combination of the subsidy rates to the R&D and the educational investment is: 50-70% and 70-80% respectively.

V. Conclusion

We investigated the effects of the population aging on the economic growth and the welfare across generations, using a general equilibrium model. The policy simulations showed that the population aging and the population size reduction impede the quantitative growth by reducing the labor force and the capital accumulation, and the technological progress. The slower technological progress is due to the fact that reduction of the market size and the production activities, caused by the population aging, reduces the return from the R&D investment.

The recent increase in the transfer payment to the elderly will hamper the quantitative growth and the technological progress. This tendency of the policy accompanied by the population aging will make the transfer payment increase faster than the GDP, which will raise the tax burden ratio, the ratio of the tax burden to GDP. The rise in the ratio will hinder the economic growth. Therefore, the revision to the cost-effective social welfare policies, which protect the people from the economic risks and prevent the explosion of its cost, is needed.

We also showed that the increase in the R&D investment by the government subsidy will partly compensate for the fall in the economic growth rate due to the population aging and population size reduction. Therefore the government needs to properly provide the subsidy program to the R&D investment. Even though its effects on the per capita GDP growth are limited, the subsidy to the education improves the labor productivity, the welfare of the future generations, and the social welfare until the subsidy rate reaches very high level.

Even though the promotion of the R&D investment to improve the technology may partly compensate for the delay of the economic growth and that of the education may substantially improve the welfare of the future generations, the problem of the population aging and the population decrease is not likely to be fundamentally dealt with by the subsidy policies. Therefore, the policies to raise the fertility rate need to be prepared.

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