

The Society Created by the Longevity Revolution - Historical Development and Associated Issues -

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I. Introduction: Achieving the Longevity Revolution

We live in an era of longevity. This means it is now natural to expect that a large number of people will live until old age. We go about our everyday lives under this assumption. However, we rarely wonder how such a situation was realized.

The growth in human lifespan was not a gradual course of increase over the long run of history. Almost all of the increase occurred very recently in human history—i.e., starting around 250 years ago when modernization was just taking off in several advanced countries (Wilmoth 1999). Prior to that point, medical technology and public health systems were not prepared to deal with most diseases, nutrition was poor, and it was considered good fortune if a newborn baby successfully lived through their childhood and adolescence years to reach adulthood. Furthermore, it was relatively rare for people to reach old age, as most people fortunate enough to survive to adulthood completed their lives during the middle-age years.

How has mankind achieved the current “longevity society”? Will this trend of increasing lifespans continue? How has the emergence of longevity changed our life and society? Will a continuing trend of longevity continue to have such impact in the future? Finally, what potential problems might this trend create? In the answer to these questions we will clearly see current, urgent problems. This is even more true in the case of Japan, which is the current global leader in terms of life expectancy.

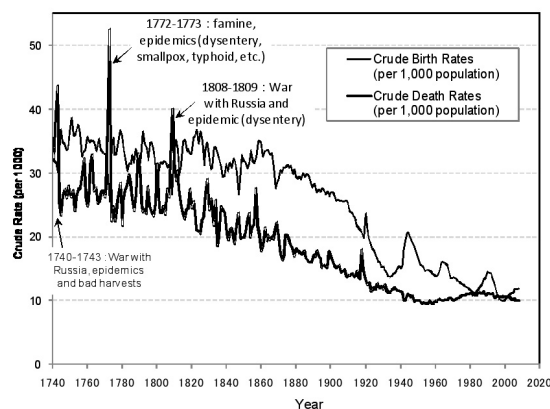
This paper will trace the history of the growth of the life span of humans referred to as the “longevity revolution”, with a particular focus on Japan. We will then examine the socioeconomic impacts, future course of life expectancy and the development of social issues that surround this longevity revolution.

II. How was Longevity Realized?

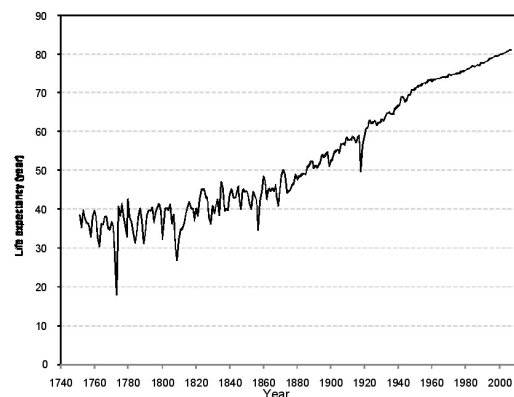
Humans have spent the majority of their lengthy history essentially defenseless against the vast number of threats arising from the environment.

Figure 1 Historical transition of crude birth rate, crude death rate, and life expectancy at birth in Sweden between 1740-2008

(1) Changes in crude birth rate and death rate



(2) Life expectancy at birth



Source: Crude birth rate and crude death rate are from Mitchell (1975) until 1969, and from Statistics Sweden (<http://www.scb.se/>) from 1970 onwards. Life expectancy at birth is from The Human Mortality Database (<http://www.mortality.org/>).

Relying on natural healing was the only option in the event that a person suffered traumatic injury or caught an infectious disease, and it is generally believed that the large majority of individuals died from these causes (Horiuchi 1999). We begin by pinpointing the period during which mortality rates began to fall.

1. A history of the epidemiologic transition and rise in life expectancy

The oldest and most reliable available data on mortality rates is from countries in northern and western Europe (Wilmoth 1999). Sweden, in particular, has data available from the first half of the 18th century. Figure 1 presents the historical transition of Sweden's crude birth rate, crude death rate, and life expectancy at birth from 1740 until 2008.

Figure 1 (1) shows that throughout the 18th century the crude death rate remained high, with significant ranges of fluctuation, and sometimes even skyrocketed upwards. The sharp rise between 1740-1743 was a result of war with Russia and the resulting epidemics and bad harvests. The rise between 1772-1773 was a result of famine as well as epidemics of dysentery, smallpox, typhoid, and others. The crude death rate rose again between 1808-1809 due to a second war with Russia and epidemic of dysentery. These incidents are typical of the fashion in which prior to modernization the crude death rate was unstable and frequently experienced sharp rises due to war, famine, and epidemics of infectious diseases.

However, the crude death rate in Sweden began to decrease after entering the 19th century, and the range of fluctuation also started to shrink. Figures show that it declined in a near linear fashion until the 1950s. This change reflects one of the first longevity revolutions experienced by mankind. The figure also shows that the crude death rate turns generally horizontal around the 1960s, and thereafter begins to increase. However, this is the byproduct of an aging population, and life expectancy continued to rise here as well (Figure 1 (2)). Furthermore, France and the United Kingdom (England and Wales), for which relatively reliable records also exist, both began a trend of gradual growth in average life expectancy in the same fashion in the 18th century.

It is believed that it was in 18th century Europe that human societies first began this trend of increasing life expectancy, which has continued until the present. Taken in the context of human history, which stretches across millions to tens-of-millions of years, this can be considered a very recent occurrence. This process of modernization

accompanied by growing life expectancy was named and formalized under the label of the "epidemiologic transition" by Omran (1971). This is none other than the process of mortality rate decline that accompanies changes in the structure of the causes of death, specifically centering on suppressing infectious diseases.

In his formalization of this concept, Omran divides the history of human death into three periods. These are 1) the age of pestilence and famine, 2) the age of receding pandemics, and 3) the age of degenerative and man-made diseases.

The first period, the age of pestilence and famine, refers to times before the advance of modernization when the mortality rate was high due to such factors as plague epidemics, famine, violence and war. This was also an age of strong fluctuation in the mortality rate. Life expectancy at birth during this period was between 20 and 40 years old. The second period, the age of receding pandemics, points to the time when deaths resulting from infectious disease, such as the rampant plague of the first period, began to decrease. During this period, life expectancy at birth was between 30 and 50 years old. In the instance of the European countries listed above, this would be approximately from the 18th century to the first half of the 20th century. "Degenerative diseases," which are indicated in the name of the third period, the age of degenerative and man-made diseases, refer to lifestyle related diseases such as heart disease, cardiovascular disease, and malignant neoplasm (cancer). During this period infectious diseases were for the most part suppressed and degenerative diseases became the main cause of death. This is also the period when life expectancy at birth is said to have passed the 50-year mark. This period corresponds to the beginning half of the 20th century until post-World War II in advanced European nations and the United States.

Omran's theory of the epidemiologic transition attempted to formalize and explain the demographic transition and social modernization that occurred between the 18th and 20th centuries from the viewpoint of declining mortality rate. However, this theory does not cover the entire history of death and life expectancy throughout the span of human existence. Thus, in response to Omran's theory, Horiuchi investigated changes in mortality and life expectancy during the course of human history and projected into the future by using a massive amount of data and literature. He then proposed a mortality transition model that was composed of five separate epidemiologic transitions (Horiuchi 1999, 2001).

Following to Horiuchi's theory, as outlined in

Figure 1, human society has experienced shifts in the leading cause of death from a situation where the chief cause of death was external injury during the hunting and gathering age to a period where the death rate was dominated by epidemics of infectious diseases in agrarian societies. The driver of changes in the mortality rate then shifts to the suppression of infectious diseases and rise of circulatory conditions between the industrial revolution until the modernization period, and subsequently to the emergence of malignant neoplasm (cancer). Finally, in the future it is forecast that a further period of longevity growth will occur as a result of the suppression of cancer and retardation and deceleration of aging.

The period of epidemic infectious diseases that Omran labeled as the first stage of the epidemiologic transition, the age of pestilence and famine, occurred after humans began to engage in agricultural activities and settle in areas with high population concentrations. There were hunting and gathering societies prior to this period, but population density was low and people migrated quite frequently during that age, resulting in a rather low level of infectious disease; the high mortality rate was due to external injury resulting from hunting accidents, contact with harmful plants and animals, and physical violence and clashes with other tribes (Horiuchi 2001).

The idea that mortality increased with the onset of agriculture is suggestive, considering the relationship between human welfare and civilization. If this were indeed a fact, as Boserup states, it is highly possible that agriculture was a way for humans to address growing population pressure, and moreover that it was not the case that the onset of agriculture served as an advancement in a

favorable direction for humans in terms of acquiring new technologies (Boserup 1965, 1981). The rise in mortality rates during this process then points to the conclusion that the first civilizations likely did not improve human welfare.

During the next change in phase in mortality rate, although seemingly contingent on the emergence of 18th century Europe as described above, the decline in mortality rate and rise in life expectancy spread widely and would last until modern times. Although much research has been conducted on the causes for this decline in mortality, there are still varying theories and there has yet to be a concise conclusion. Considering the role of medical care in modern society, it is common for people to think that the innovation in medical technology that accompanied the industrial revolution was a major factor in the declining mortality rate. However, medical history researcher McKeown concluded from an analysis of the records from England and Wales that the decline in mortality rate in Europe was instead a result of improvements in nutrition that occurred in accordance with socioeconomic development and better living standards (McKeown 1976). Further, McKeown discovered that improvements in the mortality rate had begun before modern medicine and medical care practices started to emerge.

Whether the initial improvement in mortality rate was a result of socioeconomic changes or whether it was a result of contributions to public health and medical care via the development of new technologies is an important determination to make when considering the history of modernization. Furthermore, it is also vital knowledge when considering the roles of programs in developing countries that are experiencing epidemiologic

Table 1 The five epidemiologic transitions of human history

Social scheme	Major cause of death	Changes in mortality rate (the epidemiological transition)
Hunting and gathering society	Injury	↓ (1) Mortality rise due to spread of infectious disease
Agricultural society	Infectious disease	
Industrial society (The latter half of the Twentieth Century)	Cardiovascular disease	↓ (2) Mortality fall with conquest of infectious disease
High technology society (The former half of the Twenty-first Century?)	Malignant neoplasm (cancer)	↓ (3) Mortality fall by controlling cardiovascular disease
Future (The later half of the Twenty-first Century?)	Senile decay	↓ (4) Mortality fall with conquest of cancer
		↓ (5) Mortality fall by delaying senescence

Note: Created by combining Horiuchi (1999) Figure 1 and Horiuchi (2001) Figure 1.

transitions. McKeown's research offered an important suggestion in this respect. However, later researches generated several moot points, suggesting that the development of public health technology made significant contributions at least in the latter half of the 19th century, by means of securing sanitary drinking water and developing sewage lines (Cutler and Miller 2005, Szreter 1988, 2002, etc.). Therefore socioeconomic change and changes in medical technology are seen to have played a composite roles with the decline in mortality rate (Preston 1975). Thus, it is essential that people recognize that declines in mortality rates arises not just from advancement in medical technology (as is commonly believed) but also from socioeconomic causes such as improvements in living standards (e.g., resulting from improved education and poverty reduction).

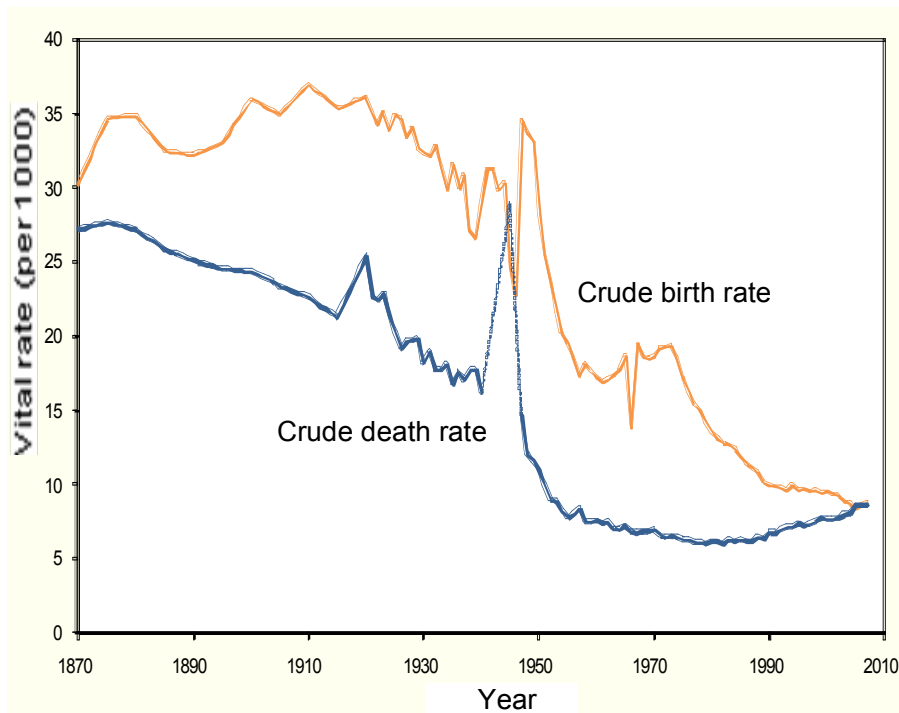
2. The epidemiologic transition and rise in life expectancy in Japan

What form did the epidemiologic transition take in Japan? Figure 2 depicts the shifts in Japan's mortality and fertility rates. Estimates measured every five years have been used for data before 1920, as

accurate data is not available for this period. As this is the case, the smaller fluctuations that likely define this period are not depicted here. However, looking at the overall shifts it is apparent that there is a long-term decline in the mortality rate and a similar longevity revolution to that in Sweden. Nevertheless, these changes started at least 70 to 80 years later than Sweden, and there are even unique points such as sudden accelerations of rate decline that can be observed over short spans of time occurring directly after the conclusion of World War II.

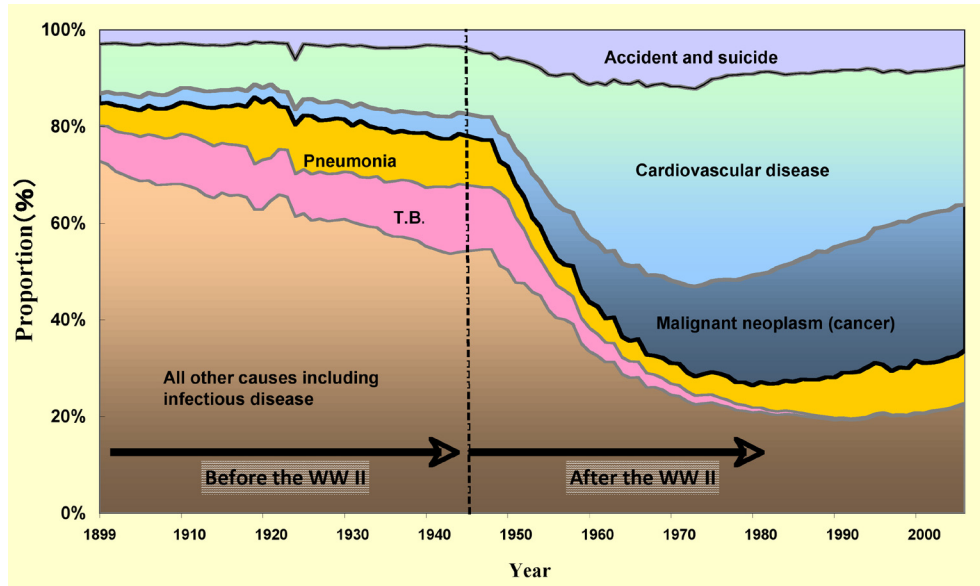
Figure 3 shows shifts in the structure of causes of death from 1899 onward. The data indicates that during Japan's epidemiologic transition the cause of death structure experienced a rapid transition in concert with end of World War II. In other words, the share of deaths resulting from infectious disease (including other causes of death such as pneumonia and bronchitis, tuberculosis) attenuated over a short span of time and lifestyle related diseases such as circulatory conditions and malignant neoplasm became the chief cause of death. This change is an archetypal example of the shift from stage two to stage three in the

Figure 2 Historical shifts in the fertility and mortality rate in Japan between 1870-2008



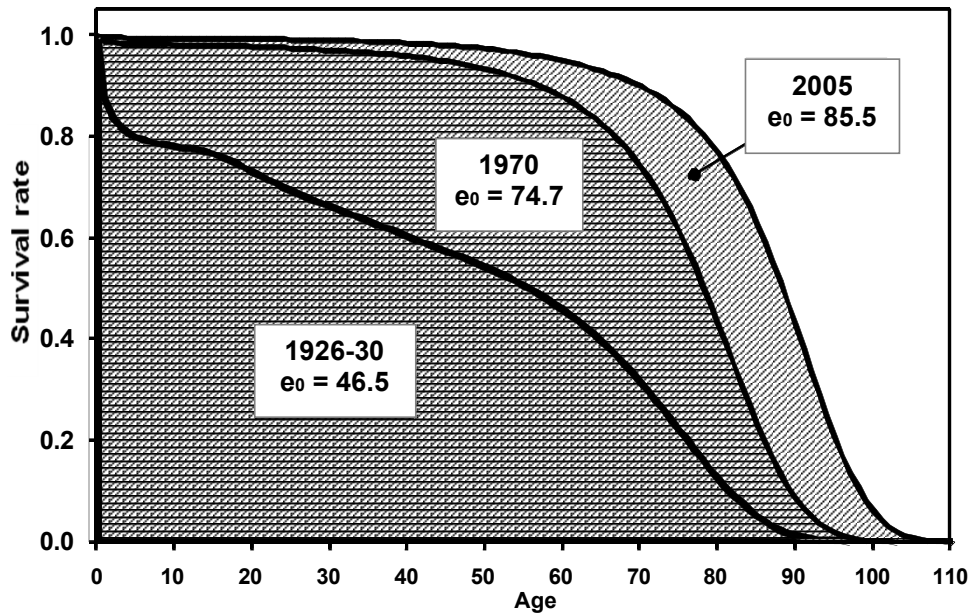
Source: Figures for before 1915 are from Okazaki (1986). Figures from 1920 onward are from "Vital Statistics of Japan" (Ministry of Health, Labour and Welfare).

Figure 3 Structural shifts in the cause of death in Japan between 1899 and 2005



Source: "Vital Statistics of Japan" (Statistics and Information Department, Minister's Secretariat, Ministry of Health, Labour and Welfare).

Figure 4 Fluctuations in the survival probability of women between 1926-2005



Source: Figures for 1926-1930 are from the "Fifth Complete Life Table" (Statistics Bureau, Cabinet Office). Figures for 1970 and 2005 are from the "Complete Life Table" (Statistics and Information Department, Minister's Secretariat, Ministry of Health, Labour and Welfare).

epidemiologic transition. As a side note, from the 1980s onward the share of pneumonia and bronchitis showed gradual increases as a result of the aging of populations.

The result of this transformation in the structure of the causes of death was a shift in the age distribution of deaths, manifesting in a significant decline in deaths by the younger generation, including infant death, and a concentration of death among the elderly generation. In other words, this means that the lifecycle of people had changed from uncertain life span to universal longevity. Figure 4 illustrates alterations in the survival curve of women from the pre-WWII era (1926-1930) to 1970 and until 2005. A survival curve is a curve that expresses the survival probability to a certain age (or ratio of people that achieved a certain age) from their birth (age 0) for each year of their life (horizontal axis). The area enclosed between the curve and bottom axis expresses life expectancy at birth.

Looking closely at the curve in the period before World War II shows us that survival probability declined significantly during the infancy and childhood periods, continued to drop at a smooth rate thereafter, and then experienced a sudden drop heading towards zero from around the 1960s. This tells us that the fraction of people who achieved old age was not very high. The amount of area under the curve, or the life expectancy at birth, was 46.5. In general, this type of life and death pattern was common during the pre-war era.

In contrast, looking at the survival curve of 1970, which is after the end of World War II and the following conquest of infectious disease via the epidemiologic transition, shows us that the fall in survival probability during the infancy and childhood periods had generally disappeared and the decline in the curve for ages following that period was very gradual. Moreover, compared to the pre-WWII era, the area below the curve has increased markedly. In fact, life expectancy at birth has risen to 74.7. Furthermore, this area increased even further by 2005, indicating a life expectancy at birth of 85.5.

Just as the change in area shows, the average expected years of survival in the pre-war period and that of the period following the epidemiologic transition after the war shows tremendous difference. As deaths showed a distinct reduction through infancy, childhood, adolescence, and middle-adult life, Japan finally became a society where all persons were expected to live to old age.

Compared to other countries that experienced similar epidemiologic transitions, Japan achieved these changes in a remarkably short period of time.

Post-WWII Japan can be credited with generating this abbreviated version of the epidemiologic transition. Figure 5 (1) compares the rise in life expectancy at birth in Japan with other major regions around the world. This data not only shows that recent levels in Japan are extremely high, but also that the slope of that increase is very sharp. Furthermore, Figure 5 (2), which depicts the rise in average life expectancy in Japan and other major advanced nations, also shows that Japan's slope is particularly high even compared with other major advanced nations.

There are some advanced nations, however, that are currently experiencing a decline in the life expectancy. One example is modern-day Russia, an advanced nation that historically (under the auspices of the Soviet Union) failed at socio-economic management. The example of Russia clearly indicates that the life expectancy is by no means something that grows automatically with time.

Japan's life expectancy became to occupy the leading position in the world during the 1980s. Why was Japan able to achieve such a rapid rise in life expectancy? Answering this question will reveal the mechanisms behind improvements in life expectancy, providing us with inevitable knowledge for future development.

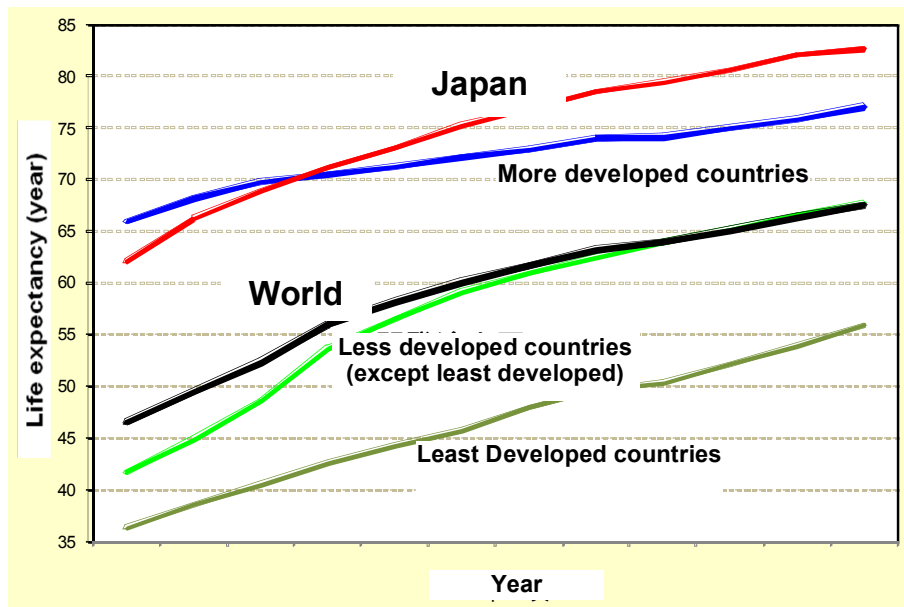
3. A new phase of the epidemiologic transition

A large number of advanced nations, including Japan, are deemed to have reached the final stage—stage three, the age of degenerative and man-made diseases (or lifestyle related diseases)—of the epidemiological transition theory around 1970. According to the original theory, the human lifespan possesses a biological limit and advanced nations that have already passed the epidemiological transition were considered approaching that limit. Therefore, the theory suggests that after reaching that limit, the life expectancy would no longer be able to grow at such significant rates. However, what actually happened after this point was the start of an unexpected decline in the mortality rate of elderly people, which consequently pushed the life expectancy to grow even further.

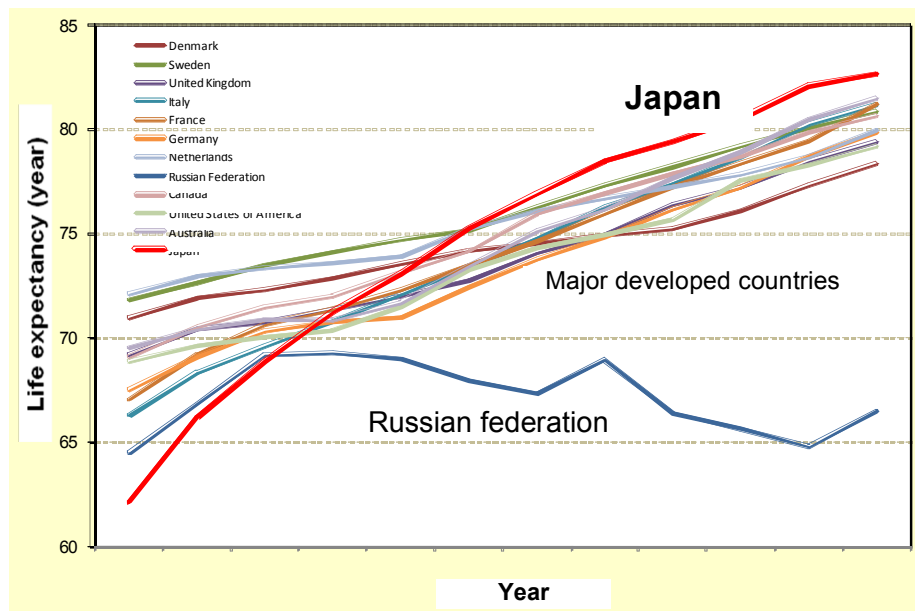
In response to this situation, longevity scholars including Olshansky theorized that the history of death and life expectancy of advanced nations had entered a new phase and they thus added a fourth stage to the epidemiological transition. They labeled the new fourth phase the Age of Delayed Degenerative Diseases (Olshansky and Ault 1986). The new phase was founded on the concept that the timing of death resulting from degenerative diseases such as cardiac disease, cerebrovascular disease, and malignant neoplasm

Figure 5 Global comparison of average life expectancy between 1950-2010

(1) Global comparison by region



(2) Comparison with other major advanced nations



Source: United Nations (2009).

had year by year been pushed later in life, and as a result life expectancy continued to rise. At present it is believed that most advanced nations, including Japan, have entered this new fourth phase. Among those nations, Japan displays the greatest rise in life expectancy.

III. How has Longevity Changed Society?

Omran, who proposed the concept of the epidemiological transition, believed that it was the decline in mortality that galvanized the demographic transition and modernization of society as a whole (Omran 1971). In addition, McKeown, whose work highlighted the importance of socioeconomic factors in the historical decline of mortality rate and led to the consideration of those factors in policy, places the change in death as the driving force that led modernization through population increases (McKeown 1976). More broadly, the epidemiological transition changed the survival probability of people, fundamentally altering the nature of the human lifecycle. The timetable of life changed significantly, and in the end that served to transform the social economy as a whole.

The effects on society elicited by rising life expectancy as a result of the epidemiological transformation can be broadly categorized and summarized in the following four points: 1) spawned a demographic transition, 2) cast away uncertainty over life and society and established an efficient social economy, 3) completely altered the life plans and outlook on life held by individuals, and 4) increased the number of people who live until old age, thereby promoting the aging of the population.

1) First, the epidemiological transition spawned a demographic transition. A demographic transition is a phenomenon characterized by a particular demographic moving from a situation of high birth and high death rates to a situation of low birth and low death rates in accordance with the modernization of society. When there are high fertility and mortality rates, the crude birth and death rates are both at high levels and the rise in population numbers needed for these rates to offset each other is generally small. Conversely, in a society with low fertility and mortality rates, vital rates balance out at low levels and there is thus no rise in population. The shift between these two equilibrium states is called a demographic transition. However, in classic examples mortality rates begin to decline ahead of fertility rates, and thus go through phase of a rapid population increase due to the marked gap between low death rate and the still high fertility rate.

Classical examples are provided in Figure 1 (1) for Sweden and Figure 2 for Japan. A demographic transition is a phenomenon that occurs in concert with the modernization of society. Considering the fact that the decline in mortality rate in Europe actually preceded industrialization, as shown in the previous chapter, there is a strong possibility that the decline was not a product of modernization, but rather the beginning of modernization. Therefore, it is possible to consider the epidemiological transition as the point of origin that first pushed the gears into motion and gave birth to modern society.

The increase in population, which takes place amidst a demographic transition as a result of the time lag between the decline in mortality rate and fertility rate, has provided an important turning point in the history of nations that have experienced such transitions. Social and political interests shaped by the concerns over a population rise that started with Malthus' theory were in itself the product of population upsurges that took place during this demographic transition. Later, consciousness of overpopulation impacted the formation of The Capital by Marx and the intellectual foundations for establishing socialistic states. Furthermore, as a historical undercurrent this consciousness has continued to steer history, for instance by serving as a background cause for coercive colonialism and two of the World Wars.

2) Next, the epidemiological transition cast away uncertainty over life and society and established an efficient economy. In other words, the rise in survival rate of people involved in economic activities, served to secure continuity for those businesses, enhance credibility, and boost the efficiency of investment. Primarily, this allowed for the development of advanced financial markets, which in turn provided a foundation for a large number of businesses to operate effectively and thus generate rapid economic growth.

3) It is likely that a similar phenomenon took place within individual people's lives. That is to say, the epidemiological transition extended the survival of people who were personally or indirectly involved in these developments. This, in turn, spawned the next change, the complete alteration of the life plans and outlook on life held by individuals. In particular, amplifying the investment effects of education along with spreading the popularity of higher education was an important effect linked to a wide array of future changes. One of those prominent changes was the prolongation of the human investment period (moratorium period), which

led to a series of changes that have culminated in today's low fertility rate problem, including altering the process of development in the adolescent years and delaying the timing of the family formation. The rise in the survival probability of humans is believed to have, on the whole, increased the effectiveness of using economic rationales when thinking about personal behavior, fundamentally changing people's attitude towards life.

4) Finally, the epidemiological transition increased the number of people that live until old age, thereby promoting the aging of the population. Although this can appear to be the easiest consequence to understand, I must note two important facts.

First, the decline in mortality rate as a result of the epidemiological transition started mainly as a decline in the infant and child mortality. Thus there was initially a relative increase in the young population, rather than an aging of the population. Only later, when the generations that experienced a decline in mortality rate started to sequentially grow older, population aging is actualized.

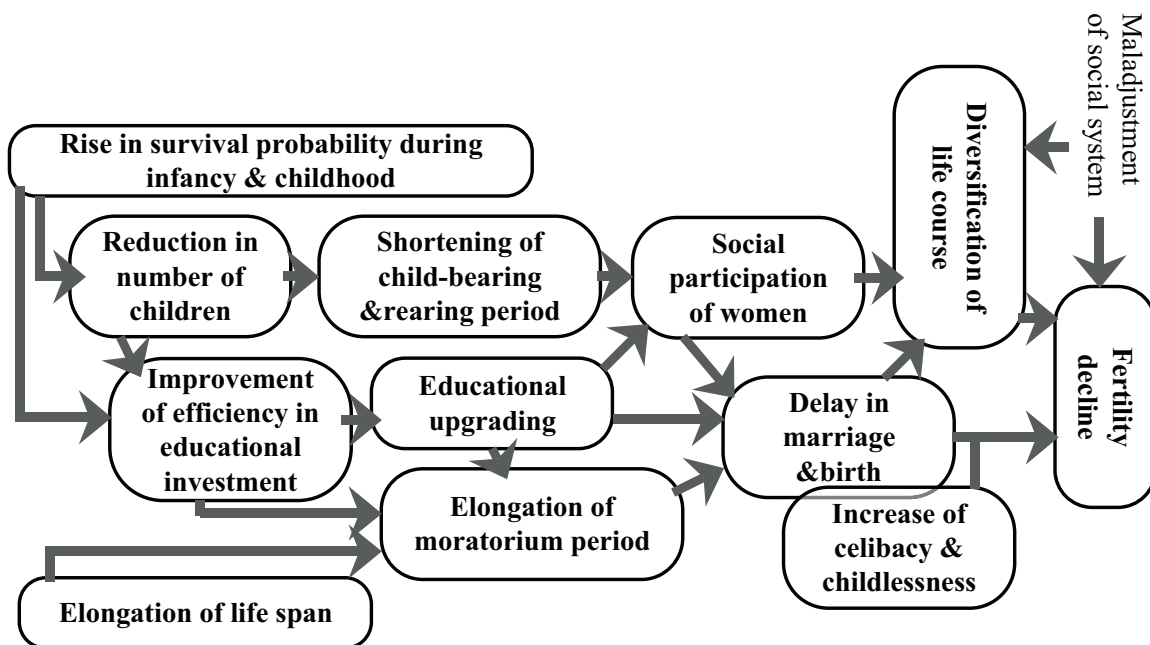
Second, the decline in mortality was of minor significance compared to the decline in fertility rate in contributing to the aging of the population. Population aging can be spawned by growing elderly populations as well as by shrinking

younger populations. The decline in fertility serves as a much larger contributing factor to population aging which is engendered by a demographic transition. In regards to this point, I will discuss how to treat population aging taking into consideration the level of health of the elderly demographic and other factors and offer a more detailed explanation using actual cases in Chapter V (How will longevity continue to change society?). However, the recent decline in the mortality rate in Japan has the effect of rapidly enlarging an older old population and promoting aging within the elderly population, so to speak, and it will be important to keep this in mind when considering future aging.

We have now described the changes in social economy that growth in longevity has spawned in the past via the epidemiological transition by breaking them down into four separate categories. Of course, these four categories did not function separately, but evolved in a complex manner in relation to each other. Here I will use the changes from mainly the life course of women as an example to show the nature of these relationships. Figure 6 presents the link between the rise in survival probability of children brought on by the epidemiological transition and the changes in female life course spawned by longevity.

The rise in survival rate during childhood allowed women to reduce the number of children

Figure 6 The evolution and consequences of the impacts of the epidemiological transition -Diversification of the female life course and fertility decline-



that they bore and increased the efficiency of investment in education. This in turn served to popularize higher education among members of the next generation. Many women among this next generation then realized social participation by entering the job market with equally higher education as men enjoyed. The low birth rate and shortening of the child bearing and rearing periods which they succeeded from their parents' generation made the social participation even more effective. Meanwhile, the elongated school terms and moratorium periods (caused by women advancing to higher levels of education) caused to delay the formation of families, creating a trend where women began to marry and have children at a later time in their life. The increased number of working women did serve to expand and diversify the female life cycle, for instance by improving economic status and creating a new trend where women married later in life. However, the mediocre adaptation of social systems, customs, and awareness to this new situation prevented people from being able to redress the delay in family formation and consequently there is a gradual rise in the ratio of women that go through life without getting married or having children. Coupled with the timing-related effects of the total period fertility rate of delayed birth, this trend of later birth and consequent fewer children apparently served to instigate a marked decline in the fertility rate.

There are surely many factors that I have not listed that also play a part in the process above. However, this figure shows a hypothetical connection of the factors generated from the morality decline engendered by the epidemiological transition that caused fertility rates to drop and weaken below the replacement level later in time. This is one example of the social changes brought about by the longevity revolution, and it is believed that growth in longevity greatly changed society as a whole by the expansion of these types of linkages. The rise in life expectancy advanced at a phenomenally fast pace in Japan, and thus the rapid advancement of this chain of changes to which only insufficient adaptation could be seen are to have created a unique modality of the society today. This type of prospect has important implications for countries that expect to experience rapid increases in longevity in the future.

IV What Path Will Life Expectancy Take In the Future?

The life expectancy in Japan has exhibited amazing growth in the past, but is this expected to continue in the future? Or is there a limit and will this trend begin to level off at a certain point? In

the past the prevailing belief even among experts was that the human lifespan had a certain limit and that we were already approaching that limit. Nevertheless, today there are challenges toward such theories as a result of the profound improvement in the mortality rate among the elderly populations of advanced nations from the 1970s onward. If those theories of lifespan limits are not the cases, just how far can we expect the human lifespan to grow?

In order to know the trajectory of life expectancy in the future, we must first figure out what the determining factors are behind it. This chapter first surveys those factors that determine human lifespan as well as the trends of those factors, and then makes some prospects about future trends of life expectancy.

1. The future path of life expectancy seen in light of its determining factors

There are a tremendously large number of inter-related factors that determine life expectancy. However, it is possible to roughly categorize these factors into four groups for analytical purposes: 1) biological factors, 2) medical factors, 3) socio-economic and legislative factors, and 4) lifestyle factors.

1) Biological factors include mechanisms organisms use to maintain their survival while responding to challenges from the environment, such as their immune systems and aging mechanisms. These functions are assumed to be common among all human groups. In other words, all societies could be expected to have around the same average lifespan if put in the same environment.

Model life tables, which are the most basic tools used in population analysis, actually apply this concept rather skillfully. These are based on the observation that age patterns of the mortality rate reflect vitality patterns common to all humans, and as environmental effects interacted with these patterns amidst their formation, it is likely possible to construct an age-specific mortality rate model that corresponds to a certain environment, or a certain mortality level. These models are referred to as model life tables and they are applied to a wide range of uses, including estimating whole series of age-specific mortality rates from fragmented information and making future predictions of life tables¹.

In this way, vitality, as a common biological attribute potentially shared by all human groups, manifests itself in the form of the mortality rate following interaction with the environmental factors

to be listed in numbers 2) to 4) here. Many of the factors that determine human vitality are not yet understood. On a cellular level, one phenomenon implicated in aging is the fact that the telomere, a specific sequence located at the ends of a chromosome, becomes shorter each time a cell divides, thus limiting indefinite growth. This is thought to regulate the lifespan of an individual. In addition, special gene types that influence life expectancy have been discovered in some living things, such as nematodes, drosophila, and mice, and are now being referred to as longevity genes or anti-aging genes. However, similar genes have yet to be discovered in humans and the general expectation is that a large number of genes contribute to the human lifespan. By and large, it seems that the life expectancy of higher-level beings including humans is not genetically programmed. Rather, it is more natural to consider lifespan to be a consequence of senescence as deteriorations of whole or part of the body system caused by the accumulation of damage incurred throughout the survival process. Therefore, the question of how to prolong lifespan is synonymous with intervention into this comprehensive process of aging. As will be mentioned later, therapeutic medicine is beginning to present the possibility of interfering with this aging process.

2) The second category of factors, medical factors, can be separated into two smaller sub-categories—factors related to the prevention of disease and death, including public health, and therapeutic factors that cure disease. Until now, preventive medical technologies used to lower the mortality rate by alleviating the environmental factors that cause death. Therapeutic medical technologies on the other hand worked to minimize the impact of illnesses that preventive medicine could not completely stave off by restoring original physical conditions. In either case both kinds of technology all together worked to improve living environments, and it is clear that the delivery and application of them are intimately connected to socioeconomic factors, as a group of environment factors.

However, the advancement of therapy technologies such as regenerative medicine and gene therapy raise the possibility of a different transformation than that noted above and possess the potential to create a new phase in the history of the rise in the human lifespan. Put differently, no matter what environmental one is placed in it is impossible to survive past the physical limits of the organs, tissues, and cells required to support life --- but manipulating these limits and exchanging

organs, tissues, and cells themselves might allow one to circumvent those restrictions. Thus, there is now the potential to achieve a human lifespan that is not constrained by inherent biological attributes via these types of revolutionary technologies. The “stage of anti-aging” that Horiuchi (2001) points out can be considered the stage when these phenomena are realized. There is no clear forecast of when these types of technologies will be achieved. However advanced-level research is already being promoted on the application of regenerative medicine, e.g., research on embryo stem cells (ES cells) and induced pluripotent stem cells (iPS cells), and some results are anticipated to be achieved over the next ten to thirty years. Just as Horiuchi has predicted, there is potential for these technologies to reach the stage of diffusion during the latter half of the century.

Nevertheless, future factors to consider pertaining to lifespan in the areas of disease and medicine are not all necessarily positive. The arrival of new infectious diseases and the reemergence of old infectious diseases threaten the lives of people around the world. Only around recent Japan there are cases of HIV, O-157, mad cow disease, SARS, swine flu, and others, and attention must be paid to the possibility of the occurrence of new infectious diseases in the future, such as the human form of the avian flu. Furthermore, there is an increasing number of cases where conventional diseases that were thought to have been suppressed— e.g., diphtheria, tuberculosis, and measles.—have reemerged. There are also numerous reports of bacteria that have become resistant to antibiotic drugs and are effectively untreatable. .. Newly emerging and reemerging infectious diseases have the potential to unleash great damage, including on the younger population. As shown by the marked decrease in life expectancy owing to AIDS epidemics in sub-Saharan Africa, if adequate measures against emerging and reemerging infectious disease are neglected, forecasts of future life expectancy even in advanced nations may have to be significantly corrected.

3) Category three, socioeconomic and legislative factors, influences the effectiveness of medical technologies. For instance, the strong correlation between the level of economic development and life expectancy can be seen throughout history and even geographically (Preston 1975, Wilkinson 1992, and others). This is not only due to the fact that the economic development level is related to improvements made to the individual environment via better living standards, but also to many other aspects of public health.. For instance, social

infrastructure development such as water and sewage treatment facilities, enhanced placement of healthcare facilities in order to improve access to medical treatment services, creation of health insurance systems, and spread of health education are all a consequence of economic development. Furthermore, the development of medical technologies is likely to take place more effectively in societies that are economically developed.

The average economic level of a society, as well as inner structural factors such as income inequality, all significantly impact the life expectancy and the overall death levels of a society. Preston has discovered a positive correlation between income and the life expectancy on the national level. He points out that the redistribution of income to the low-income group serves to efficiently improve the overall health of society and engenders a rise in life expectancy because the increase in lifespan as a response to an increase in income declines the higher the income level (Preston 1975). In fact, there are a large number of reported cases where overall life expectancy is higher the less income inequality the society possesses, even on an equal to low economic level (McCord and Freeman 1990, Ross et al. 2004, Sen 1993, and others).

Kondo suggests that once domestic income inequality surpasses a certain level, the occurrence of social stress begins to impact the health and life expectancy of the high-income demographic as well as the low-income demographic (Kondo et al. 2009). Wilkinson points out the high levels of murder, accidents, and alcohol-related death in non-egalitarian societies (Wilkinson 1997). Furthermore, Horiuchi (in private communications) has cited the egalitarian society of Japan as one factor behind the country's high life expectancy at birth. It has even been estimated that the loss in average lifespan owing to socioeconomic inequality in the United States in 1990, for instance, exceeded the loss in survival period in the same year that resulted from death resulting from lung cancer, diabetes, automobile accidents, HIV infections, suicide, and murder combined (Lynch et al. 1998).

Health and death also share a close relationship with education. International and domestic comparisons alike show a correlation between high life expectancy and high education levels (Cutler and Lleras-Muney 2006, Kunst and Mackenbach 1994). That trend is especially pronounced among men (Mustard and Etches 2003), and it has even been pointed out that improving the education level will boost the life expectancy among

men (Preston and Elo 1995, Meara et al. 2008). Taking these observations and the existence of these mechanisms into consideration, whether socioeconomic inequality is shrinking or expanding will influence life expectancy trends.

4) Category four, lifestyle factors, refers personal daily behaviors—smoking, exercise habits, diet, etc.—that influence one's survival rate by impacting one's health. Special attention should be paid to lifestyle choices that contribute to the occurrence or progression of risk factors implicated in so-called lifestyle related diseases, such as cerebrovascular disease, heart disease, and malignant neoplasm (cancer).

One example of pioneering research that showed that one's lifestyle heavily impacts health and lifespan was the Alameda County Study conducted by Breslow and others. His research team used follow-up surveys to show that lifestyle habits—such as smoking, drinking, exercise, weight (obesity), sleep time, breakfast, and lunch— influence one's health and survival probability, while social networking—such as interaction with friends and family and participation in religious and other organized activities—also impact one's health (Belloc and Breslow 1972, Guralnik and Kaplan 1989). This close relationship between lifestyle and health and survival has been corroborated by a great deal of subsequent research.

In addition to these lifestyle factors, behavior conducted for the direct purpose of personal health maintenance (health behavior) is also believed to greatly impact the survival rate, particularly for the elderly. For instance, behavior and awareness related to health differs between men and women, and apparently it is easier for women to receive the benefits of medical technological advancements because they use healthcare services more frequently than men (Vallin 1995). Mortality rate differences correlated with marital status and socioeconomic attributes are in many areas ascribable to health behavior and other differences in lifestyle, including such differences between men and women (Manzoli et al. 2007, Trovato and Lalu 1998). In order to redress disparity in life expectancy in the future it is believed to be important to spread knowledge regarding health behavior and to have a support structure to implement it.

In Japan, lifestyle related diseases are a leading cause of death. Disease prevention via lifestyle improvements including health behavior (called primary prevention²) will extend people's healthy life expectancy as well as the life expectancy at birth. This is also a national-level issue of the ever-

increasing burden of national healthcare costs. For this reason, in 2000 Japan drafted the National Health Promotion in the 21st Century (Healthy Japan 21) act with the purpose of lifestyle related disease prevention, establishing numerical targets for improvements to be made in various fields. Furthermore, the establishment of the Health Promotion Act in 2002 created a foundation for promoting the creation of an environment where citizens can be aware of their own health status and work to enhance it throughout their lives.

We have now discussed the factors that regulate life expectancy, broken down into four categories. One's lifespan is determined by all of these factors acting in concert and it is believed that of rising longevity can only be achieved once all of these aspects have been improved. There is no question that it is the high level of Japan's achievements and favorable balance in all of these fields that allows it to maintain the longest life expectancy in the world. Therefore, research on Japan's situation as a whole is sure to have many things to contribute to understanding the future of life expectancy for all mankind.

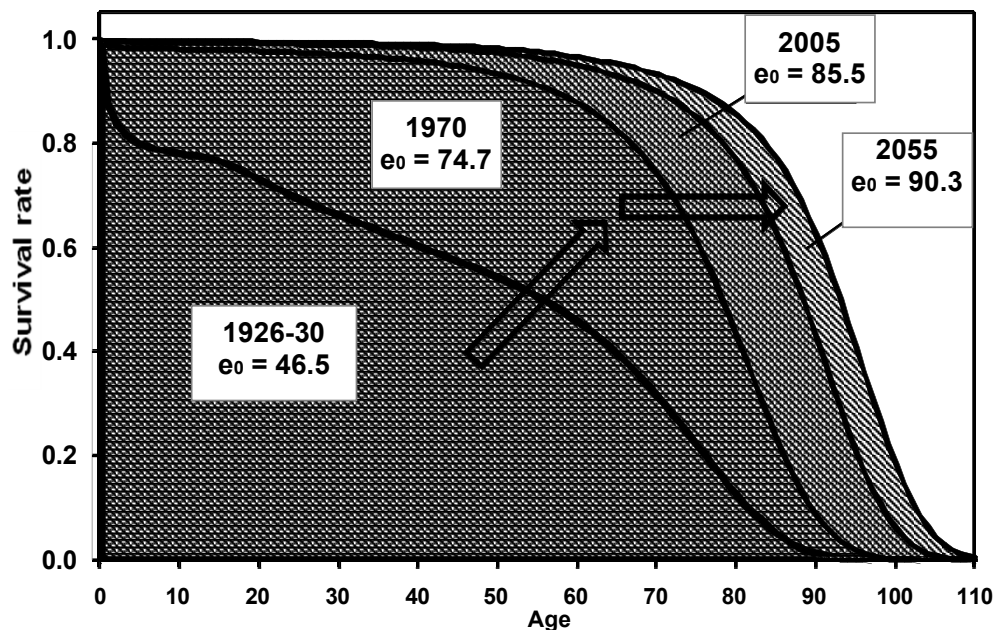
2. Life expectancy in the future

As already noted, from the 1970s onward in advanced nations showing a decline in the mortality rate, the drop in mortality rate of the elderly

population was particularly marked and the life expectancy has continued to rise at a pace that exceeds previous forecasts. This has shown us that it is no longer appropriate to assume that there is a particular proximate limit on lifespan when forecasting future life expectancy. Figure 7 depicts the past survival curve along with the future survival curve of Japan's projected population. The life expectancy in 2055 is expected to be 90.34 years for women (83.67 years for men). However the increase is not just due to the survival curve growing more rectangular like it did before the 1970s, but because it expands out into the old age area. One can understand why it is impossible to apply specific limits to this form of growth in the life expectancy. In order to forecast future life expectancy, we must pay consideration to the trends of each factor introduced in the previous section and comprehensively calculate their impacts.

In particular, it is possible to maintain the current rise in the life expectancy resulting from delays in deaths from degenerative diseases by increasing primary preventive behavior (such as improving on proactive lifestyle habits) and by promoting a secondary preventive structure of early detection and treatment, for instance through enriching health checkup systems. These trends are supposed to be reflected in the projection noted above, as these were attained by projecting

Figure 7 Developments in the survival curve (female) between 1926-2055



Source: Data until 2005 is the same as Figure 4. Data for 2055 is from median death estimates from "Population Projections from Japan" (December 2006 estimates).

past trends of the changing mortality rate on the future, and past data already takes those trends into account. However, there is the possibility for the advent of a situation where life expectancy is dramatically prolonged due to the suppression of aging via the discovery of treatment methods for malignant neoplasm (cancer) as well as revolutionary medical technologies such as regenerative medicine and gene therapy. This situation is not necessarily reflected in life expectancy projection. Nevertheless, past rises in the life expectancy have only been minimally impacted by the onset of revolutionary technologies, such as the past development of vaccines and discovery of antibiotics, allowing such rises to maintain generally a linear path (Oeppen and Vaupel 2002). It is therefore possible to imagine that the impact of the dramatic onset of these technologies has already been reflected in past trends. However, it is of course difficult to discern beforehand whether the revolutionary technologies that might be developed in the future will have cause deviation from that trend.

At the same time, the possibility that new infectious diseases and reemerging older infectious diseases will pose real threats to the survival of people in the future and work to decrease life expectancy cannot be discounted. In the event of an epidemic of an infection via unknown micro-organism or highly toxic drug-resistant bacteria,

modern society could quite possibly suffer a serious blow at least temporarily. Moreover, we must stay alert to the weakening and aging of medical and public health infrastructure as a result of financial difficulties of national and local governments, as well as the spread of economic inequality within nations, as these are all elements that hinder the rise of life expectancy.

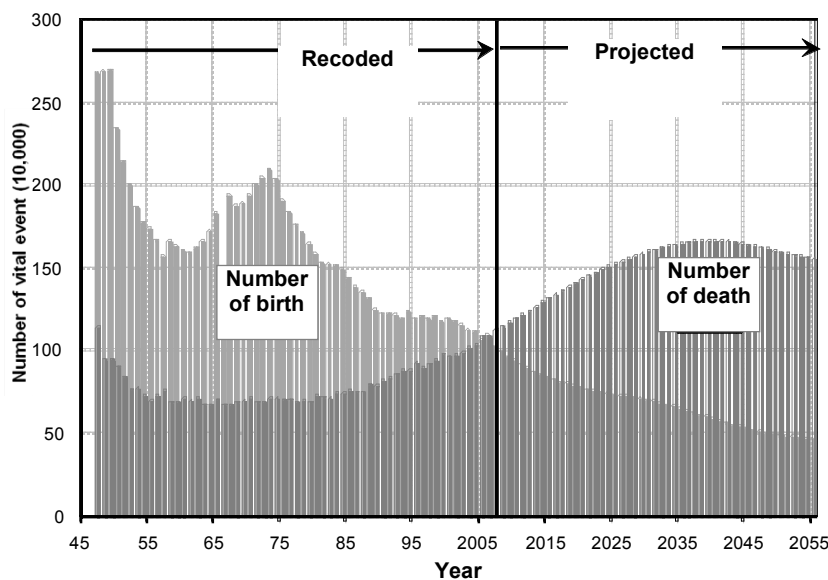
At any rate, national life expectancy trends are going to be closely related to the overall direction of a nation's social economy. It is impossible to continue increasing life expectancy alone without also working to stabilize and develop the socioeconomic systems.

V How Will Longevity Continue to Change Society?

Any issue accompanied with rising longevity will certainly materialize first in Japan, since it is the forerunner of the race. But what will these issues be?

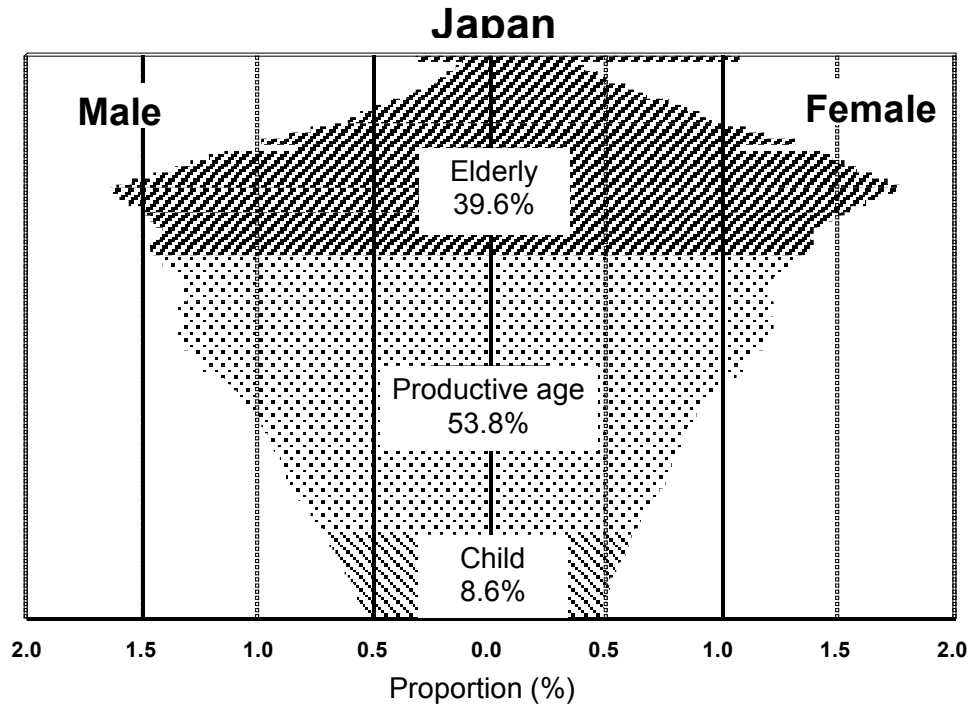
First, there will be an increase in number of death, decline in population, and an aging of the population. Growing number of death seems peculiar for a society with rising life expectancy, but death incidences will certainly show a rapid increase today because stock of postponed deaths owing to past growth in longevity will gradually take place. Furthermore, the increase in death will work together with the decline in birth (see Figure

Figure 8 Intersection of fertility and mortality between 1945 and 2055

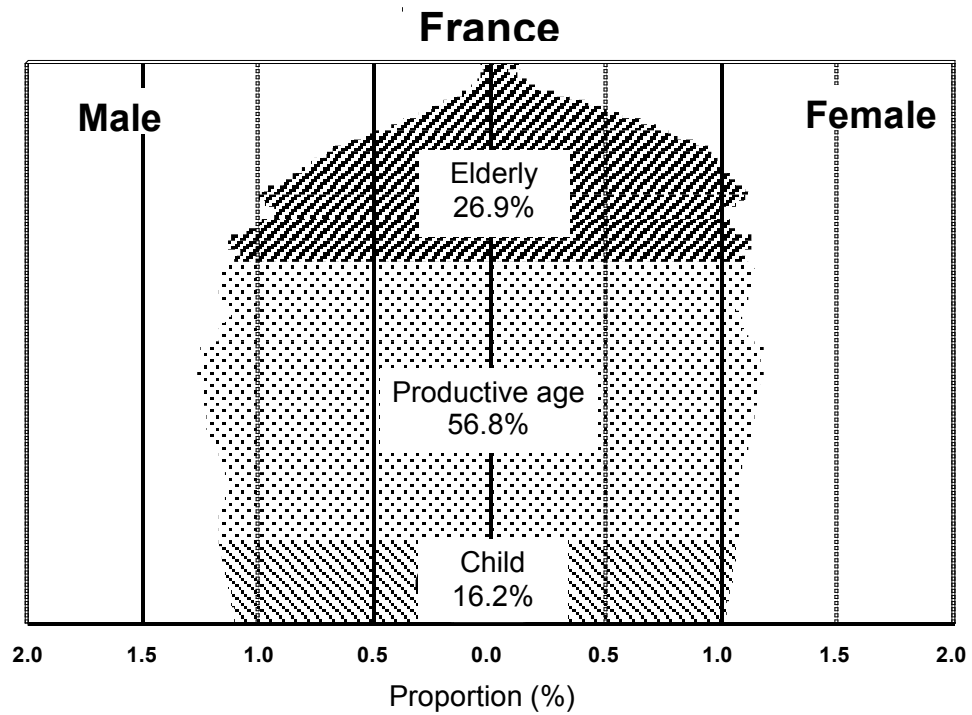


Source: "Vital Statistics of Japan" (Statistics and Information Department, Minister's Secretariat, Ministry of Health, Labour and Welfare). Estimates of median fertility and mortality from "Population Projections for Japan" (December 2006 estimates) (National Institute of Population and Social Security Research).

Figure 9 Future population pyramid comparison (2050)



Source: Estimates of median fertility and mortality from "Population Projections for Japan" (December 2006 estimates) (National Institute of Population and Social Security Research).



Source: United Nations (2009)

8) to cause an accelerated population decline. As the population growth is mainly determined by the difference between number of birth and death, if international migration is assumed to remain the same, Japan's population will begin to decline at an accelerating pace.

Though a decline in population generally will have extensive effects on the society and economy, the main issue for Japan is the rate of change at which it will occur. It will have to cope with an unprecedented speed of depopulation. Another even greater problem than rapid decline in population size will be the changes in various population structures, such as one in the age structure (or population aging in other words), and the regional structure (shift in population distribution over the land). Population aging in particular will destabilize the foundation of the social security systems that has long been relied on mutual supports between generations in the past³.

Nevertheless, while we must stay alert to the close connection between growth in longevity and population aging, they are distinct concepts and

thus may produce entirely opposite consequences depending on the situation. First, while growth in longevity is one cause for future population aging, the main cause for population aging is the decline in fertility. France, for instance, has enjoyed a high life expectancy similar to Japan, but the fertility rates are much higher in this society, as its current rate is near the replacement level while Japan stands at only two-thirds of the level. The difference become visible in the age composition of projected population in future (for instance, year 2050). While population aging is to advance at a marked rate in Japan, France is to maintain a relatively stable age composition even at that time (Figure 9).

In other words, however far longevity advances, population aging will tail off at a certain level and cease to advance any further as long as there is a sufficiently high fertility rate⁴. Many people believe that Japan's population aging is more prominent than other advanced nations because Japan has the world's highest life expectancy. However, that notion is completely

Table 2 Ages when 1955 and average remaining life expectancy are equal and changes in buffer years

(1) Average remaining life expectancy equivalents

Age in 1955	Age at which the life expectancy is equivalent to that in 1955 (year)							
	Male				Female			
	1980	2005	2030	2055	1980	2005	2030	2055
40	45.1	49.8	53.0	54.8	46.2	52.7	55.7	57.3
50	54.9	59.6	62.8	64.6	55.7	62.2	65.2	66.8
65	69.0	73.8	77.1	78.9	69.5	75.9	78.8	80.3
75	77.9	82.5	85.8	87.5	78.2	84.5	87.2	88.7
80	82.3	86.7	90.0	91.6	82.5	88.7	91.3	92.7
90	91.6	95.3	98.9	100.4	91.8	97.4	100.1	101.3

(2) Buffer years (=equivalent age minus age in 1955)

Age in 1955	Difference between the equivalent age in each year and age in 1955 and (year)							
	Male				Female			
	1980	2005	2030	2055	1980	2005	2030	2055
40	5.1	9.8	13.0	14.8	6.2	12.7	15.7	17.3
50	4.9	9.6	12.8	14.6	5.7	12.2	15.2	16.8
65	4.0	8.8	12.1	13.9	4.5	10.9	13.8	15.3
75	2.9	7.5	10.8	12.5	3.2	9.5	12.2	13.7
80	2.3	6.7	10.0	11.6	2.5	8.7	11.3	12.7
90	1.6	5.3	8.9	10.4	1.8	7.4	10.1	11.3

Source: Data from 2005 and before is from "Complete Life Table." Data for 2030 and 2055 is a tentative life table of death medians from "Future Population Projections (December 2006 projections)." All figures were calculated by applying a spline interpolation to the average remaining life expectancy function.

incorrect. As a comparison with France shows, there is clearly no need to regulate increases in longevity in order to prevent population aging. This is not the only reason why we should not mix up the longevity with population aging. Instead, we must understand that promoting longevity will actually serve to create policies for addressing a number of issues that population aging bring about. A rise in the average lifespan means that death will be delayed, but also that one's healthy condition will be prolonged. For instance, compared to elderly people in the past, the elderly people of today are much more healthy and active at the same age. This means that boosting longevity will allow for delaying the actual "old age" period of life.

It is possible to see this effect directly by using the healthy life expectancy index. Healthy life expectancy is the average number of years that people of a certain age are expected to live independently without losing their health due to some disability, such as disease or injury. This is used to express the average level of health of people of that age in a society. However, due to the difficulty of defining and measuring health, it is not easy to use this index to measure long-term changes in health condition. Demography, on the other hand, provides a substitute concept—age measured by average remaining lifetimes, or the life expectancy (Sanderson and Scherbov 2005). This is an age at which a person has same average remaining lifetime as that of a person in different generation. Let us use this barometer to trace the trends in the old-age period. The age at which old-age period starts as expressed by remaining lifetime equivalent to 65 year-old in 1955 has dramatically increased since then.

Table 2 (1) presents age data for several ages

between 40 and 90 years and the average remaining life expectancy equivalent ages in 1955 for four different target years. Looking at the age of 65, for example (underlined), you will see gender-based data for four target years where people's remaining life expectancy is the same as people that were 65 years old in 1955. For instance, if it were 2005 today, males age 73.8 and females age 75.9 would be the equivalent level of health as a 65-year-old was in 1955 (using average remaining life expectancy as a barometer). The lower table reveals that men and women both show a high number of buffer years as well, 8.8 and 10.9 respectively, so if we were to set the old-age period at 65 or older in 1955, the old-age period in 2005 would have this amount of buffer years. In other words, for this period of buffer years people will enjoy a level of health that is equivalent with those in the last phase of their productive years, and thus can be expected to handle the same level of activity.

Comparing equivalent ages of the start of the old-age period (65) using a time line shows us that, while there is market growth from the base year 1955 until 2005, that growth will become more gradual in the future and by 2055 both men and women will be around the age of 80 (78.9 for males and 80.3 for females).

Viewing these remaining life expectancy equivalent ages as the beginning of the old-age period, Table 3 presents calculations of the proportion of elderly and the old-age dependency ratio⁵. Those are, calculations of the true aging indices, which have been reduced using the health levels of each period of time.

The traditional type of the proportion elderly that fixes the old-age period as starting at the calendar age of 65 reaches 40.5% in 2055, however the

Table 3 Old-age population ratio and old-age population index of people with an average remaining life expectancy equivalent of 65 in 1955

Year	Proportion elderly (%)		Old-age dependency ratio (%)	
	Traditional	life expectancy equivalents (with year 1955)	Traditional	life expectancy equivalents (with year 1955)
1955	5.3	5.3	8.7	8.7
1980	9.1	6.2	13.5	8.8
1990	12.1	6.7	17.3	8.9
2005	20.2	9.2	30.5	11.9
2030	31.8	16.1	54.4	21.7
2055	40.5	19.6	79.4	27.3

Source: See Table 2 for calculations of average remaining life equivalents. Old-age population ratio and old-age population index was calculated by first calculating the remaining life equivalent old-age population in 1955 by gender. However, the beginning age of the production population is 15 years old.

new index that takes into consideration health level via average remaining life expectancy is 19.6%, or less than half that figure. Moreover, while the traditional type figure for the old-age dependency ratio stands at 79.4%, this is reduced to 27.3% after taking in to consideration improvements in health level via increased longevity. This means that while in the former case 1.3 people in their productive years will support 1 elderly person, in the latter case 3.7 people are available to support each elderly person. Using indices that take into consideration improvements in health level due to rises in longevity shows us a completely different picture of the imminent aging of Japan than we are used to seeing.

As rises in longevity serve to increase the number of people living until old age in the conventional way of examination, people tend to believe that expansion of longevity is the main cause of population aging, and that they are one and the same phenomenon. However, in actuality, it is the declining birth rate that first causes population aging to surpass the limit and keep advancing. Furthermore, rises in longevity help to control true population aging by boosting the health levels of the elderly population, which in turn serves to mitigate the many issues engendered by such aging. Therefore, while this may seem paradoxical, advancing increases in longevity is an effective way, and a necessary means, to overcome population aging.

VI Summary and Conclusion

This paper first traced the historical process of the rise in longevity, or the “longevity revolution.” This was the process of so called the epidemiologic transition—the conquest of infectious diseases and the resulting dramatic improvement in survival probability. The epidemiologic transition completely altered the lifecycles of humans, inevitably changing the society and economy. We focused on the course of the rise in longevity in Japan, as the epidemiologic transition took place at an extremely rapid rate there and the country has maintained the world’s highest life expectancy since the 1980s.

The rise in life expectancy that resulted from the epidemiologic transition 1) set off the demographic transition, 2) reduced social uncertainty and promoted an efficacious economy and society, 3) changed the individual lifecycle, and 4) contributed to the aging of the population. There is no question that these are the comprehensive socioeconomic changes that we refer to as “modernization.” Moreover, the shortening of the child-bearing and child-rearing stages are bringing about

the next phase of social fluctuations— diversification of the female life course and associated declining birth rate which may be the response to a delay in the adaptation of social systems to the new situation. As a consequence, the population is shrinking and aging precipitously.

Currently, there is an apparent decline in the mortality rate in most advanced nations that takes the form of delayed death from degenerative disease (or lifestyle related disease) in the elderly. As a result, the average life expectancy continues to grow in these countries. The current delay in death due to degenerative disease is forecasted to continue for quite some time, as a result of promotion in primary prevention—proactive improvements to lifestyle habits, etc.—and in secondary prevention—early detection and treatment by improving medical checkups, etc. At the same time, we are now beginning to see the possibility of allegro extension of life expectancy due to the inhibition of senescence via the advanced treatment methods for malignant neoplasm (cancer) and other revolutionary medical technologies, such as regenerative medicine and gene therapy.

On the other hand, the recent emergence of new infectious diseases and the reemergence of old infectious diseases have the potential risk of deterring longevity growth. It is also unrealistic to ignore the effects of socioeconomic factors, such as the weakening of the medical care and health structure as a result of national financial difficulties and expanding income inequality in society. It is not possible to continue extending life expectancy without also stabilizing and developing the national economy.

In the near future, Japan will experience an upsurge of deaths that have been postponed due to past growth in longevity (put differently, due to population aging). Coupled with the declining births, this will create a largely negative natural increase in population and fostering population aging. These population trends are expected to cause a wide range of difficulties, including the shrinking of the consumer and labor markets and unbalancing of the current social security system. Nevertheless, the common belief that growth in longevity is what causes population aging, or that it escalates the problem of population aging, is false. First, it is the decline in birth rate (low fertility rates that fall far below population replacement levels) that causes the decline in population and pushes population aging. Second, growing longevity serves to expand the amount of human resources in society and contribute to socioeconomic development by boosting the level of health of the elderly population. It is not inadequate to

assess the true complexion of the aging society by evaluating the fraction of elderly people as defined by calendar age. For example, the age at which the average remaining life expectancy was equal to that of people who were age 65 in 1955 was 73.8 for males and 75.9 for females in 2005, and it is projected to be 78.9 for males and 80.3 for females in 2055. If the word "elderly person" is used to refer to those defined by these ages, the number of working people to support each elderly person in 2055 will change from 1.3, which is the figure when using the conventional definition, to 3.7. In order to address the issues of an aging society in Japan, which has the highest rate of population aging in the world, the only thing to do is to utilize the merits of the world's greatest longevity itself. However, in order to do that it is necessary to promote longevity growth in accordance with rises in healthy life expectancy, and that will in turn require the development of technology and socioeconomic infrastructure to make it effective at all.

After the Second World War, Japan achieved a high level of economic growth along with the world's highest life expectancy. However, the growth in longevity that Japan has achieved is largely due to the application of existing technologies developed by the other developed countries. It seems difficult to overcome the issues that Japan is to face in the future using the existing technologies and the present social systems. The society's true wisdom has yet to be tested in its fight to boost national health and longevity and overcome the challenges therein by creating innovative technologies and insights.

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Notes

- 1) Representative examples of model life tables include the Coale-Demeny regional model life table and the Brass Logit life table system (Coale and Demeny 1983, Brass 1978). Refer to Preston et al. (2001) for commentary on these models.
- 2) "Secondary prevention," on the other hand, refers to the early detection and treatment of health problems through health checkups and other means.
- 3) For more information about forecasts of future population decline, population aging, and their respective impacts on the economy and social structure, refer to the Ministry of Health, Labour and Welfare (2006), Tsuya and Higuchi (2009), etc.
- 4) For instance, if the fertility rate is at the population replacement level, population size and age structure will both remain stable for the long-term.
- 5) The old-age population index uses equivalent age (old-age population divided by productive age population) to calculate productive age and the boundaries of old age. However, the age of 15 is fixed as the starting age for the productive population.