The Effect of Pension on the Optimized Life Expectancy and Lifetime Utility Level

Shin, Inyong

Asia University

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Inyong Shin*

Abstract

In this paper, we analyze the effect of a pension system on the life expectancy and the lifetime utility level using an optimal dynamic problem of individuals who live in continuous and finite time. Our model yields a number of intriguing results: 1) Life expectancy is not always proportional to lifetime utility. 2) The pension system can make life expectancy longer or shorter. 3) It is not always true that the pension system improves the lifetime utility level.

JEL Classification Codes: C61, H55, I31

Keywords: Pension system, Optimized life expectancy, Lifetime utility level, Health investments

1 Introduction

According to an anecdote in Europe, as soon as a pension system was introduced, the number of people who jog in the park for their health increased. Believe it or not. Anyway, under pension system, it looks like a good deal, if we live long enough. This paper analyzes the effect of a pension system on the life expectancy and the lifetime utility level. Bloom et al. (2007) and Dushi et al. (2010), etc. examine the effect of improvements in health or life expectancy on social security system, however, we focus on the effect on the opposite direction.[1]

A vest amount of emprical and theoretical researches about the pension system has been accumulated. Many previous researches analyze economic welfare using overlapping generation

*Department of Economics, Asia University,
5-24-10 Sakai Musashino Tokyo 180-8629 Japan,
Tel.: +81-422-36-5259,
Fax: +81-422-36-4042,
e-mail addredss: shin@asia-u.ac.jp

[1]Weil (2007), Acemoglu and Johnson (2007), Zhang and Zhang (2004), Zhang et al. (2001), etc. analyze the effect of improvements in health or life expectancy on economic growth.

models. The main results of some previous studies on pension system and economic welfare can be summarized as follows: under a fully funded system, the economic welfare is not affected, however, under a pay-as-you-go pension system, depending on the economic situations and generations, the economic welfare might be both improved and worsened. The public pension system as a risk-hedging device can increase welfare by providing a certainty in the imperfect market. (Shiller, 1999, Krueger and Kubler, 2002, Sánchez-Marcos and Sánchez-Martin, 2006, Bohn, 2009, etc.) Meanwhile, the public pension system crowds out the private savings. It can have a negative effect on capital accumulation and can retard growth. (Cutler and Gruber, 1996, Feldstein and Liebman, 2002, Zhang and Zhang, 2004, etc.) The overall welfare impact depends on the balance between the insurance effect and the crowding-out effect.

We use the optimal dynamic problem of individuals who live in continuous time, not discrete time like the overlapping generation models used in the presvious studies. (e.g. Sánchez-Marcos and Sánchez-Martin, 2006) This is one of the difference of our model from the previous models. In lifetime uncertainty models, e.g. Pecchenino and Pollard (1997), Chakraborty (2004), Momota, et al (2005), etc., we assume that it is possible to extend life span by the effort of an individual through health investments.[2] For examples, eating good food, taking some nutritional supplements, getting in shape by going to the gym, investing in development of medical technology, etc. Longevity will arise due to the given examples on health investments. An individual distributes his budget to his basic needs and to his health investments to maximize his lifetime utility. We consider that individual's longevity is based from the result of individual's utility maximization problem. We investigate how the optimized life span and the lifetime utility level can be changed by a pension system.

Our model yields two impotant results: i) Life expectancy is not always proportional to lifetime utility level. ii) Pension system can make the life span longer or shorter. The life span depends on the type of pension system. From the combination of the results i) and ii), it is possible that 1) pension system makes the life span longer and increases the utility level. 2) pension system makes the life span longer, however decreases the utility level. 3) pension system makes the life span shorter and decreases the utility level. Case 1 is preferable. but Case 2 and 3 are not preferable cases, but could possibly happen.

This paper is organized as follows: Section 2 presents the model and drives the benchmark

[2]Lifetime uncertainty models assume that the health investments can increase the surviving probability. However, we do not consider uncertainty in our model.

outcomes. In section 3, we introduce the pension system to the benchmark. Section 4 solves the models numerically and analyzes the results and concludes. And finally, we include an Appendix.

2 The benchmark Model

2.1 Setting

We consider an individual's utility maximization problem under the finite period. He can live up to T years old and dies at the age of T. An individual maximizes his lifetime utility which is affected by consumption. The instantaneous utility function is specified in log form as follows:

$$u(c) = \ln c \tag{1}$$

where c is a consumption. We think that it is possible to extend the life span by the efforts of the individual. We assume that there is a linear relationship between health investment and life span as follows

$$T = a + bz, \ (a > 0, \ b > 0) \tag{2}$$

where T and z are life span and health investment, respectively. And a and b are positive constants. We assume that the health investments do not affect the utility directly.[3] We also assume that the interest earning is the only source of income of the individual. And to simplify, a small country is assumed, then the interest rate is constant at all period. Let us denote the individual's asset as x, then his budget constraint is written as:

$$\dot{x} = rx - c - z \tag{3}$$

where r is an interest rate.

An individual's utility maximization problem can be written as follows:

$$\begin{gathered} \max_{c(t),T} \int_0^T e^{-\rho t} \ln c(t) \ dt, \quad (0 < \rho < 1) \\ \text{s.t} \quad \dot{x}(t) = rx(t) - c(t) - z \end{gathered} \tag{4}$$

[3]We can divide the consumption c into two categories. These are the general consumption c^G and the consumption for health improvement c^H. The effect of the latter c^H on the utility of individual is unclear whether positive or negative. For examples, there might be a person who drinks wheat grass for his health maintenance even though it is unpalatable, while there might be a person who drinks it with the thinking that it is delicious. There might be a person who commutes to the gym for his health maintenance though it is painful, while there might be a person who goes happily to the gym. Nutritional suppliments are benificial for health but are not delicious. Therefore, we assume that the consumption for health improvement c^H is neutral to an individual's utility. This means $\frac{\partial u(c^H)}{\partial c^H}$=0. $u(c^H) = u(c^G, c^H)$.

where ρ is a discount rate. We assume $r \geq \rho$.[4] For simplification, we assume that z has a constant value from initial period until T period and that z is decided at the initial period. In unrealistic assumption, we assume that as an individual is born, he decides how much he invests for his health and how long he lives under a social environment.

2.2 Solving the Model

The maximization problem is solved in two stages. At the first stage, we do not consider the Eq. (2). Maximize over c and x for any given T and z, and then the objective function maximized with respect to c and x could be described as a function of T and z. At the second stage, we consider the Eq. (2). Maximize over T and z taking into account c obtained in the first stage.

2.2.1 The First Stage

We use the Hamiltonian method to solve the maximization problem. The Hamiltonian is written as follows:

$$H = \ln c + \lambda(rx - c - z) \tag{5}$$

By differentiating Eq. (5) with respect to c and x, we can get Eq. (6) and Eq. (7).

$$\frac{\partial H}{\partial c} = \frac{1}{c} - \lambda = 0 \quad \Rightarrow \quad c = \lambda^{-1}, \tag{6}$$

$$\frac{\partial H}{\partial x} = \rho\lambda - \dot{\lambda} = \lambda r \quad \Rightarrow \quad \frac{\dot{\lambda}}{\lambda} = \rho - r. \tag{7}$$

We integrate Eq. (7) to time t, then we get

$$\ln \lambda = (\rho - r)t + k \tag{8}$$

where k is a constant of integration. Taking exponential both sides of Eq. (8), then we can get

$$\lambda = C_1 e^{(\rho - r)t} \tag{9}$$

where $C_1 = e^k$. Substituting Eqs. (6) and (9) into Eq. (3), we obtain the following

$$\dot{x} - rx + z = -C_1^{-1} e^{-\rho t} e^{rt}. \tag{10}$$

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[4] If $r = \rho$, there is no transitional path, because the jump from the initial state upto the terminal state occurs. If $r < \rho$, there is an overshooting, the economy turns back to the terminal state and has a negative growth rate. We do not consider the negative growth in our analysis.

This differential equation is solved as folllow

$$x = \frac{1}{C_1}\Big(\frac{e^{-\rho t}-1}{\rho}\Big)e^{rt} + C_2 e^{rt} + \frac{z}{r} \tag{11}$$

where C_2 is a constant. See Appendix for the detailed calculation. C_1 and C_2 can be obtained from substituting the initial condition and transversality condition. Let us $x(0) = x_0$, then we get C_2 as follows

$$C_2 = x_0 - \frac{z}{r}. \tag{12}$$

To maximize his utility, when dying, he uses up all his asset and leave nothing. In other words, $x(T) = 0$. We get C_1 as follows

$$C_1 = \frac{1}{\rho}\frac{1-e^{-\rho T}}{x_0 - (1-e^{-rT})\frac{z}{r}}. \tag{13}$$

Substituting Eqs. (12) and (13) into Eq. (11), we obtain the following

$$x(t) = \frac{x_0 - (1-e^{-rT})\frac{z}{r}}{1-e^{-\rho T}}(e^{-\rho t}-1)e^{rt} + (x_0 - \frac{z}{r})e^{rt} + \frac{z}{r}. \tag{14}$$

Substituting Eq. (9) into Eq. (6), we can get

$$c(t) = \rho\frac{x_0 - (1-e^{-rT})\frac{z}{r}}{1-e^{-\rho T}}e^{(r-\rho)t}. \tag{15}$$

Eqs. (14) and (15) are the optmal paths of x and c, repectively by regarding the variable T and z as fixed.

2.2.2 The Second Stage

In the second stage, to maximize his lifetime utility, the individual chooses his optimal T with considering Eq. (2). We can rewrite the utility maximization problem as follows:

$$\begin{aligned} &\max_T \int_0^T e^{-\rho t}\ln\Big(\rho\frac{x_0 - (1-e^{-rT})\frac{z}{r}}{1-e^{-\rho T}}e^{(r-\rho)t}\Big)\,dt \\ &\qquad \text{s.t} \quad T = a + bz \end{aligned} \tag{16}$$

We solve the integral in Eq. (16), then we can induce Eq. (17)

$$\begin{aligned} &\int_0^T e^{-\rho t}\ln\Big(\rho\frac{x_0 - (1-e^{-rT})\frac{z}{r}}{1-e^{-\rho T}}e^{(r-\rho)t}\Big)\,dt \\ &= -\ln\Big(\rho\frac{x_0 - (1-e^{-rT})\frac{z}{r}}{1-e^{-\rho T}}\Big)\Big(\frac{e^{-\rho T}-1}{\rho}\Big) - (r-\rho)\Big(\frac{(\rho T+1)e^{-\rho T}-1}{\rho^2}\Big) \end{aligned} \tag{17}$$

See Appendix for the detailed calculation. Substituting Eq. (2) into Eq. (17), Eq. (16) can be rewritten as Eq. (18) which has no integral and has only one control variable T. Eq. (18) is just a static maximization problem, not a dynamic one.

$$\max_T \ \ln\Big(\rho\frac{x_0 - (1-e^{-rT})\frac{T-a}{rb}}{1-e^{-\rho T}}\Big)\Big(\frac{1-e^{-\rho T}}{\rho}\Big) + (r-\rho)\Big(\frac{1-(\rho T+1)e^{-\rho T}}{\rho^2}\Big) \tag{18}$$

We take the derivative of Eq. (18) with respect to T and set the first derivative to zero.

$$e^{-\rho T}\ln\Big(\rho\frac{x_0-(1-e^{-rT})\frac{T-a}{br}}{1-e^{-\rho T}}\Big)-\frac{1-e^{-\rho T}}{\rho b}\frac{e^{-rT}(T-a)+(1-e^{-rT})\frac{1}{r}}{x_0-(1-e^{-rT})\frac{T-a}{br}}-e^{-\rho T}+(r-\rho)Te^{-\rho T}=0 \tag{19}$$

Eq. (19) is an implicit function as $f(x_0, T|a, b, r, \rho) = 0$ which is highly non linear and difficult to solve analytically.

3 Pension System

We introduce a pension system into the benchmark model. He pays a pension p from 0 to s period, gets a pension q after s period. Government decides p, q and s which are constants as given to individuals. This pension system plays as a compulsory saving for individuals. For simplification, we do not consider the balanced budget of the government for the pension system. It can be a fully funded system or a pay-as-you-go pension system, because we do not need to consider where the financial resources of pension come from, under the situation where there is no need for the balanced budget.

We shall call the period from 0 to s period as young period and after s period as old period. His budget constraint Eq. (3) is changed to Eq. (20).

$$\dot{x}=\begin{cases} rx-c-z-p, & \text{if} \quad 0\le t\le s\\ rx-c-z+q, & \text{if} \quad s<t\le T.\end{cases} \tag{20}$$

The way to solve the model with this pension system is similar to that of the benchmark model even though we have to divide it into young period and old period. Eq. (11) is changed as follow

$$x=\begin{cases} \frac{1}{C_1^Y}\left(\frac{e^{-\rho t}-1}{\rho}\right)e^{rt}+C_2^Y e^{rt}+\frac{z+p}{r}, & \text{if} \quad 0\le t\le s\\ \frac{1}{C_1^O}\left(\frac{e^{-\rho t}-1}{\rho}\right)e^{rt}+C_2^O e^{rt}+\frac{z-q}{r}, & \text{if} \quad s<t\le T.\end{cases} \tag{21}$$

where, C_1^Y, C_2^Y, C_1^O and C_2^O are constants of integration which are as follows:

$$C_1^Y=\frac{1}{\rho}\frac{1-e^{-\rho s}}{x_0-(1-e^{-rs})\frac{z+p}{r}-x(s)e^{-rs}} \tag{22}$$

$$C_2^Y=x_0-\frac{z+p}{r} \tag{23}$$

$$C_1^O=\frac{1}{\rho}\frac{(e^{-\rho T}-e^{-\rho s})e^{rs}}{\frac{z-q}{r}(1-e^{r(s-T)})-x(s)} \tag{24}$$

$$C_2^O = \frac{\frac{z-q}{r}(1-e^{r(s-T)}) - x(s)}{(e^{-\rho T} - e^{-\rho s})e^{rs}}(1-e^{-\rho T}) - \frac{z-q}{r}e^{-rT} \tag{25}$$

where, $x(s)$ is interpreted as both the terminal value of young period and the initial value of old period at the same time. By the same way as the previous, Eq. (15) is changed as follows

$$c(t) = \begin{cases} \frac{1}{C_1^Y}e^{(r-\rho)t}, & \text{if} \quad 0 \le t \le s \\ \frac{1}{C_1^O}e^{(r-\rho)t}, & \text{if} \quad s < t \le T. \end{cases} \tag{26}$$

Substituting Eq. (26) into the utility function, we obtain the following

$$\int_0^s e^{-\rho t} \ln\Big(\frac{1}{C_1^Y}e^{(r-\rho)t}\Big)\, dt + \int_s^T e^{-\rho t} \ln\Big(\frac{1}{C_1^O}e^{(r-\rho)t}\Big)\, dt \tag{27}$$

We integrate Eq. (27) to time t, then we get

$$\ln\Big(\frac{1}{C_1^Y}\Big)\frac{1-e^{-\rho s}}{\rho} + \ln\Big(\frac{1}{C_1^O}\Big)\frac{e^{-\rho s}-e^{-\rho T}}{\rho} - (r-\rho)\Big(\frac{(\rho T+1)e^{-\rho T}-1}{\rho^2}\Big). \tag{28}$$

There are z's in C_1^Y, C_2^Y, C_1^O and C_2^O. We substitute $z = \frac{T-a}{b}$ into C_1^Y, C_2^Y, C_1^O and C_2^O, then, the original dynamic optimization problem with the pension system is nothing less than the static optimization problem with respect to T and $x(s)$ as seen in Eq. (29). In other words, all he has to do is just to decide his own life expectancy and the initial asset at the old period.

$$\begin{aligned} \max_{T,x(s)} U\big(T,x(s)\big) = \ln\Big(\frac{1}{C_1^Y\big(T,x(s)\big)}\Big)\frac{1-e^{-\rho s}}{\rho} + \ln\Big(\frac{1}{C_1^O\big(T,x(s)\big)}\Big)\frac{e^{-\rho s}-e^{-\rho T}}{\rho} \\ - (r-\rho)\Big(\frac{(\rho T+1)e^{-\rho T}-1}{\rho^2}\Big) \end{aligned} \tag{29}$$

4 Results and Conclusion

Taking the derivative of Eq. (29) with respect to T and $x(s)$, and setting each first derivatives to zero, and solving the system of equations, we could obtain the optimal T^* and $x(s)^*$. Since the profit function of Eq. (29) is highly nonlinear, however, it is very difficult to get an exact analytical solution for this problem. The alternative option is to provide the solutions numerically. The suitable parameter values are used for the calculation, though they are arbitrary. The parameter values that we used to calculate are the following: $a = 20$, $b = 10$, $x_0 = 100$, $\rho = 0.01$, $r = 0.02$. To show the effect of p, q and s on life expectancy and lifetime utility, p and q are controlled from 0.0 to 2.0, and s is controlled from 0.0 to 20.

Each panel in Figure 1 shows the results as the coutour lines. Figure 1(1) and 1(2) show the results of the life expectancy and the lifetime utility level, respectively, when s is fixed at 10.0

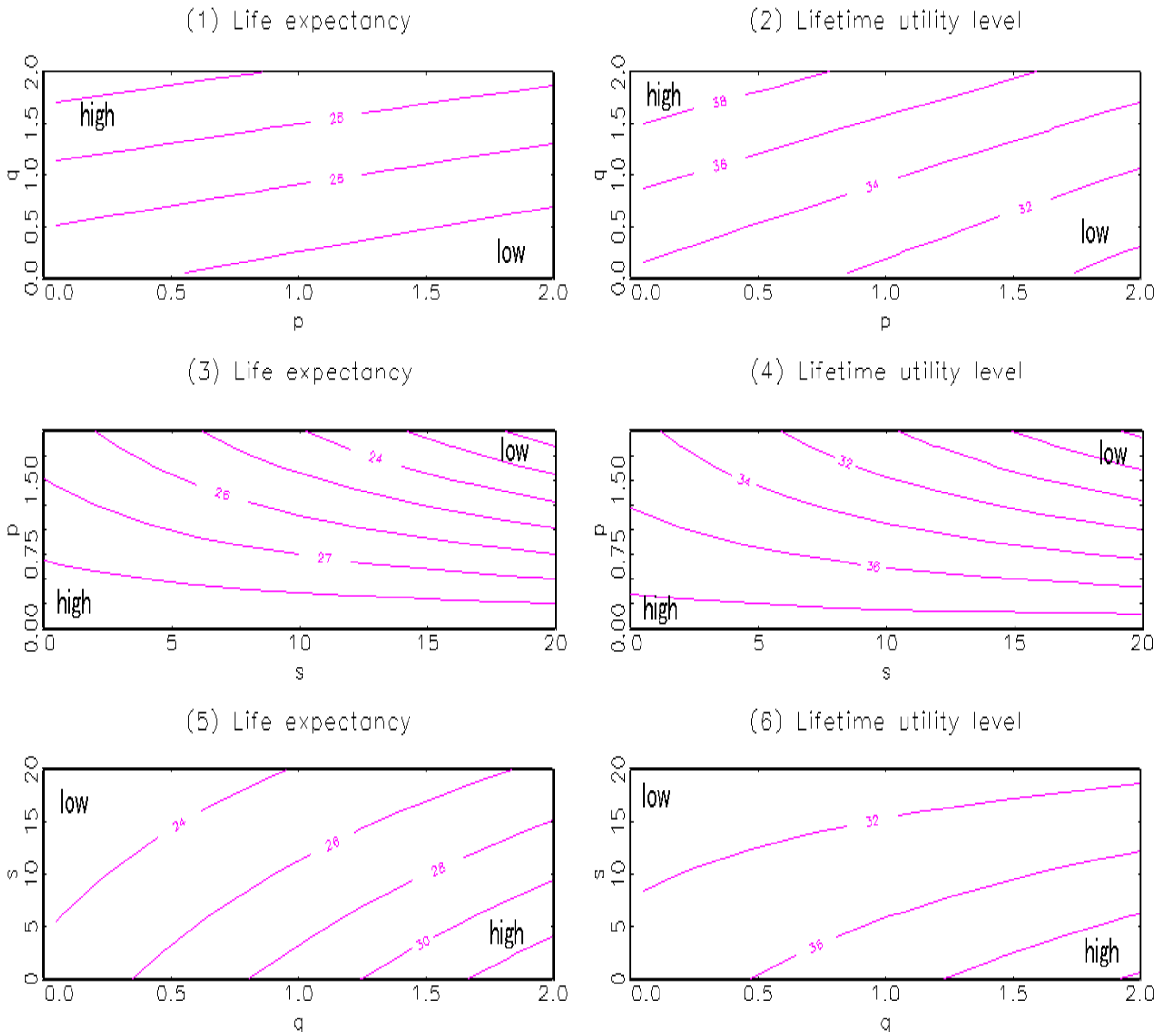

Figure 1: Life expectancy and lifetime utility level

while p and q are changed. In Figure 1(1) and 1(2), the values on the left-upper side are high and the values on the right-lower side are low. Under fixed s, when p is small and q is big, the life expectancy is longer and the lifetime utility level is higher. Figure 1(3) and 1(4) show the results of the life expectancy and the lifetime utility level, respectively, when q is fixed at 1.0 while p and s are changed. In Figure 1(3) and 1(4), the values on the left-lower side are high and the values on the right-upper side are low. Under fixed q, when p is small and s is short, the life expectancy is longer and the lifetime utility level is higher. Figure 1(5) and 1(6) show the results of the life expectancy and the lifetime utility level, respectively, when p is fixed at 1.0 while q and s are changed. In Figure 1(5) and 1(6), the values on the right-lower side are high and the values on the left-upper side are low. Under fixed p, when q is big and s is short, the life expectancy is longer and the lifetime utility level is higher.

To summarize these results, when p is small, when q is big, and when s is short, that is, when an individual pays a small amount of money for a short period of time and gets a big amount of money from his pension, the life expectancy is longer and the lifetime utility level is higher. These results accord with intuition.

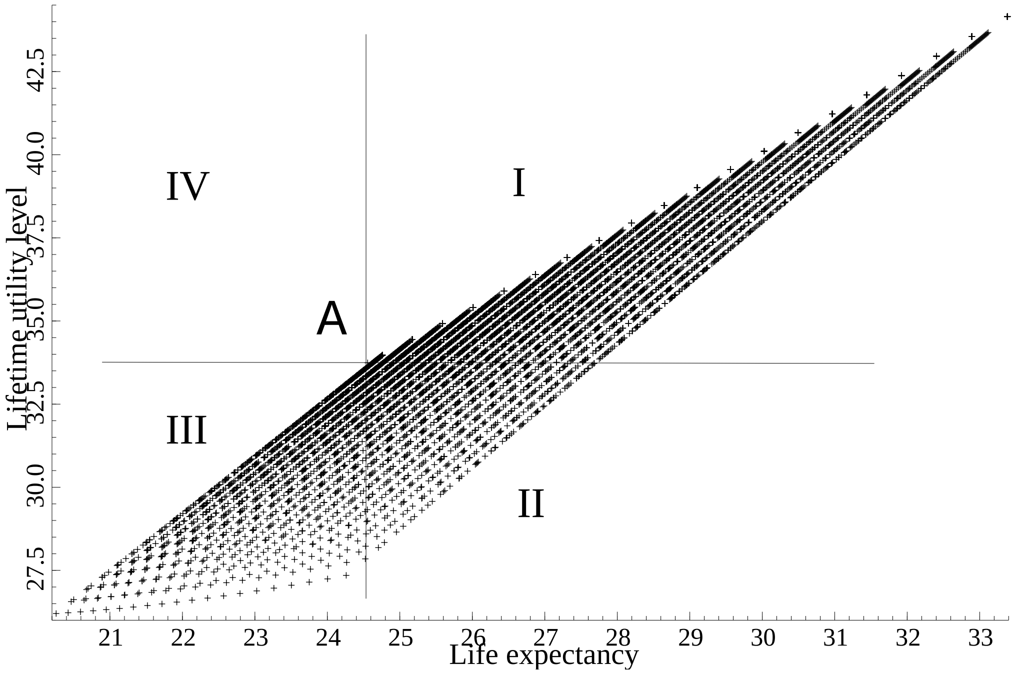

Figure 2: Comparison of the results with and without the pension system

Figure 2 plots the relationship between the life expectancy and the lifetime utility level. The horizontal line and the vertical line present the life expectancy and the lifetime utility level, respectively.[5] The +'s in Figure 2 are the corresponding values of the life expectancy in Figure 1(1), 1(3) and 1(5), and the lifetime utility level in Figure 1(2), 1(4) and 1(6). And point A (24.556, 33.742) shows the pair of the life expectancy and the lifetime utility level obtained from the benchmark model. All of these +'s except point A show the pairs when the pension system exists in some way or another. We draw a vertical and horizontal line from point A and divide the plain into 4 areas. In area I, the life expectancy is longer and the lifetime utility level is higher compared to point A. In area II, the life expectancy is longer but the lifetime utility level is lower compared to point A. In area III, the life expectancy is shorter and the lifetime utility level is

[5]The figures of the life expectancy tell nothing about the relative length of life expectancy. As the concept of the ordinal utility, the differences in the figures of the life expectancy are treated as meaningless. The figures do not mean the number of years.

lower compared to point `A`. There is no pair in area IV.

The life expectancy is not always proportional to the lifetime utility level. Comparing with a '+' in area II and point `A`, even though the life expectancy is longer, the lifetime utility level is lower. And the pension system can make life expectancy longer or shorter and can make lifetime utility level higher or lower. If we get big amount of pension in the future, the life expectancy can be extended and the lifetime utility can go up. It is the most preferable, however, in today's reality, the pension system cannot avoid the problem of financial resources.

The pension system could also lead to some kind of infirmity as follows: 1) Even though the life expectancy is extended, the lifetime utility level goes down. By that, an individual is forced to pay the pension during his young period, the pension system leads to less personal consumption in his young period. Even though he tries to prolong his life for a long time to get his money back which he paid mandatorily, his lifetime utility level can go down compared to a case of no pension system. 2) The life expectancy is decreased, moreover, the lifetime utility level goes down. This is the worst scenario. An individual can choose a short life to refuse to pay the pension until such period s and to increase his consumption in his young period.[6]

It is not always true that the pension system improves the lifetime utility level as shown in area II and III in Figure 2. Not only the government has to exert effort to avoid infirmities as stated above, but the government also has to reconsider about the raison d'etre (the reason for existance) of the compulsory pension system.

Appendix

Derivation of Eq. (11)

Let us put $B = -C_1^{-1}$. Multipling both sides of Eq. (10) by e^{-rt} and integrating to time t, we get the following

$$\begin{aligned} (\dot{x} - rx + z)e^{-rt} &= Be^{-\rho t} \\ xe^{-rt} - \frac{z}{r}e^{-rt} + D_1 &= -B\frac{e^{-\rho t}}{\rho} + D_2 \end{aligned} \tag{A1}$$

[6]There was an accident reported in South Korea last 2005, where in a person who was against the compulsory pension system and was in arrears with his pension took away his life.

where D_1 and D_2 are constants of integration. Eq. (A1) can be arranged as follows

$$\begin{aligned} xe^{-rt} - \frac{z}{r}e^{-rt} &= -B\frac{e^{-\rho t}}{\rho} + B\frac{1}{\rho} + C_2 \\ \Big(x - \frac{z}{r}\Big)e^{-rt} &= -B\Big(\frac{e^{-\rho t}-1}{\rho}\Big) + C_2 \end{aligned} \tag{A2}$$

where $C_2 = D_2 - D_1 - B\frac{1}{\rho}$. Multipling both sides of Eq. (A2) by e^{-rt} and substitutig $B = -C_1^{-1}$ into Eq. (A2), Eq. (A2) can be arranged as Eq. (11).

Derivation of Eq. (17)

Let us put $A = \ln\Big(\rho\frac{x_0-(1-e^{-rT})\frac{z}{r}}{1-e^{-\rho T}}\Big)$.

$$\begin{aligned} &\int_0^T e^{-\rho t}\ln\Big(\rho\frac{x_0-(1-e^{-rT})\frac{z}{r}}{1-e^{-\rho T}}e^{(r-\rho)t}\Big)\,dt &&= \int_0^T \big[Ae^{-\rho t} + (r-\rho)te^{-\rho t}\big]\,dt \\ =&A\int_0^T e^{-\rho t}\,dt + (r-\rho)\int_0^T te^{-\rho t}\,dt &&= A\Big[-\frac{e^{-\rho t}}{\rho}\Big]_0^T - (r-\rho)\Big[\frac{(\rho t+1)e^{-\rho t}}{\rho^2}\Big]_0^T \\ =&-A\Big(\frac{e^{-\rho T}-1}{\rho}\Big) - (r-\rho)\Big(\frac{(\rho T+1)e^{-\rho T}-1}{\rho^2}\Big) \end{aligned} \tag{A3}$$

Substitutig $A = \ln\Big(\rho\frac{x_0-(1-e^{-rT})\frac{z}{r}}{1-e^{-\rho T}}\Big)$ into Eq. (A3), Eq. (A3) can be arranged as Eq. (17).

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