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7.1 Population Dynamics and Forecasts

The Principle of Sustainable Population

-On the future of human population and revision of Malthus' Law -

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Abstract

This study focuses on the future of human population and proposes to revise Malthus' Law. The United Nations projects that the world population will top 11 billion by 2100 and its growth will be near an end. It will find a new equilibrium on the long demographic transition in history from high birth and death rates to low ones. But the author reviews the fertility developments reported in World Population Prospects 2017, which are near or below the replacement level in most regions, with the important exception of Sub-Saharan Africa, and the author warns of a possible scenario of the extinction of human society. Returning to Malthus, his Essay on the Principle of Population is critically reconsidered. Simple simulations show the exponential growth and decay unsustainable beyond the narrow ranges of the net reproduction rate. In addition, the length of reproduction periods, which depends on women’s lifespans, plays a basic role. The limits of growth are given in any case, to the extent that time and space will permit. When the population deviates too far from the replacement level, either its shrinking or exploding will overshoot the limits of its existence. This principle of sustainable population indicates that the demographic transition must follow a logistic curve. Using a system dynamics approach, the author has constructed the demographic transition model of Japan (DTMJ) composed of four major loops: fertility, reproduction timing, social capital accumulation, and lifespan. Using only endogenous variables, this model successfully reproduces the historical process of the demographic transition of Japan. Thereby, the timing and periods of reproduction, maximum fertility, and maximum lifespan hold the key to sustainability. Based on those findings, the post phase of demographic transition could begin in all the regions of the world, including Sub-Saharan Africa. In contrast to the UN projection from 2017, the world will enter the post phase and its fertility will decline to below replacement level and become stabilized. Then, the world population will begin to decrease drastically. Finally, the author discusses recovering replacement fertility, extending lifespan, and the demographic future of human population.

1. Introduction: the Sustainability of World Population

1.1 Increasing of the World Population and Decreasing of the Japanese Population

The United Nations stated that the world's population in 2015 was 7.38 billion and projects that it will increase continuously. The population will top 11 billion by 2100 (World Population Prospects, 2017) (Fig. 1).

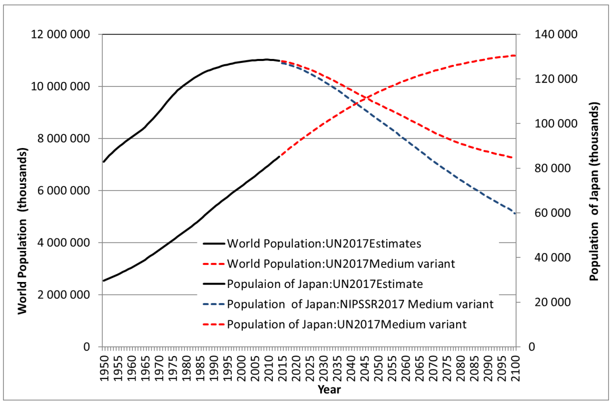

Figure 1 : Increasing of the world population and decreasing of the Japanese population
Note: Estimates (1950-2015) and projections (1916-2100) in medium variant (United Nations, 2017)

This means that the population will increase by more than four billion people in the next 85 years, which is a huge increase. One might feel the threat that the population may eventually break through to 10 billion people. In fact, we have already experienced the population increase of 4.8 billion people, from 2.5 billion in 1950 to 7.3 billion in 2015. This increase happened in only 65 years. That was the so called “population explosion,” with the record high population growth rate of 2.05% between 1965 and 1970. In contrast, the next four billion will be the gradual rise for 85 years (Fig. 1). The increasing rate will be near 0%. The age of population growth is expected to be at an end.

On the other hand, the same UN projection from 2017 states that Japan’s population will decrease from 0.13 billion (130 million) in 2015 to 0.08 billion (80 million) by 2100. According to the 2015 Population Census, Japan’s total population (including non-Japanese residents) was 127.27 million. Based on a medium-fertility and mortality projection of NIPSSR (2017), Japan is expected to undergo a long period of population decline to 88.08 million by 2065. This projection represents a 30.8% decrease (39.19 million) compared to 2015. According to auxiliary projections, Japan’s population will be less than 60 million (0.06 billion) by 2100 (Fig. 1).

1.2 World's Next Four Billion People

Professor David Lam pointed out the important features of increasing the world's next four billion people in his N-IUSSP essay, “The world’s next four billion people will differ from the previous four billion” (Lam, 2017).

If we see the additional population by 2100 to break into age groups, it consists of about 19 billion elderly (65+), 18.5 billion working-age adults (15-64), and less than 0.5 billion children (0-14). Most of the population increase is expected in elderly (65+) and working-age adults (mostly older working ages), and the population increase of children and young adults will be low (Fig. 2).

The next four billion will also come from different regions. Most of total increase (about 80%) is expected to occur in Sub-Saharan Africa (area of the continent of Africa that lies south of the Sahara Desert). In addition, the future increase of working-age adults (15-64) in the world will be 18.5 billion, as above mentioned, but only 20.5 billion in Sub-Saharan Africa. This means that most of the working-age adults will belong to this area. As a result, almost 45% of the working-age world population will be composed of Sub-Saharan African (Fig. 2). In Asia, the population growth will continue. However, only elderly (65+) will increase, while working-age adults (15-64) and children (0-14) will decrease. In Latin America and the Caribbean, also in Europe, increasing population will be only elderly (65+) people. Above all, the number of elderly (65+) will increase tremendously in Asia, where the countries will enter a post-demographic transitional stage similar to Japan, as Shrinking society (Hara 2014) characterized by a fertility rate below replacement level, and a decreasing and rapid aging population (Fig. 2). In other regions, including Northern America, the elderly (65+) and working-age adults (15-64), as well as children (0-14), will increase, although their growth will be on a small scale (Fig. 2).

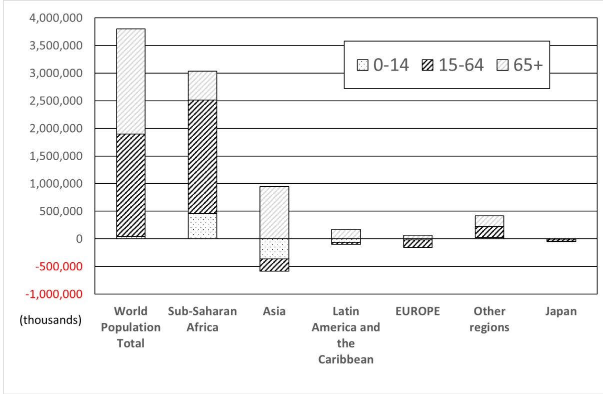

Figure 2 Population changes in the next four billion by age group and region

1.3 The Demographic Transition of the World Population

As described above, the world's population will be confronting a rapid aging and decline in most regions, except in Sub-Saharan Africa. A fertility rate below replacement level and an increasing life expectancy, which has been the usual phenomena in Japan, are spreading globally and the demographic transition of the world population will enter in the last phase.

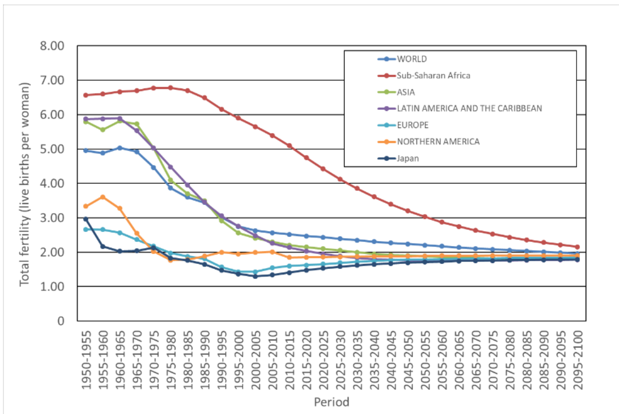

Figure 3 Changing total fertility rates by region

The United Nations estimates and projects the fertility trends of the world from the past to the future (Fig. 3). The average total fertility rate (TFR) of the world declined from 5.05 at peak (in the period of 1960-1965) to 2.57 at present (in the period of 2010-2015). The region, which stays at the world's peak, is Sub-Saharan Africa with a TFR of 5.10. This value indicates 2.02 in Asia and 2.14 in Latin America and the Caribbean. The fertility trends of both regions show that they are nearing the replacement level. As for highly developed regions such as Europe, Northern America and Japan, these values are far below replacement level, 1.60, 1.85, 1.40, respectively. Among the main regions driving the world economy, the total fertility rate shows to be below 2.1 births per woman at present (Fig. 3). According to the most recent UN estimates (United Nations, 2017), almost one half of the world's population lives in countries below replacement fertility (Frejika, 2017).

The net reproduction rate (NRR) indicates the level of actual fertility (TFR) in comparison with the replacement level of fertility, which is adjusted with sex ratio at birth and the survival rate of a woman at the end of reproductive age. An NRR of one means that mothers in each generation are having exactly enough daughters to replace themselves. If the NRR is less than one, the population does not reproduce enough. For example, if the NRR is 0.70, the fertility level of the population is only 70% of replacement fertility and the population shrinks by 30% each generation.

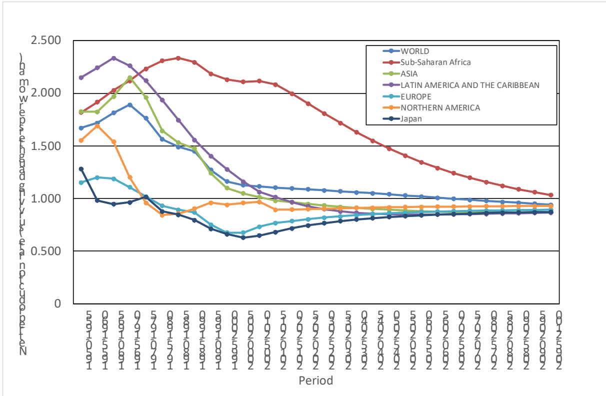

Figure 4 Changing net reproduction rate (NRR)

According to UN estimation (United Nations, 2017), the NNR of the world's population is 1.102, the one in Sub-Saharan Africa is 2.08 at present (in period 2010-2015). Nevertheless, the NRR in Latin America is 1.01, almost at a reproductive level, and the one in Asia is 0.997, slightly less than a reproductive level. In contrast, in highly developed regions in the world economy, such as Europe, Northern America and Japan, the values of NNR are far below replacement level, 0.766, 0.891, and 0.680, respectively (Fig. 4). As already mentioned, almost half of the world's population lives in countries below replacement NNR. Thus, it is easy to understand that more children (0-14) and working-age adults (15-64) should not be expected in the future, outside of the Sub-Saharan Africa.

On the other hand, UN estimations and projections (United Nations, 2017) show the trend of an average life span from the past to the future. The life expectancy at birth (both sexes combined) of the world's population was extended from 47.0 years in the period of 1950-1955, to 70.8 years as of the period of 2010-2015. According to the projection in the medium variant, an average life span of the world's population will be 82.6 years in 2100 (Fig. 5). Interesting are the developments of an average life span in Japan and in Sub-Saharan Africa. Japan's life expectancy increased from 62.8 years in the post-war period of 1950-1955 to 75.4 years in the period of 1975-1980. Japan joined the longevity countries. Then, the life expectancy in Japan has continued to increase steadily until now. It is expected to be prolonged to 93.9 by 2100. On the other side, Sub-Saharan Africa's life expectancy started from 36.3 years in the post-war period of 1950-1955, in which most of the countries in this region were suffering under the colonial conditions. Life expectancy has remained at 57.8 years as

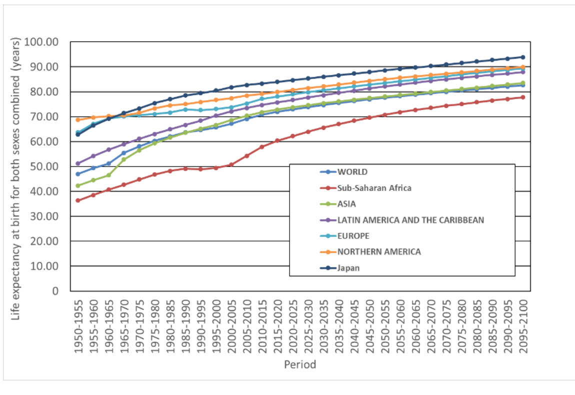

Figure 5 Changing life expectancy by region

of the period of 2010-2015. Nevertheless, according to the UN projection, the life expectancy in Sub-Saharan Africa is expected to expand to 77.8 by 2100, which will be almost the same level with the developed countries at present.

1.4 Discussion about the Sustainability of the World's population

With Professor Lam's N-IUSSP essay, "The world's next four billion" (Lam, 2017), there are some debates about the future of humankind. Grossman wrote, "My concern is that the past four billion have degraded natural world upon which we depend, and that this degradation will make the world much less welcoming to the next four billion" (Grossman, 2017) and criticized Lam's optimistic view of additional world's population increase. Martine also argued that the recent expansion of economic growth has boosted the availability of goods and services for global population. However, this success is unsustainable because economic growth based on constant increases in production and is stimulated by consumerism which produces an imminent ecological collapse (Martine, 2018). Furthermore, Livi Bacci pointed out two of the several threats to sustainability: the environmental consequences of the struggle against poverty and backwardness, and the increasing anthropization of land (Livi Bacci, 2018).

Essentially, the entire discussion stands on the viewpoint that the increasing next four billion population is threating the sustainability of ecological environments on the earth. Neither of debaters express concern about the demographic sustainability of the world's population.

As described above, the world's population is entering the last phase of the demographic transition. Except in Sub-Saharan Africa, the world will be confronting a rapid aging and decline. Fewer children (0-14) and working-age adults (15-64) are expected in the future. According to the United Nations' projections, most of the total population increase (about 80%) is expected to occur in Sub-Saharan Africa. However, this expectation is based on the assumptions that a TFR of 5.10 in Sub-Saharan Africa will decreasing slowly to a replacement level of 2.1, and life expectancy will expand from 57.8 years as of the period of 2010-2015 to 77.8 by 2100, which is almost the same level of the present developed countries.

On the other side, the main regions driving the world economy, such as Europe, Northern America and Japan, a total fertility rate shows to already be below 2.1 births per woman. The world has entered a post-demographic transitional stage characterized by below replacement fertility rate and a decreasing and rapid aging population. If this situation remains unchanged, it is unsure which region can support the economic growth of Sub-Saharan Africa.

Logically thinking makes it clear that the UN projection about the world's next four billion should be the scenario, in which Sub-Saharan African will realize the self-sustained economic growth and almost 45% of working-age world population will be living in Sub-Saharan Africa. Although this scenario is undeniable, the possibility of another scenario, in which the highly developed countries lost their economic power with their decreasing and rapid aging populations, is more likely. In this case, the demographic transition of Sub-Saharan Africa will fall by the wayside, and the entire human society will be at high risk of collapse.

In addition, even if the next four billion increase successfully by 2100, the demographic transition of Sub-Saharan Africa may also enter the final stage sooner or later. After then, the entire world's population may be living in a "shrinking society." Livi Bacci wrote, "Malthus again?" in the last chapter of his N-IUSSP essay (Livi Bacci, 2018). However, it is not necessary to simply go "back to the Malthus," but to instead revise his principle of population.

2.The Principle of Sustainable Population

2.1 What Malthus says

In 1798, T.R. Malthus published his first edition of *Principle of the Population (*An Essay on the Principle of Population, as it affects the future improvement of society, with remarks on the speculations of Mr. Godwin, M. Condorcet, and other writers). He said, 'I think I may fairly make two postulata (postulates). First, that food is necessary to the existence of man. Secondly, that the passion between the sexes is necessary and will remain nearly in its present state. (the rest omitted). ' (Malthus 1978: (chapter 1- paragraph 14) . 'Assuming then, my postulata as granted, I say, that the power of population is indefinitely greater than the power in the earth to produce subsistence for man.'(chapter 1 - paragraph 17) . Then, he declared his famous principle of population, 'Population, when unchecked, increases in a geometrical ratio. Subsistence increases only in an arithmetical ratio. A slight acquaintance with numbers will shew the immensity of the first power in comparison of the second '(chapter 1 – paragraph 18).

Malthus' finding was essentially the fact that the population increases geometrically. This fact is described as a function of the four variables in the following equation,

$$N_t = N_0 e^{rt}$$

N_t represents the population number at time t and N_0 is the population number at time 0. The large e is the base of natural logarithm (alias Napier's constant, e≒2.71828) and r is the rate of population increase (alias growth rate). The small t is the length of time. The reason why population increase is geometrical is very simple. A population increases in proportion to the cumulative number of a population at a given time. That is referred to as exponential growth, which is applied not only to the population, but also to various phenomena in various disciplines. Malthus himself did not clearly explain the case, in which a population growth rate takes a negative value (r<0). But in this case, a population decreases also geometrically (Fig. 6). Thus, Malthus' famous phrase cited above can be more exactly rewritten. When unchecked, population increases in a geometrical ratio (exponentially) if the population growth rate is positive (r>0). Population is stationary if the population growth rate is 0 (r=0). Population decreases in a geometrical ratio (exponentially) if the population growth rate is negative (r<0). In the case of an exponential decrease, a population reaches a minimum (0) at infinite position (Fig. 6).

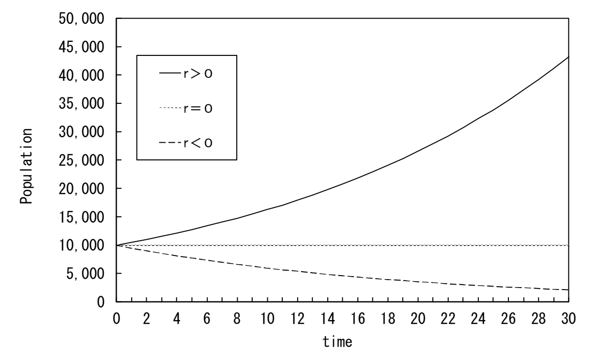

Figure 6 Exponential Growth

2.2 Exponential Growth and Exponential Decay

The condition given by Malthus as 'when unchecked,' is still very important in our age in relation to the concepts of 'Limits to Growth (LTG)' or 'Sustainable Growth (SG)'. However, it is difficult to predict, when it will be checked. Malthus' other principle, 'subsistence increases only in an arithmetical ratio' was defeated during the industry revolution and the following industrial development in modern history. Thus, 'when checked' depends on the relative relation between the population and the environment. It would not be possible, to predict the absolute limits to growth of human population.

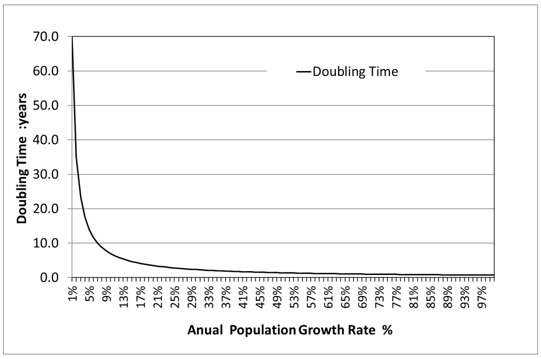

Figure7 Doubling time by Population Growth rate

Nevertheless, the common characteristic of exponential growth is that the speed of increase is accelerated according to the growth rate(r), if it is deviated from 0%. As a result, the system adaptation to the changing environment will be difficult and cannot succeed in time. In such cases, the system faces a crisis of 'limits to growth' or 'sustainability'.

The above mentioned equation of exponential growth can be transformed, and a doubling time can be calculated. Doubling time means the length of time in which the number of a population in the given time is doubled. It is about 70 years at the annual population growth rate 1% (r=1%), 35years at 2%, 23.4 years at 3%, 17.5 years at 4%, 14years at 5%（Fig.7）. For example, a population with annual growth rate 1% doublesevery70 years. Thus, after 140 years, it will be 2X2=4 times, after 210 years, it will be 2X2X2=8 times and after 280 years, it will be 2X2X2X2=16 times.

A population increase greater than 2% annually can degrade socio-economic circumstances and the natural environment. It is unsustainable in the long time, what we know as the 'population explosion' of the world population in the 1960s. However, it may not be ignored that doubling time is the same length for a decreasing population. In this case, instead of "a doubling time", the notion of "half-life(halving time)" is applied. The term "half-life" is rarely used in demography but very popular in archeology and atom physics to express the lifetime of radioisotopes.

In other words, in a shrinking society like Japan, the population is decreasing by half every 70 years under the condition of a population growth rate of -1% per year (r=-1%). This rate of decreasing population is unsustainable and can degrade Japan's socio-economic circumstances and natural environment.

Conversely thinking, the present human beings, homo sapiens have been living for nearly one hundred thousand years on the earth. In that case, a population growth rate near to ±1% must be extraordinary rare and be maintained for only a short period. According to the fact, the humans' are still existing from past to present, the average annual population growth rate must be less than 0.01%, which is known as the rate of increase in prehistoric hunter gatherer society. It may be at a very low level, which is slightly positive, but near to 0%.

2.3 Limit of Growth and Logistic Curve

Malthus said, 'Population, when unchecked, increases in a geometrical ratio.' In that case, when checked, what happens to the population? In population biology, there is supposed to be a support threshold that the environment can maintain (represented by the symbol K). Population is increasing to draw an s-shaped curve and reaching K. This s-shaped curve is called a logistic curve and this art of population growth is described as a function with K in the following equation,

$$N_t = \frac{N_0 K e^{rt}}{K - N_0 + N_0 e^{rt}}$$

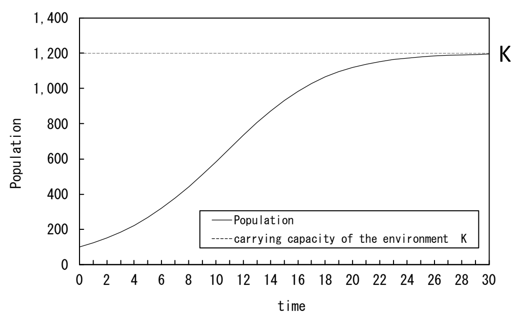

Figure 8 Logistic curve and carrying capacity of the environment K

As already mentioned, it is difficult to predict the level of K in the case of human beings, because the K is not fixed a priori but relatively changed according to the adaptation capacity of human being. It is decided a posteriori, when the growth rate reaches 0. Thus, K is the result of adaptation in the case of human society. The population growth rate (r) is the difference between the birth rate (b) and the death rate (d) (without migration) in the following equation,

$$r = b - d \quad \rightarrow 0$$

In the process, in which the population growth rate (r) is reaching 0, the birth rate(b) and the death rate (d) are changing to reduce the difference between them. The demographic transition is known as the historical process from high fertility and mortality in pre-industrial society, to low fertility and mortality after World War II. The actual historical timing and speed are different in each population and country but the historical processes are common, in which the population growth rate (r) is reaching 0, the birth rate(b) and the death rate (d) are changing to be nearer in level. However, this process does not happen automatically like a thermostat works. It would need some socio-economic and cultural conditions to promote the transition. And there shouldn't be any assurance that the transition ends up at a stationary state of 0 growth rate. Rather, only the population that has successfully realized the stationary state could exist continuously. Otherwise, a population would have overshot beyond the limit of growth and would have degraded the socio-economic circumstances and natural environment. In such a case, social systems would have decayed and the population would have begun to decrease drastically. It would have disappeared or been absorbed into another population.

On the other side, it would also be possible that the birth rate and the death rate are changing beneath the stationary condition and the population growth rate is turning to the negative, like present Japan. That is called the post demographic transition phase. In this case, the population is decreasing rapidly and the social system is confronting a crisis of sustainability (Hara 2014).

2.4 The Principle of Sustainable Population

In our time, what we need is not simply to go back to Malthus, but to rewrite his principle to the principle of a sustainable population. According to him, this principle appears as follows, 'I think I may fairly make three postulates, First, that human is mortal. Secondly, that the maximum number of childbearing is limited in a lifetime, and that the limits of growth exists a posteriori. Under these three conditions, the birth rate and the death rate should be balanced to 0 for a sustainable population. The population, when unchecked to be deviated from the replacement level of fertility at a given life expectancy, confronts increasing socio-economic cost and a loss of its sustainability.'

Conversely, only the society successfully maintaining or recovering a stationary state can be sustainable. The survival of the fittest in evolution is not the one with the highest population growth rate but the one with the longest sustainability while maintaining the replacement level. This principle is applicable for all human societies from the past to the present, and into the future.

3. Demographic Transition Model of Japan (DTMJ)

3.1 Causal Model of Demographic Transition in Japan

Based on the historical data analyses (Hara 2014), a causal model of the demographic transition in Japan could be postulated. The model describes two phases of women's life expectancy: from 40 to 70 years, and over 70 years of age.

In the first phase, the average life span of Japanese began to expand under the modernization during Meiji period (1868–1912). Infant mortality rate and maternal mortality rate also began to decrease. This increased the survival rate of women in reproductive age, as well as extending the average female life expectancy. These new conditions decreased the theoretical replacement-level TFR (NRR = 1.00) lower levels than ever before, which in turn created pressure to have fewer children (Fig.9).

If modernization did not improve these conditions, the birth rate would

Figure 9. Female life expectancy and fertility change. (Statistics Bureau 2006: NIPSSR 2012)

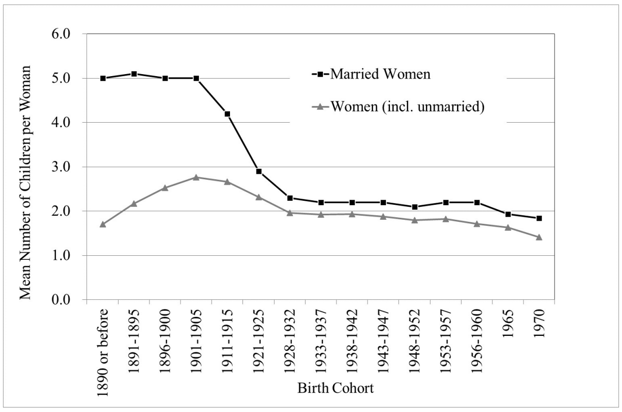

Figure 10. Mean number of children born to women by birth cohort. (Statistics Bureau 2006;NIPSSR 2012)

have remained high or even increased. Thereby limiting women's average life expectancy and infant mortality rates, and in turn leading to a higher fertility rates. However, the fertility rates decreased during the Taishō period (1912–1926). After World War II, the increase in female life expectancy from 50 to 70 years decreased the average number of children per married woman from five to two (Fig.10). After the baby boom between 1947 and 1949, adaptive birth control for a natural increase of children was spreading with the family planning movement, and the average family size was reduced to two children per family.

In the second phase, as women's life expectancy surpassed 70 years, mortality rates of children/youth, and the working age population in general, have decreased to virtually zero. However, it remains possible to decrease late age mortality rates. Therefore, life expectancy is continuously expanding. On the other hand, even if the actual fertility rate met the theoretical replacement-level TFR (NRR = 1.00) (Fig. 9), women's views on minimizing the risk of childbearing/child care remained unchanged. Thus, from 1975 onward, fertility in the second phase began to decline, as women began to shift marriage age and have children later (age of 30 and over), and to minimize the life course risk of childbearing/childcare. Such risk reduction strategies including never getting married, having a single child, and remaining childless. Subsequently, the fertility rate dropped below the replacement level (Fig.10). This shift in the timing of family formation reduced the effective use of reproductive lifetime on average. As a result, the fertility rate stagnates far below the replacement level.

A causal model of the demographic transition in Japan could be illustrated with three important feedback loops (Fig. 11);

1)Population increase enlarged the scale of social production. On that account, social capital accumulation and growth are promoted. Social capital formation decreased infant mortality, youth mortality and elderly mortality in a sequential order. With social capital growth, the life expectancy is increasing. On the other side, the social capital formation enables individual decision making on the number of birth (children) and on the timing of family formation.

2)The increasing life expectancy increase the survival rate of women in the reproductive age range, increases the risk of total fertility beyond theoretical replacement-level TFR (NRR = 1.00), in turn it creates pressure to minimize the risk of childbearing. The desired number of children becomes smaller. On the other hand, social capital provides the possibility to control the

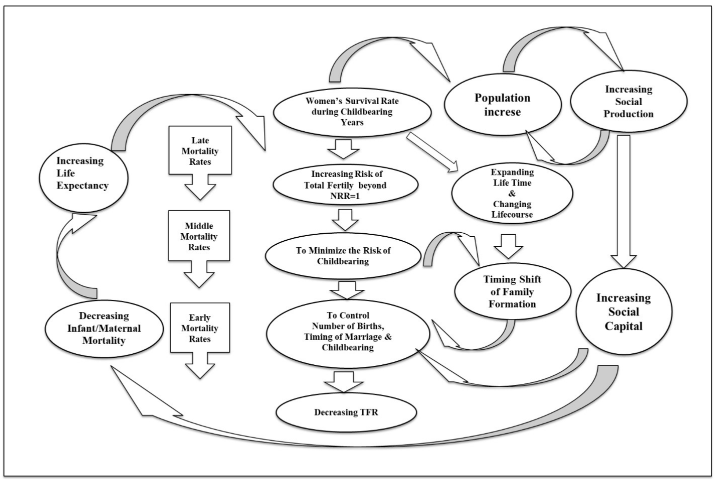

Figure 11. Casual Loop diagram of 3 important feedback loops in the demographic transition in Japan

number of births. Thus, total fertility is decreasing to theoretical replacement-level TFR (NRR = 1.00). During this process, the population increases.

3)Social capital accumulation and growth increase the life expectancy and expand total lifetime from 50 to more than 80 years. This brings life course changes like prolonged schooling, higher educational attainment and labor participation rate, above all, of women. These changes promote the timing shift of family formation to a later life stage. This timing shift reduced the effective use of reproductive lifetime and decreased fertility below the replacement level. The population ceases to increase and begins to decrease.

3.2Research methods and basic ideas

Using a system dynamics (SD) approach referencing the World3(Meadows et.al.1972). The author has constructed a macro simulation model to reproduce the demographic transition of Japan. This model is composed of four major loops: fertility, reproduction timing, social capital accumulation, and lifespan. To create a model, the following points are considered;

1) The mutual relations among the variables of the model should be defined logico-mathematically. The use of historical data should be kept to the minimum necessary to this purpose, with a few exceptions of initial values to set up. This is a logico-mathematical model, without any purpose for exact estimation or projection.

2) The main engine to promote changes in variables is social capital accumulation by increasing the population. Population increase enlarges social production and social consumption. This process should require more energy, natural resources and also degradation of natural environment. But this model has no built-in limitation for energy-resource and environmental load, with the aim of observing a demographic transition, under circumstances without any environmental limitation.

3) In this model, amount of social production equals the sum of social consumption and social investment. Most of social production is redistributed to consumption. A part of social production is invested and accumulated to social capital. This model has no assumption for social structures to diversify the redistribution.

4)This model is based on the assumption that social capital accumulation increases the possibility to expand life expectancy and to control the number and timing of births.

3.3 Fertility Equations

Total Fertility(TF) indicates the number of children (live births) per woman during her life time, which is almost equivalent to the cohort total fertility rate (CTFR) , but TF does not include any effects based on the timing shift of childbearing, thus, takes an approximate value to cohort marital fertility. In this model, TF is described as a function of three variables, total fertility maximum（TFM）, desired total fertility（DTF）and fertility control effect（FCE）, in the following equation.

$$TF=MIN(TFM,(TFM\times(1-FCE)+DTF\times FCE))$$

It should be noted that MIN(a, b) is a logical function to choose the least of two values, a or b. Thus, TF takes the smaller between biological fertility and adjusted fertility. It depends on the fertility control effect. For example, if FCE=0 (any effective fertility control) then TF=TFM (total fertility equals biological fertility), if FCE=1 (perfect fertility control) then TF=DTF (total fertility equals desired total fertility), if FCE=0.5 (fertility control effect 50%) then TF=TFM×(1-0.5)+DTF×0.5（total fertility equals sum of adjusted biological fertility and adjusted desired total fertility）.

The total fertility maximum TFM is the maximum number of live births per woman if there are no voluntary or societal checks on reproduction. This is not totally equivalent with natural fertility or fecundity, for TFM includes the effect of the survival rate of woman at age 45. Thus, TFM is described as a function of Total Fertility Maximum Normal（TFMN）multiplied by the survival rate of woman at age 45 (SVRat45) in the following equation.

FM＝TFMN×SVRat45

A standard value of TFMN is given as 15 births, based on the following standard conditions;

TFMN=RLT/BIN

Reproductive life time (RLT)=30 years (age 15-45) . Birth interval on average (BIN)=2 years. Bourgeois-Pichat (1965) proposed 13.2 births as a theoretical value at maximum with an 80 year lifespan (as an average life expectancy) （Meadows et.al.1974：99）.

The desired total fertility DTF is defined as the desired number of children per woman during her life time, which is almost equivalent to the fertility research. DTF can be influenced by various factors such as standard of living, social norms and so on. However, we assumed here that DTF is determined only by a function of the desired completed family size（DCFS）divided by the survival rate of woman at age 45 (SVRat45) in the following equation.

DTF=DCFS/SVRat45

For example, if parents desire two children as a family size in their lifetime but half of children who are born cannot survive to become adults, then the desired number of children (births) should be 4 children. Thus, DTF takes the value of a replacement level fertility. Meadows wrote; Families (generally low caste) that experience high mortality produce more live births but end up with significantly fewer surviving children（Meadows et.al.1974：109）.

The standard value of desired completed family size DCFS is set as two children, according to the principle of sustainable population.

Fertility control effect, FCE, is defined not in terms of particular birth control methods but terms of the degree of possibility to control births. As a basic assumption, social capital accumulation should promote life expectancy expansion and birth control possibility. According to my own analysis of the World Bank data (2012), the economic growth increase GDP per capita and Health expenditure per capita. They are correlated with expansion of life expectancy and with spreading use of birth control means. Thus, Fertility control effect FCE is described as a function of life expectancy (LE) divided by the life expectancy maximum (LE max) in the following equation.

FCE=LE/LE Max

For example, if LE max=100 years and LE at simulation time =80years, then FCE=0.80(80%).

3.4 Marriage timing

The Marriage timing (MT) of this model refers the starting age of family formation with a partner, not only in legal marriage, but also in various other cases. As a basic assumption, this MT should be shifted to a later age with expanding life expectancy. MT is described as a function of age 15 multiplied by life expectancy multiplier (LE MLT) in the following equation.

MT＝15×LE_MLT

For example, if life expectancy expands two times of the initial value, then MT=15×2=30. Thus, the starting age of family formation is 30.

The marriage timing(MT) is almost equivalent to the average age of first marriage in the case of Japan. In Japan, the trend of the late marriage and the late childbearing since 1975 can be regarded as the main factor of the reduced replacement fertility. According to my own analysis, this trend has been promoted by the extended average time of schooling for higher educational attainment, which has increased the average age of first marriage in Japan. Nevertheless, this trend can be seen as a life course change with expanding lifetimes. Thus, MT is linked to life expectancy.

Marriage timing effect (MRTE) refers the effect of late marriage/childbearing, which reduces the effective use of the reproductive life time RLT. Through this effect, the number of women with total fertility TF is limited. MRTE is described as a function of the reproductive lifetime ratio RLTR divided by its initial value RLTRi in the following equation.

MRTE=RLTR/RLTRi

For example, if the age of the first marriage increases to 25, the reproductive life time is limited from 30 years (age 15-44) to 20 years (age 25-44). This limited reproductive life time is 66.6％of initial value of RLT. Thus, MRTE is 0.666.

This MRTE does not directly affect total fertility TF but act total number of births per year(Birth T) . The total number of births per year is calculated by the multiplication of the total fertility TF, the number of women in the 15-44 age group and the marriage timing effect MRTE, divided by the reproductive life time RLT in the following equation,

Birth T＝(TF×(Women_Ratio_POP1544×POP1544) ×MRTE)/RLT.

Thereby, Women_Ratio_POP1544 is the proportion of the female population in the 15-44 age range to the population in the 15-44 age range, and the reproductive life time RLT is 30 years (age 15-45).Thus, the total number of births can be reduced by the marriage timing effect MRTE, even though total fertility TF stays at the replacement level.

The total fertility rate (TFR) is almost equivalent to a period total fertility rate (PTFR, simply TFR). However, TFR is calculated by total number of births per year (Birth T) multiplied by the reproductive life time RLT(30 years), divided by the number of women in the 15-44 age range. This method is different from the usual procedure but the result is almost same value as the usual TFR, which includes unmarried women in the denominator. TFR is described,

TFR=(Birth T×RLT)／(POP1544×Women_Ratio_POP1544)

Thus, the total fertility rate TFR can have a below replacement value as a result of decreasing Birth T, even though total fertility TF stays at the replacement level.

3.5 Social Production

Social production (SP) indicates the sum of the Goods that a society produces for one year excluding the sum of foreign trade. It is almost equivalent to the Gross Domestic Product (GDP) in macroeconomics but SP is a purely conceptual variable, of which the amount is given as production units (unit per person). In this model, SP is described as a function of two variables, the labor population（LP） and the labor productivity（LPRD） in the following equation.

SP=LP╳LPRD

Under no limitations for energy-resource and with a constant labor productivity LPRD, the social production SP increases proportionally with the labor population LP.

The labor population LP are calculated by the multiplication of the total population (POP T) and the labor force participation rate (LFPR) in the following equation.

LP=Pop T╳ LFPR.

The labor force participation rate (LFPR) of this model is almost equivalent to the usual term in labor economy. However, LFPR is the proportion of active labor to the total population (POP T) instead of the working-age adults (15-64) used in usual statistics.

Labor productivity（LPRD） is defined as the social production output per capita in labor population. LPRD can be changed by various factors, such as a sort of production (in hunter-gatherer, agricultural, industrial or information societies), degree of mechanization, scale of social capital, and so on. Even so, we assumed here that LPRD is constant, with the aim of observing a demographic transition under circumstances without a labor productivity change. Thus, LPRD is described as multiplication of the initial value of LPRD (LPRD min) by the labor productivity multiplier (LPRD_MLT) in the following equation, but the LPRD min is adjusted to the dependency ratio of the initial population and a standard value of LPRD_MLT sets to be 1 as a constant.

LPRD=Init(LPRDmin) ╳LPRD_MLT .

LPRD min=(POP0014+ POP65&over)/ POP1564

It should be noted that Init(a) is a function to give the initial value of a.

Therefore, the labor productivity LPRD of this model is constant at the level in which the labor population is productive enough to sustain the total population (POP T).

Social consumption (SCON) indicates the sum of the Goods that a society consumes for one year excluding the sum of foreign trade. It is almost equivalent to general consumption (GC) in macroeconomics, but SCON is a conceptual variable of which amount is given as consumption units at the initial condition. SCON is described as a function of three variables, the total population（POP T）, the social consumption per capita normal（SCON n）and the social capital generation normal（SCGN） in the following equation.

SCON=POP T ╳SCON n ╳ (1-SCGN)

The social consumption per capita normal（SCON n）refers the units of annual consumption per capita in the total population. SCON n suggests the level of average consumption in a society and can be changed by various factors, the same as labor productivity（LPRD）. However, we assumed here that SCON n is constant, with the aim of observing a demographic transition, under circumstances without consumption level change. Thus, SCON n is given as 1, which refers to one unit of consumption per person annually. Social capital generation normal（SCGN） is the investment rate for social capital formation, which is subtracted from one (total social consumption). Therefore, the above equation shows the social consumption SCON increases in proportion to the total population (Pop T) at the assumption of a constant SCON n and no limitation of economic resources, but with subtracting its small amount for social capital generation (SCG).

The rest of the Social Production (SP), subtracting social consumption (SCON) and social capital generation (SCG) is accumulated as Stock(t) in the following equation.

Stock(t) = Stock(t - dt) + (SP - SCON - SCG) * dt

It should be noted that this type of equation is a difference equation. It refers the Stock at time t is equal to the Stock at t - dt (differential time) plus (SP - SCON - SCG) in dt. The Stock(t) works practically as a buffer for some delay between social production and social consumption. In addition, a surplus of the accumulated stock is invested and is converted to social capital (SC).

The social capital (SC) is defined as tangible and intangible assets which increase with the development of society, such as social infrastructure, human relations, knowledge, technology, education and so on. In this model, SC is supposed to be built up chiefly through population increase. In this context, SC could be interpreted as human capital itself. The social capital (SC) is formed accumulatively in the following difference equation,

SC(t) = SC(t - dt) + (SCG - SCD) * dt

It refers the social capital at t is equal to social capital(t - dt) plus (SCG - SCD) in dt.

Social capital generation (SCG) is derived from the Stock(t) multiplied by the social capital generation normal（SCGN). The social capital (SC) is discarded by the social capital discard (SCD), which is derived from SC(t) multiplied by the social capital discard normal（SCDN）. The standard values of SCGN and SCDN are annually 1% and 0.1% respectively.

3.6 Life Expectancy (LE)

Life expectancy(LE) changes accumulatively. It is described as the following difference equation.

LE(t) = LE(t - dt) + (LE_change) *dt

It refers the life expectancy at t is equal to the life expectancy at (t - dt) plus the life expectancy change in dt. The life expectancy change (LEchange)is calculated in the following equation.

LE change =SCPC Ｘ ((LE Max-LE)/LE Max) /LEchange T.

The amount of annual life expectancy change is expressed as the multiplication of the social capital per capita (SCPC) and the remaining proportion of the life expectancy LE to life expectancy maximum (LE Max) , divided by the life expectancy change time (LEchange T).

The social capital per capita (SCPC) is calculated by the social capital SC divided by total population in the following equation.

SCPC=SC/POP T

The life expectancy change time (LEchange T) is set to be 200 years. That means that life expectancy reaches the life expectancy maximum (LE Max) in 200 years based on the social capital per capita (SCPC) at the initial condition. This speed of life expectancy change increases according to the level of the social capital per capita (SCPC). The initial value of SCPC is set to be 1. SCPC works as the multiplier of life expectancy change. Therefore, the life expectance (LF) is set to increase faster but nearing the maximum value becomes slower with the increase of the social capital per capita (SCPC). It is also supposed that life expectancy increases slower, but does not decrease if the social capital per capita decreases.

According to my own analysis of the World Bank data (2012), the economic growth increase GDP per capita and Health expenditure per capita. They are correlated with expansion of life expectancy. However, it was indicated at a constraint of the model that the life expectancy change in the long term is accumulative and its relation to economic growth is rather indirect, because the feedback produced by the direct linkage of GDP per capita is too strong on the life expectancy. Thus, the accumulative growth of the social capital per capita (SCPC) is chosen as the driver for the life expectancy development.

4. Simulating the Demographic Transition of Japan

4.1 Initial settings of the standard run

For simulating the demographic transition of Japan, the total population at start time (POP T int) is set to be 100 at start time. Actually, the number of Japan's population was approximately 34.806 million in 1872 but a simple number 100 is chosen as an indicator of population change. For example, POP T=200 shows the population increase twofold from the initial population.

The life expectancy for the initial value (LE int) is set to be 44.3 years. This is the historical value of the life expectancy at birth based on the first life table of woman in 1891/1898 during the Meiji period. The life expectancy maximum (LE max) is set to be 85 years. This value is near about 85.52 years in 2005. Even so, this value sets to be short in a standard run of the model, with the aim of observing a demographic transition, under the longer life expectancy maximum such as 90, 100 years and so on in a sensitive run.

The initial value of desired family size is set as 2.07, which is the replacement level of fertility at the present condition of life expectancy of woman while taking the sex ratio at birth into account. A standard value of total fertility maximum normal（TFMN）is given as 15 births. The reproductive life time (RLT) is given as 30 years (age 15-44). The other values of initial fertility variables are automatically calculated from other settings. The initial value of social production (SP) and Stock(t) are set as 100. They are derived from POP T int=100 with a standard value of LPRD_MLT =1.

The simulation time (ST) is set at 200 years. This setting is supposed to be the historical process in Japan from 1872 to 2072.

4.2 Total population, Crude birth rate and Crude death rate

The total population (POP T) is 100 at start. The crude birth rate (CBR) and the crude death rate (CDR) are 42.4‰ and 22.2‰ respectively (Fig.12). Both are derived from initial value of life expectancy, 44.3 years. This state of high fertility and mortality in Japan are not far from the real state compared with historical records of CBR 36.2‰, and CDR25.4‰ in 1900.

The simulation shows the CDR began to decline, the CBR followed this trend. The difference between them was gradually reduced and the population increase was slowed down. The deviation between CBR and CDR reached 0 at simulation time ST139 and then the population decreased. ST139 is supposed to be 2011 according to simulation assumption 1872 - 2072. It is not far from the actual peak of Japan’s population in 2008. On the other hand, the number of population (POP T) at peak is 596.17, which refers almost 6 times of the 34.806 million in 1872. That should be over 200 million versus the actual population (130 million) in 2015.

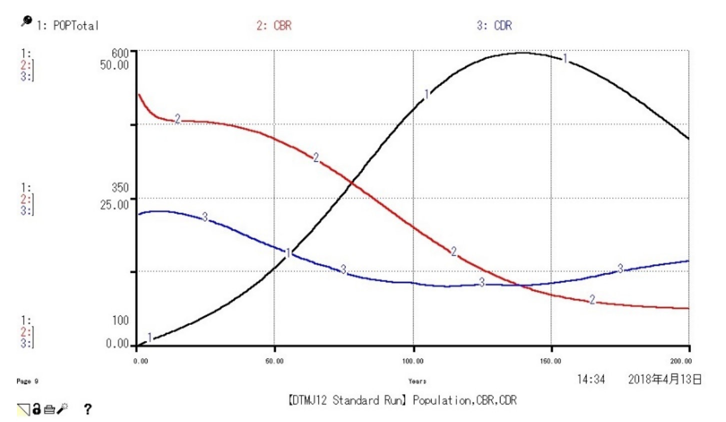

Figure 12. POP T・CBR・CDR

Nevertheless, the simulation generates the situation after the peak, in which CBR decreases continuously, CDR began to rise, due to low fertility and ageing. Then, the population began to decrease rapidly with spreading deviation between CBR and CDR. That resembles the Second Demographic Transition (SDT) (van de Kaa/Lesthaeghe, 1986) or the post demographic transition of Japan (Hara 2014). At the end of the simulation (ST 200), the total population decreased to 449.7 (-24% reduction from the peak) , CBR went down to 6.1‰ and CDR rose to 14.3‰.

4.2 Dependency Ratio

The demographic transition simultaneously and drastically changes the age structure of the population. As a consequence, the child dependency ratio (DPNDRch) is declining and the elderly dependency ratio (DPNDRold) is rising. At the intersection of both ratios, the dependency ratio (sum of both ratios, DPNDR) reaches the minimum level. These phenomena are known as the demographic bonus which brought the economic growth from 1960's to 1970's in Japan and the demographic onus from 1995 to present, which magnifies the volume of the burden of working-age adults (15-64) . The simulation reproduces those phenomena perfectly (Fig.13).

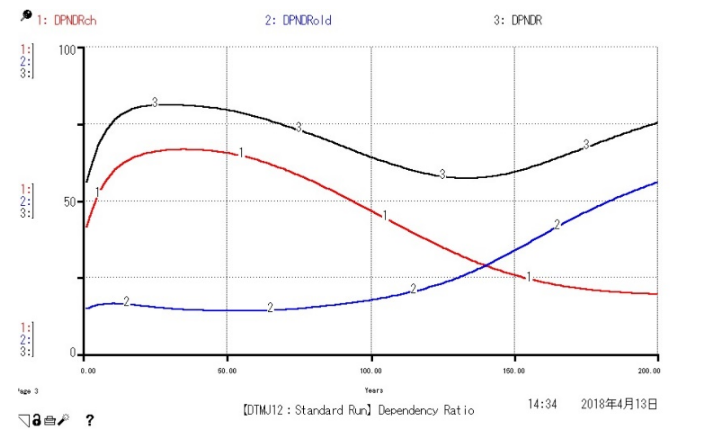

Figure 13. DPNDRch・DPNDRold・DPNDR

4.3 Social capital formation and average life expectancy

Social capital (SC) increased from 100 at ST1, to 1,221,480 at ST200. That was a typical exponential growth, 122 thousand times the initial amount. The social capital per capita (SCPC) increased from 1 at ST1, to 2716 at ST200. It showed the same exponential trend with SC. According to the social capital formation, life expectancy (LE) increased gradually from 44.3 years at ST1 to 85.0 years, drawing a typical logistic curve. The historical development of actual life expectancy (LE his), of which the curve is generated by extrapolation, seemed to run differently to the simulation (Fig.14). Life expectancy in Japan could not reach the length of 50 years before World War II. After the war, it began to expand dramatically and attained 85.0 years around 2005. It is clearly impossible for this model to express such a drastic change without any additional functions.

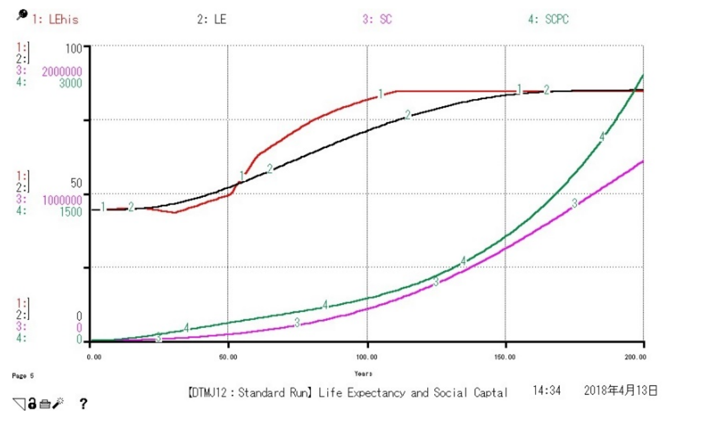

Figure 14. LEhis・LE・SC・SCPC

4.4 Fertility development

In this model, the social capital accumulation expands life expectancy. As a result, the fertility control effect (FCE) and the marriage timing effect (MRTE) are strengthened, which decreases the total fertility (TF) and the total fertility rate (TFR).

At ST1, the total fertility maximum TFM indicated 8.16 births, which was about 50% of the standard value TFMN given as 15 births. The desired total fertility DTF was also high, 3.77 births given as the replacement level of fertility, which reflected the survival rate of woman at age 45 (SVRat45) at the initial life expectancy 44.3 years (Fig.14). However, with the increasing social capital accumulation and the expanding life expectancy, TFM increased to 14.8, nearly to 15 (TFMN), but on the other side, DTF decreased to 2.10, nearly to 2.07 (DCFS). At ST172, FCE reached 1 and TF stayed at 2.10. TFR declined more rapidly than TF and continuously due to MRTE. The value of TFR indicated the below replacement level of 2.05 at ST122 (approximately 1994, converted to actual time) and was stabilized at 1.14 since 188 (about 2060)(Fig.15). In

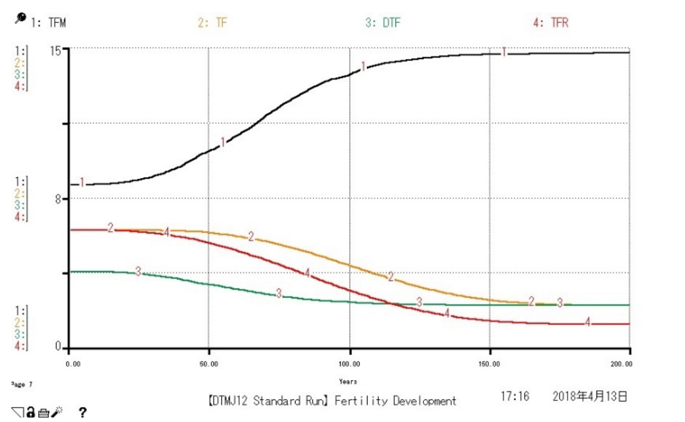

Figure 15. Fertility Development: TFM・TF・DTF・TFR

Japan, TFR has been below replacement level since 1975. Thus, the timing in the simulation run was about 20 years later than the actual case. Nevertheless, the model successfully generated the transition process in Japan from high fertility to low fertility below the replacement level.

In Japan and also in other developed countries, some TFR recovery trends have been observed since 2005. Most of them assumed the tempo effect caused by the timing shift of childbearing to a later age. This model has no age-specific birth rate setting, so it cannot replicate this phenomenon. However, the recovery caused by tempo effect lasts literally temporal. Thus, fertility should be stabilized to a level below the replacement level in the long term.

4.5 Timing Shift of Reproduction

According to expanding life expectancy (LE) which results in a prolonging lifetime, the marriage timing (MT) was shifted from age 15 at ST1 to age 28.8 at ST182. As a result, the marriage timing effect (MRTE) declined from 1 at ST1 to 0.54 at ST170. That means only 54% of reproductive life time (RLT)(Fig.16). As mentioned above, TFR decreased to below the replacement level of 2.05 at ST122 and was stabilized at 1.14 since 188(Fig.15).

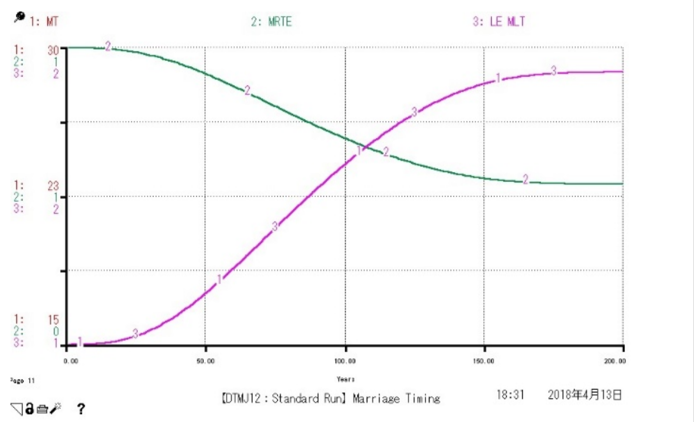

Figure 16. Timing Shift of Marriage: MT・MRTE・LEMT

4.6 Social Capital Generation and Population Growth Rate

The development of population growth rate (POP r) depends on the social capital generation normal（SCGN）. The sensitive runs of this value show the following differences (Fig.17);

1)SCGN=0%. Without social capital accumulation, the demographic transition did not happen. POP r decreased at first from 2.03% at ST1 to 1.54% then increased to 1.76% at ST67, and then was stabilized at this level.

2)SCGN=1% (the standard value). Social capital was accumulated and the demographic transition happened. POP r reached 0% at ST 142, then decreased by -0.81% at ST200.

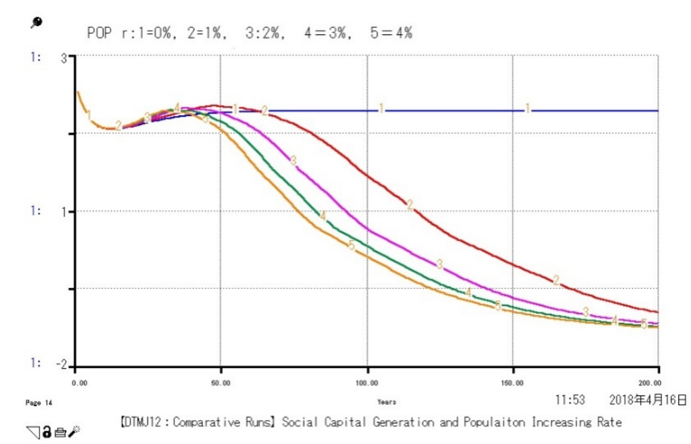

Figure 17. Social Capital Generation and Population Growth Rate

3)According to SCGN=2%,3%, 4%, POP r reached 0% earlier at ST116, ST105, ST99, respectively and the value of POP r decreased to lower than 0% at ST200, －0.96%、－0.99%,－1.01% respectively.

Therefore, the social capital accumulation could accelerate the demographic transition process.

4.7 Maximum Fertility and Population Growth rate

The standard value of Total Fertility Maximum normal (TFMn) is set to be 15 births. The sensitive runs of this value show the following differences; According to TFMn=15,16,17,18,19, POP r reached 0% and became negative later at ST140, ST145, ST160, ST166 respectively (Fig.18).

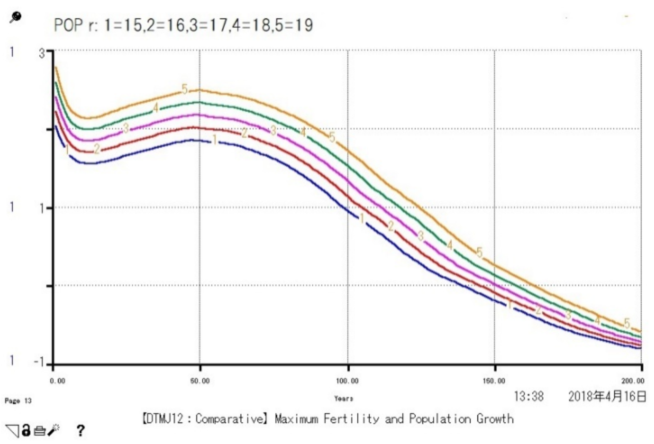

Figure 18. Maximum Fertility and Population Growth

4.8 Maximum Lifespan and Population Growth Rate

The standard value of life expectancy maximum (LE max) is set to be 85 years. The sensitive runs of this value show the following differences; According to LE max=85,90,95,100,105, POP r reached 0% became negative later at ST140, ST145, ST148, ST149,150 respectively . However, the value of POP r decreased to the lowest value at ST200, －0.81%、－0.89%、－0.98%,－1.05% ,-1.11% respectively (Fig.19).

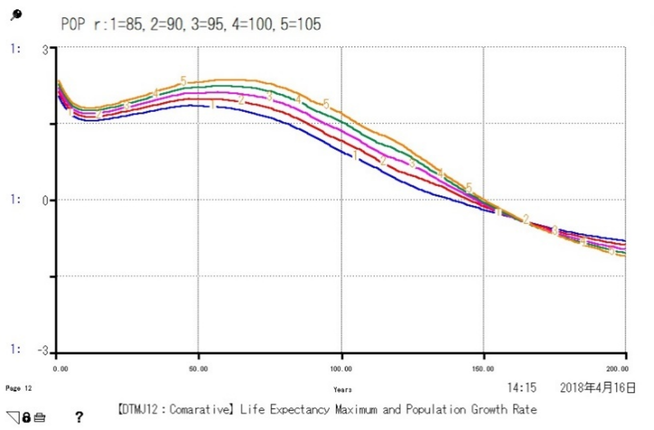

Figure 19. Maximum Life Expectancy and Population Growth Rate

This result suggests that if the biological conditioned maximum life expectancy were expanded, the process of demographic transition could be delayed but the population would decrease drastically in future.

5. Conclusion: Demographic Future of Human Society

5.1 Driving Force of Demographic Transition

The demographic transition model of Japan (DTMJ) demonstrates that the small portion of the surplus social production could be accumulated to create the social capital, which increases the possibility to expand life expectancy and to control the number and timing of births. The expanded life expectancy increases the survival rate of women in the reproductive age range, which reduces the replacement level of fertility and the desired number of children. On the other hand, the possibility to control births is increasing with the social capital accumulation, so the completed family size becomes smaller. Furthermore, the expanding life expectancy is prolonging the lifetime from 50 to more than 80 years. This change promotes the shift in timing of family formation to a later life stage and reduced the effective use of the reproductive lifetime. The total number of births becomes smaller in relation to the total number of women in reproductive ages. Thus, in post demographic transition phase, TFR stays below the replacement level of fertility, even though the desired number of children is greater than two on average.

Therefore, the main engine to promote the demographic transition is social capital accumulation by increasing the population. As DTMJ shows, the demographic transition can happen without an increase in productivity, as far as the labor population increases with no resource limitation. In actual history, some innovation in productivity, resource limitation, foreign trade, migration could have surely influenced the speed and/or the timing of the demographic transition. However, they were not the main factor to promote the process. What promotes and degrades the social capital is the population. In this meaning, the main engine of the demographic transition is the population itself. Thus, this phenomenon could commonly happen in human society.

Meanwhile, in this model, the amount of social production equals the sum of social consumption and social investment. This could be realized under the condition of fair redistribution. The impacts of social conditions, such as diversity of social distribution, on the demographic transition should be examined in further studies.

As far as DTMJ shows, the post phase of demographic transition could begin in all the regions of the world, including Sub-Saharan Africa. In contrast to the UN projection from 2017, the world will enter the post phase and its fertility will decline to below replacement level and become stabilized. Then, the world population will begin to decrease drastically. Logico-mathematically, that is highly possible.

5.2 Condition of Recovering Replacement Fertility

The UN projection from 2017 assumed the convergence to the replacement levels, which would be realized by decreasing fertility in Sub-Saharan Africa and by recovering fertility in other countries, including Japan (Fig.3). The demographic transition model of Japan (DTMJ) does not suggest any such a predetermined harmony. Instead of this, two possible measures could be proposed for the recovery of fertility to the replacement level;

1)The timing shift of family formation to a younger age could magnify the range of the effective use of reproductive lifetime on average. For this purpose, the society should support and guarantee early marriage and childbearing to be successful in their life course.

2) Another possibility is to support and guarantee late marriage and childbearing though the assisted reproductive technology (ART). This also expands the range of the effective use of reproductive lifetime on average and the Total Fertility Maximum normal (TFMn). Using the ART, the number, timing and interval of births could theoretically be adjusted to the desired rate. Especially, if we could shift the end of reproductive age from 45 to 60 or to elder, we can compensate for the negative effect of expanding lifetime on fertility.

5.3 Limits of Expanding Lifespan

Concerning life expectancy, it is possible to be reduced to a lower level because of increasing medical/care cost for the elderly. At least, the focus of elderly care in Japan began to shift from the extension of life expectancy to the a better quality of life. In addition, the increasing social capital increases individual possibilities to artificially control their own lives and also to make a decision regarding their own lives. In this context, our society can evolve to guarantee the human right not only to live but also to die according to their own will. The recent tendency indicates the direction to the right for death with dignity, mercy killing and suicide. All these tendencies could reduce the lifespan and accelerate the population decrease.

5.4 Conditions for Sustainable Future of Human

In any case, the possibility to control childbearing and lifespan through individual decision making will be developed further in the future. As a result, two of the three postulates mentioned above will be meaningless; First, that humans are mortal. Secondly, that the maximum number of childbearing is limited in a lifetime. But the third must be unchanged, which is that the limits of growth exists a posteriori, and the principle must be also unchanged that the birth rate and the death rate should be balanced to 0 for a sustainable population.

We need to have a balance between the freedom of individual decision making and the social control for births and deaths to realize a sustainable population, while avoiding a fall to eugenics, as happened in the past.

Acknowledgments

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