Japan's Demographic-Momentum on a Deflationary Spiral Tracing a Path toward Extinction: Ecological Economics of a Declining Population

ABSTRACT

In the future, Japan will suffer an accelerating decrease of the population, which is predicted by a demographic report of the National Institute of Population and Social Security Research (IPSS). The authors have reanalyzed this issue from a viewpoint of ecological economics and resource statistics and have come to confirm that the results of IPSS indicate Japan's population to have entered an "extinction mode".

An economic situation called "deflationary spiral" means a vicious cycle in which a decline in income levels causes a general price reduction and this reduction causes a further decline in income levels. In Japan, there is [illegible]ng on a cycle of this kind that a population decrease leads to a socio-economic contraction, which in turn will cause a further decrease in population. Such a situation can be called a "deflationary spiral of population". This research treats this population down-spiral in Japan with an analytical approach considerably different from the usual demography.

In the meantime, some UN statistics shows that Asian countries are highly liable to face a population decline, which may realize, following Japan, after some decades toward the end of the 21[illegible]entury. We would like to show that Japan's case can provide an effective and forward-looking suggestion for these countries.

Keywords: Declining Population, Demographic-Momentum, Hubbert function, Logistic function,

1.THE BACKGROUND AND THE PURPOSE OF THIS RESEARCH

Japan *'is entering an uncharted societal stage of perpetual population declining, after achieving the world's longest life expectancy'*. [1]

We do not know how far this fact is recognized worldwide; however, the population-dynamical prediction of the National Institute of Population and Social Security Research (IPSS) shows an objective estimation of harsh Japanese population decline. (Fig.1)

The IPSS says that *"As in the previous projections, the cohort component method is used for the Population Projections for Japan. This is a method of projecting the future population of each age- and sex-specific group according to assumptions about three components of population change, namely fertility, mortality, and migration"* [2] ; where 'cohort' means, in their estimation, a birth cohort born in the same year (a cohort in general means a group that shares demographic events such as birth or marriage at the same time).

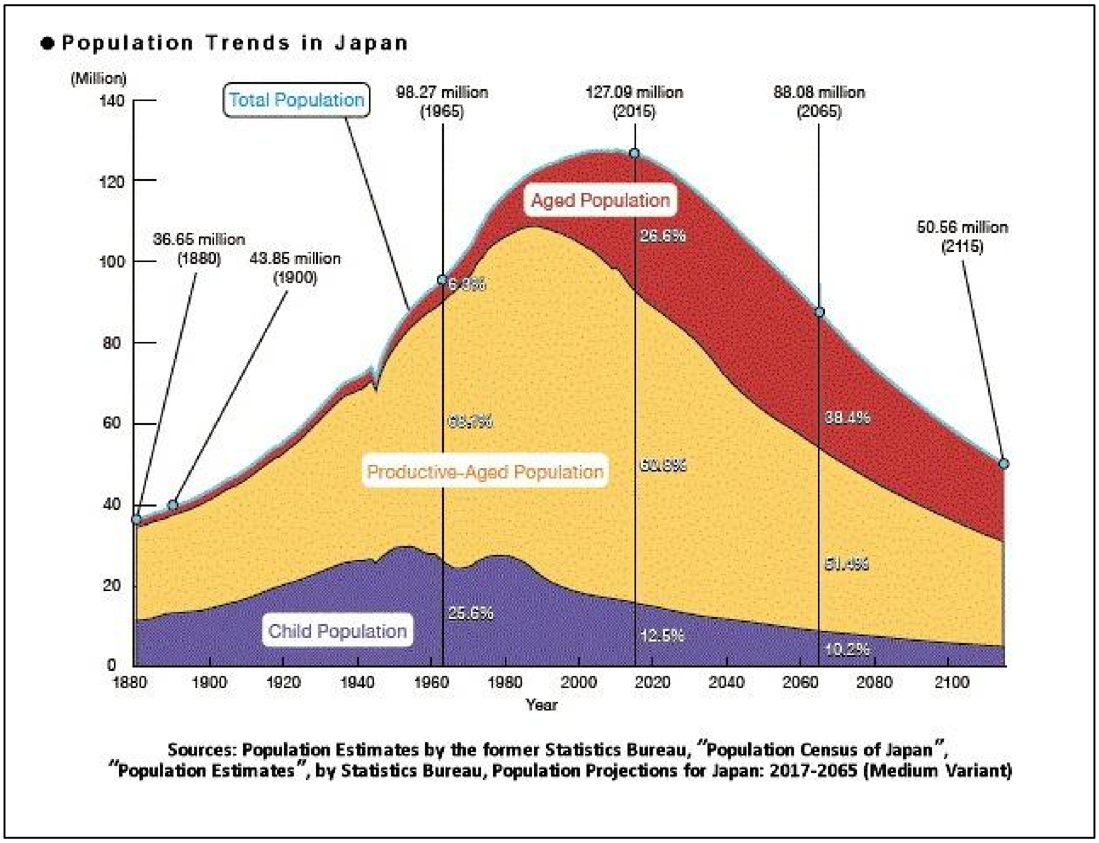

Figure 1. Population Trends in Japan Source: [3]

Estimation of future populations is also called "population projection" because it calculates population trends from the past to the present and 'projects' the results for the future, by setting certain adequate assumptions. The simplest way of population projection is a "function fitting method" which applies a mathematical function to express the trend of the population in the past. However, IPSS does not adopt this method seemingly because they cannot find an appropriate function to fit the hill-shaped curve. Indeed, the population curve of Japan does not conform either to the exponential function (to rise ever acceleratingly) or to the logistic function (to saturate asymptotically).

On dealing with a function curve to show a hill-like shape, what comes first to mind would be a normal distribution curve; however, there is another important case, “the Hubbert function” especially in the field of resource statistics and ecological economics.

We have come aware that the curve in Fig.1 be very similar to the "Hubbert function". Therefore, we tried to apply this function to a sequence of <the past population transition and the population projection> by IPSS (on the cohort factor method). Let us examine this assumption.

2. JAPAN'S DEMOGRAPHIC DYNAMICS TO REGRESS TO A HUBBERT CURVE

The Hubbert function is a formula originally used by M. King=Hubbert to describe production of exhaustible resources, specifically to show trends of oil and coal production in the mainland United States. Although this mathematical equation itself has been known as "the first derivative of logistic function" from a long time ago, it is Hubbert who utilized this function systematically in the context of growth theory or growth limit theory. The naming as "Hubbert curve or function" comes from his theoretical achievement.

The Hubbert curve basically represents a transition of "annual productions" of exhaustible resources. He predicted in 1956 that the crude oil production in the southern US would follow a bell-shaped curve and that it would reach a peak in the late 1960s (Fig.2). The subsequent production of crude oil in the United States had nearly reconfirmed Hubbert's prediction and his analysis was accepted as the first theoretical accomplishment for forecasting resource productions.

He assumed that cumulative production of fossil fuels (≦ the ultimate reserves) should generally follow the logistic function, and therefore their annual production could be estimated by its differential.

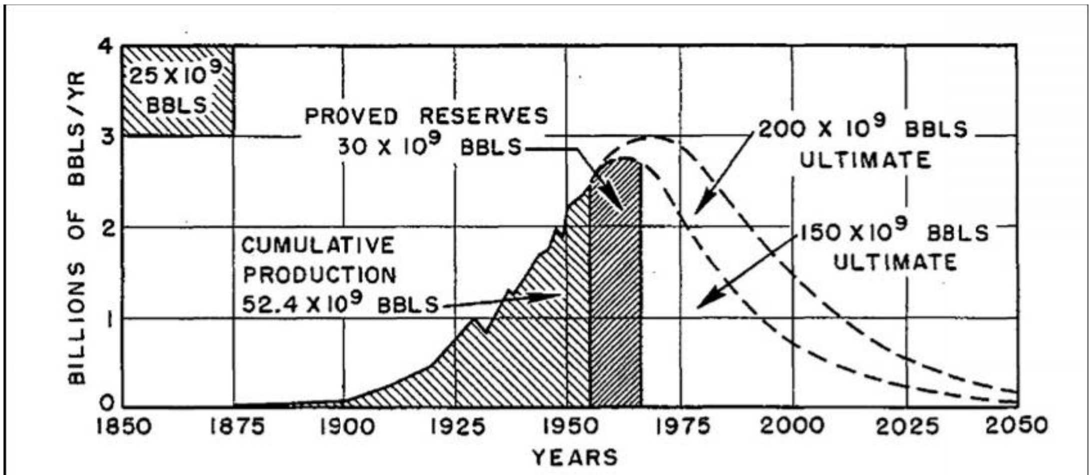

Figure 21 – Ultimate United States crude-oil production based on assumed initial reserves of 150 and 200 billion barrels.

Figure 2. Estimation of M. K. Hubbert Source: [4]

If the time and the height of the vertex and the point corresponding to the half of the vertex height can be determined, these points can designate the Hubbert function parameters. The population of Japan reached its peak at 128,084 thousand in 2008. The half of the peak value was 64,400 thousand. This population lies halfway between in 1929 (63,461 thousand) and in1930 (64,450 thousand) and the half-peak point can be assigned approximately to 1929.5. The time interval between 1929.5 and 2008 is 78.5 years.

We tried to derive the exponential coefficient of the Hubbert function under this condition (see Appendix for details). Together with Japan's population dynamics, we draw the curve at the top of in 2008, between in 2115 (the IPSS's research forecast, it is 107 years ahead from 2008) and in 1901 (107 years before from 2008).

Next, the real population from 1901 to 2015 is plotted as it is; and after that, the closest values among the estimated values of the nine types denoted by the IPSS (Table 1) are plotted we extended it until 2115.

Table 1. Nine Types Suggested by the IPSS

	Fertility		
(Mortality)	Low-fertility (Low-mortality)	Medium-fertility (Low-mortality)	High-fertility (Low-mortality)
	Low-fertility (Medium-mortality)	Medium-fertility (Medium-mortality)	High-fertility (Medium-mortality)
	Low-fertility (High-mortality)	Medium-fertility (High-mortality)	High-fertility (High-mortality)
Projection	Low Variant	Medium Variant	High Variant

Figure 3 shows the superimposition of the regressed Hubbert function and the IPSS data close to the former.

The demographic dynamics of our country is confirmed clearly to have regressed to the Hubbert curve from the past to the future. It may be said that the future part of the Hubbert curve approximately suggests the most probable values (maximum likelihood) out of the nine estimates by IPSS.

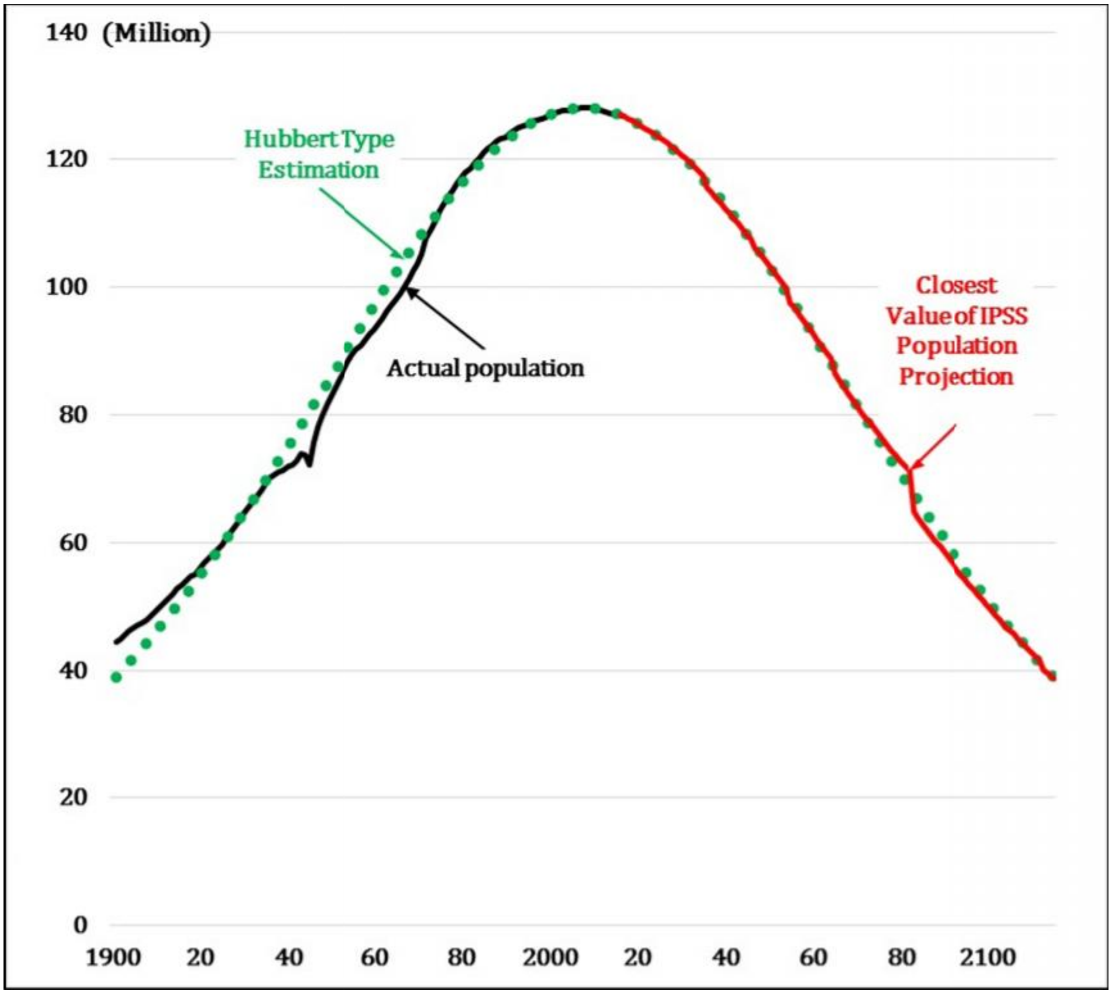

Figure 3. Regression of the Population Trends to the Hubert Type Estimation

3. THE HUBBERT THEORY

What is the Hubbert function and how is it different from the conventional growth function? This is shown in brief in Fig. 4 below.

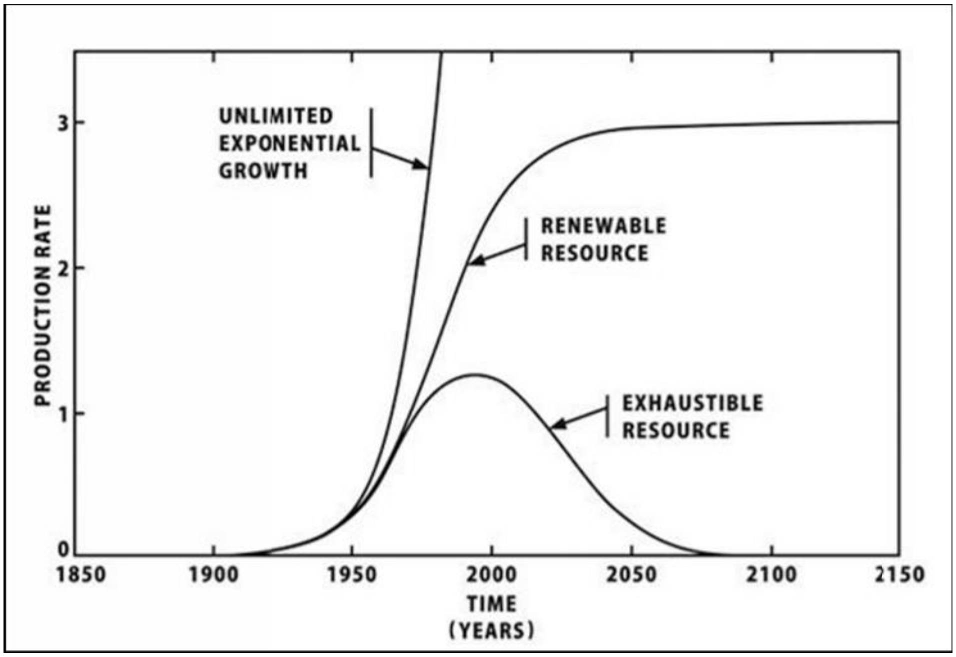

Figure 4. The type of growth Source: [5]

In the Fig. 4, the curve of "unlimited exponential growth" is an exponential function, the curve of "renewable resource" is a logistic function, and the curve of "exhaustible resource" is the time derivative of the logistic function (the Hubbert function).

As seen clearly from this figure, both the exponential function (the first type) and the logistic function (the second type) are monotonically increasing, and essentially express an aspect of perpetual growth. Only the function of the third kind can express a trend toward a decrease through the peak.

Growth = increase had been predominant in the past human culture. Therefore, the first and the second type alone are recognized, and discussion of growth rate has been deemed sufficient to argue, where the highest rate corresponds to an exponential function and the lowest rate, to a logistic function.

In contrast, Hubbert insisted that the third type, an <increase/peak/decrease> mode should also be included in the group of "growth patterns" (secular changes). And he proved that infinite growth (exponential type) is only a temporary/transient phenomenon in human history.

As far as we deal with a process of growth, we can presuppose that the growth curve will neither exceed the exponential function, nor fall below the logistic function. If all the growth patterns that could happen have to fall in between the two curves, to deal with ~~the~~ both sides would be sufficient. By the way, even a Hubbert curve of the third kind shows a sharp increase for a considerable period (e.g., in Japan’s population, until the latter half of 20th century), like the first and the second type. In other words, during this period we cannot tell which of these three courses represent the actual growth trajectory. Hubbert had recognized this complex situation from the beginning. Therefore, he pointed out that, transitionally, an exponential growth would seem to be a general phenomenon.

However, Hubbert's initial indication was released at the heyday of the “infinite growth” theory. As a result, his pioneering research was severely reproached or neglected by the then mainstream economists; his theory had been pushed into a corner of an academic journal.

Reevaluation of Hubbert in earnest began when the "peak oil" was recognized as a real problem in the 21st century.

4. WHY DOES JAPAN'S POPULATION DYNAMICS DRAW THE HUBBERT CURVE?

Then why do Japan's population dynamics follow the Hubbert curve? What mechanism has caused this phenomenon? This is a difficult question so hard to solve. Tentatively, it might be considered as follows.

First, consider one birth cohort, for example the generation born in 1955 (population group). Perhaps the cumulative number of children whose would-be mothers were born that year will start to rise from around 15 years later (1970), will peak at around 30 years later (1985), and will draw a logistic curve with a ceiling at about 40 years later. If so, the number of annual births will be on the Hubbert curve. On the other hand, the cumulative number of deaths of the people who were born in the same 1955 will begin to rise from the age of 70 (i.e., 2025), will be accelerated around the age 80 to 85, and will draw a logistic curve ending at about 95 years old. If so, the annual number of deaths will also follow the Hubbert curve. Naturally, every cohort will show the same trend.

However, if and only if a cohort can reproduce a next generation greater than itself, the birth trend and the mortality trend will be offset, and exhaustion will not occur. But, since this depletion offsetting has been lost in the present Japan, the trend of the total population comprising all the generations also seems to follow the Hubbert curve.

Here, the number of newborn babies has decisive significance for either case of the increase or the decrease. On the left side of the Hubbert curve (increasing phase), it will determine an increasing trend. And next, the vertex becomes broad because of the prolonged lifetime. After that, on the right side of the Hubbert curve (decreasing phase), the increasing death of the generation, who once took up the population increase, dominates the decreasing trend.

5. WHAT MEANS THE POPULATION DYNAMICS FOLLOWS THE HUBBERT CURVE

The Logistic curve to express the logistic function of Verhulst and the Hubbert curve, the derivative of the logistic function, have different meanings for renewable resources versus for exhaustible resources.

In the case of renewable resources, the [Logistic curve] shows the "proliferation potential" under a constant reproductive condition, therefore its derivative, [Hubbert curve], represents "annual proliferation amount possible". However, it does not mean that the proliferation be unilateral along the time axis. The proliferation never goes out of the [Logistic curve] trajectory, but the movement is reversible, and it is possible to go backward. When collecting biological resources such as blue fin tuna, as far as the growth (supply) and the collection (consumption) are balanced, the state can be sustained (steady state) and will remain at a certain point on the logistic curve. Although the curve form under constraints should bring a growth saturation (gradual decrease in growth), it will not result in reproduction shrinkage. This situation should apply also to the human population, which in principle belongs to a "renewable resource" as a kind of biological resources.

In contrast, in the case of exhaustible resources, there can be no "proliferation"; there is only "withdrawal - attenuation/depletion" of resource reserve. Therefore, the Logistic curve shows a unilateral time transition of the "cumulative output" (under a given state of technology). The differential [Hubbert curve] represents "an amount that can be redeemed annually" and proceeds unilaterally and irreversibly to the right side on its track as far as the withdrawal (mining) continues. For this reason, unilateral contraction is inevitable after the peak. Even if the pace might slow down, the reducing trend of annual output will remain firmly rigid.

The population of Japan should be, intrinsically, a "renewable resource" (an attribute common to all living things). Therefore, the growth trajectory of the population should be on the [Logistic curve]. However, the actual population of Japan deviates far below this orbit; and it fits perfectly for the [Hubbert curve] that peaked at 128,084 thousand people in 2008.

What does the [Hubbert curve] mean at the stage of beginning and acceleration of the resource decrease? It represents, for example, an annual output of an aging oil field or a coal field past one’s heyday. It is a stage where the annual output declines steadily as the residual reserve decreases. Ultimately, the "Hubbert curve" at this stage represents the route leading to resources depletion/extinction.

The fact that the population transition of Japan matches this function means that the total population runs on an "orbit to depletion". Unless the population trend can escape from this route, the end will be “extinction.”

Furthermore, the Hubbert curve is determined mechanically from the statistics of population transition. In other words, it does not allow arbitrary operations such as "optimistic outlook" by taking into consideration factors for example "improving birthrate".

Even if the total fertility rate of the current 0-year-old children can recover the replacement level immediately, yet it will be around 20 to 40 years later that the actual decrease trend become moderate and the total population move toward a steady state: the time when the newborn women will reach child bearing ages.

Anyway, the fact that the population dynamics of Japan is on the Hubbert function is 'astonishing' at all events. This cruel fact compels us again to recognize that each cohort is an "exhaustible resource" in the sense that everyone dies sooner or later.

Moreover, unlike underground resources such as fossil fuels or minerals, the "exhaustible resources" of population does not accept any artificial control like "resource conservation". After passing the peak, it will proceed irreversibly toward shrinkage. Population decline is a "confirmed future".

This population trend seems not limited to Japan alone. Many other countries are falling into the same situation. Let us see it in the following.

6. JAPAN'S POPULATION PROBLEMS TO PRECEDE THE WORLDWIDE CIRCUMSTANCES

Inaba [1] introduced that, according to C. Wilson and G. Pison (2004), [6] half of the world's population by 2003 lived in countries where the average birthrate per woman is less than 2.1. Considering this, Inaba [2008] said that *‘The level of Total Fertility Rate (TFR) of 2.1 is the population replacement level that allows for simple reproduction of the population in developed countries. In higher death rate countries, it is impossible to simple reproduction on the levels. Therefore, now more than half of the world people live in a low-birthrate society that cannot hold a simple reproduction". Furthermore, he commented that “we have an estimate that the probability that the world population will reach a negative growth rate by the end of the 21st century is about 80%’*. [7]

The United Nations has released estimates that will back it up. First, let's see what the population trends of the world's largest population from 1st to 3rd, China, India and the United States. (FIG. 5)

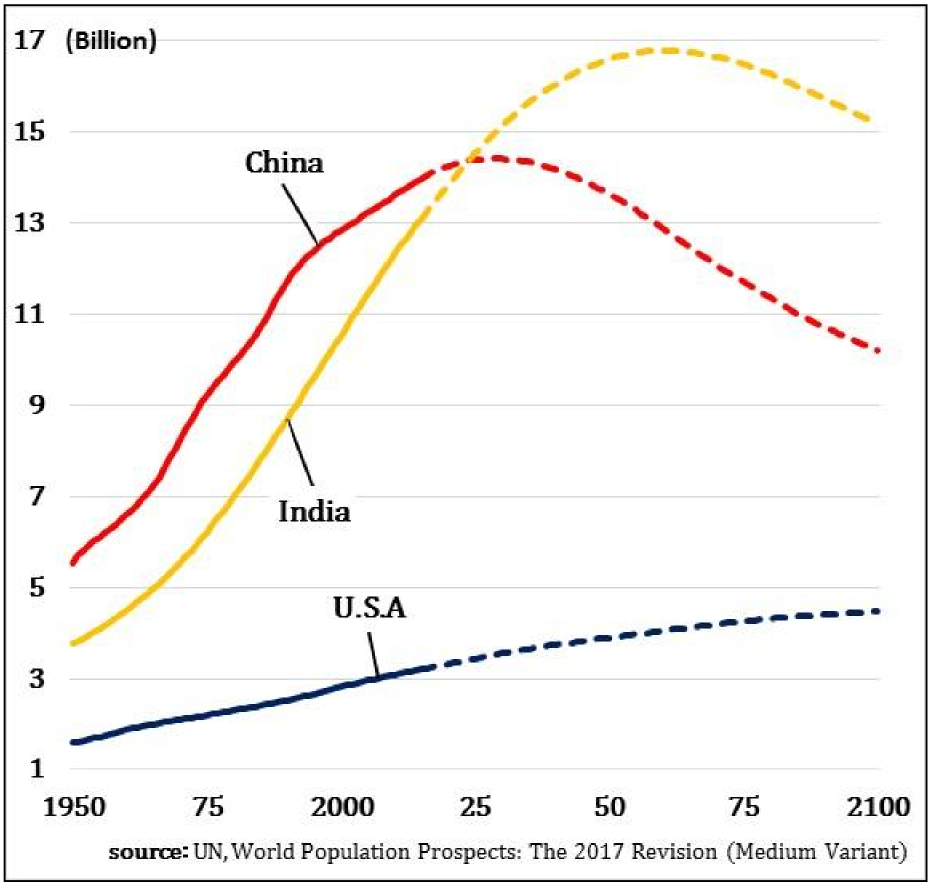

Figure 5. Demographic Dynamics Forecast for China, India, and U.S.A Source: UN data [8] adapted by the authors.

It is estimated that China will reach the population peak (1.44 billion people) by 2030, when China will give the top position to India, and the population will shrink down to 1.02 billion in 2100. Also, it is estimated that India will reach 1.68 billion people by around 2060 but will decline to 1.52 billion at the end of the century.

In contrast to both countries, the US is estimated that its population of 320 million in 2015 will continue to grow steadily to 450 million in end of 21st century.

Next, let's look at the trends of the countries of about 100 million to 250 million people as of 2015. (FIG. 6)

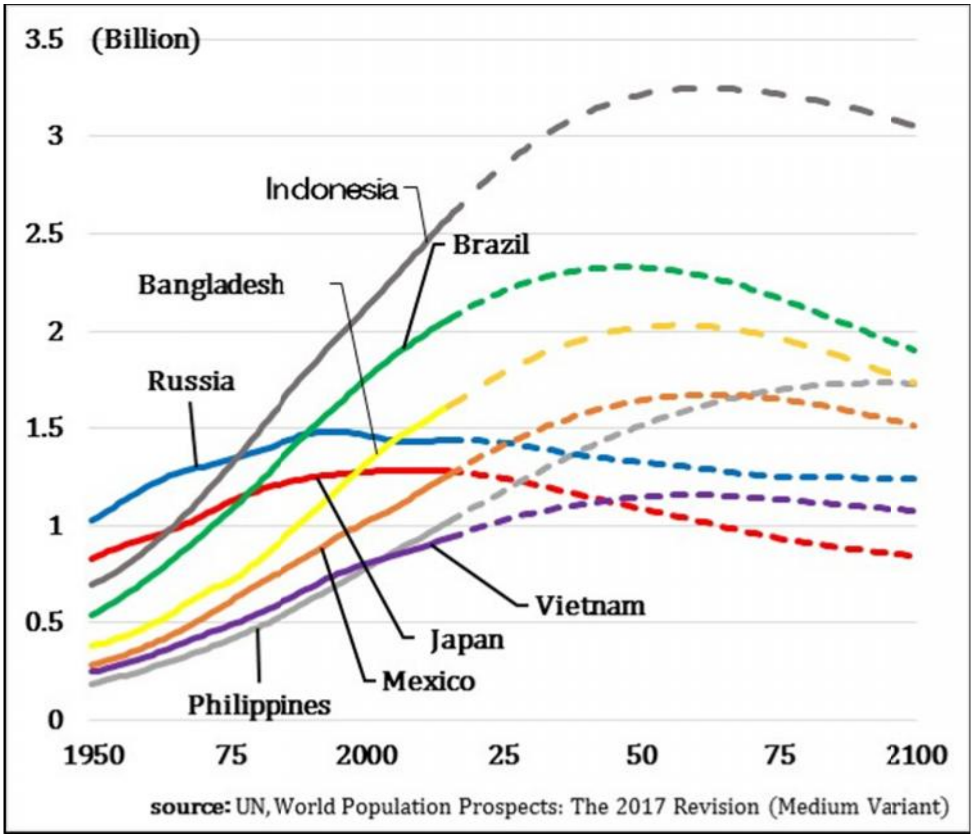

Figure 6. Demographic Dynamics Forecast for Countries with Population over 100 Million Source: UN data [8] adapted by the authors.

The sharp decline in Japan stands out, but also other countries' population will begin to decrease after reaching a peak, similarly to Japan.

Finally, we will list the trends of the countries with a population of less than 100 million as of 2015. (FIG. 7)

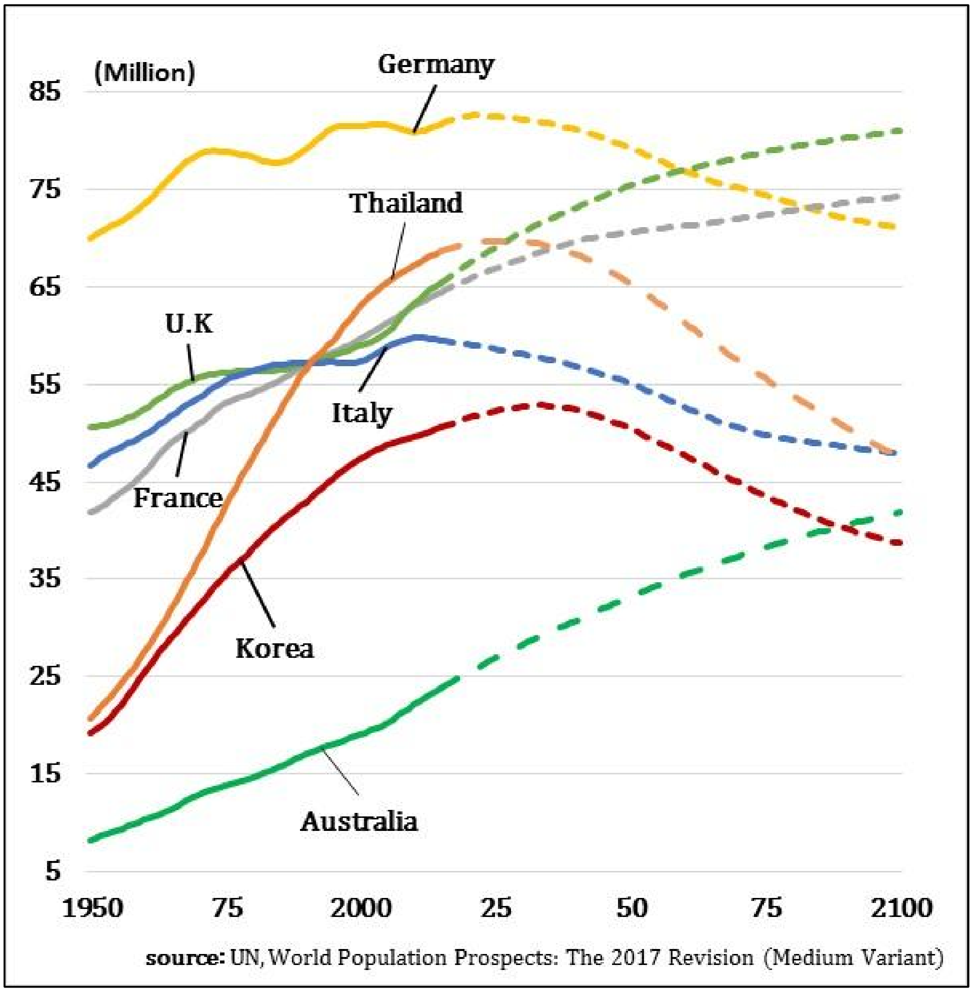

Figure 7. Demographic Dynamics Forecast for Countries with Population under 100 Million Source: UN data [8] adapted by the authors.

It clearly turns out that Germany, Italy, Thailand and Korea are on the same population transition curve as that of Japan.

By comparison, it is definite that a certain exceptional country which actively accept immigrants and aim for a multiethnic state, such as the United States, France, the UK and Australia, can alone maintain population growth.

We can learn, from these countries, one countermeasure against population reduction: i.e. "social increase" by immigration, however, cannot hold forever because emigrating countries are also facing population decline. After all, to keep the population steady, it is essential for each cohort including immigrants and their successors to achieve population-replacing fertility rate. In addition, the factor of "social increase" by immigration sustains basically the population increase of immigrant countries. When the population decline begins in the supplying countries, the immigrant population will also decrease greatly.

Anyway, it is highly possible that many countries, including China, India and other Asian countries, will follow Japan's population transition. Japan's population problem should be considered as a clear and grave precursor.

8. CONCLUSION

In the field of demography, the concept of [population momentum] is generally accepted. To be brief, it is <a virtual equilibrium population ÷ the current population>. It is defined as: “the ratio of the population level to which the [virtual population transition] ultimately quiesces to the current population level on the assumption that the birthrate be immediately recovered to population replacement level (death rate is constant, international migration movement is zero)”. In other words, it is understood that "it represents a kind of inertia that a population structure of a certain point keeps increasing/decreasing its total population". [9]

In this research, we analyzed past trends of the population of our country and forecasted the future by using the ecological economics approach. As a result, we confirmed what the population decline rate in Japan will increase from the current 0.1% or 0.2% to 0.5% in the 2030s, 0.7% to 0.8% in the 2040s and over 1% in the 2050s, and we can regard that "population momentum in Japan is entering extinction mode".

The purpose of this research is to verify the "nearly confirmed future" of the population trend projected by IPSS by a statistical approach different from traditional demographics. We think that the purpose has largely been achieved.

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APPENDIX

Logistic Function and Hubbert Function

As mentioned in the main text, the Hubbert function is the derivative of the logistic function, which was devised by P. F. Verhulst as follows. In 1798, Thomas Robert Malthus pointed out in his population theory that population would increase exponentially in principle. However, there are constraints by the environment and resources, which would prevent any infinite increase: as the population increases, the rate of increase would decrease, resulting finally in population saturation. Verhulst treated this problem analytically and came to devise his "logistic equation" to model a population growth of creatures.

If N is the number of current individuals; K, the number of individuals ultimately sustainable in the given environment; and a, the growth rate coefficient; then, the rate of population increases, ${}^{\mathrm{d}N}/_{\mathrm{d}t}$, is to be expressed by the following equation.

$$\frac{\mathrm{d}N}{\mathrm{d}t} = aN\left(\frac{K-N}{K}\right)$$

The right side = the rate of increase consists of [aN : a growth rate proportional to N, a positive feedback term] and [$(K-N)/K$: an indicator of the environmental allowance to afford the population to grow up to the breeding age, a negative feedback term].

If one divides the both sides of this equation by K, set $y = N/K$, and $a = 1$, one obtains a normalized form of the logistic equation:

$$\frac{\mathrm{d}y}{\mathrm{d}t} = y(1-y) = y - y^2$$

The solution will be:

$$y = \frac{1}{(1+\exp(-t))}$$

If this expression is multiplied by ${}^{\exp(t)}/_{\exp(t)}$, the result is:

$$y = \frac{\exp(t)}{(1+\exp(t))}$$

This equation will be illustrated as follows:

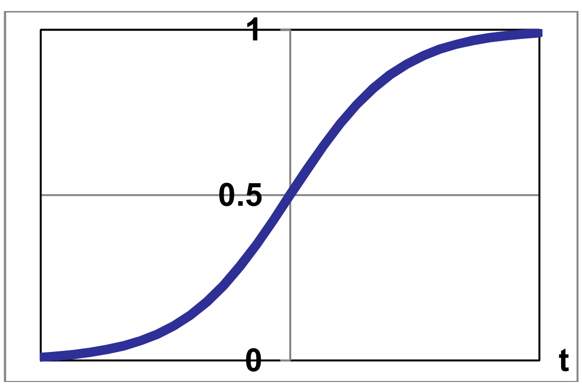

Figure A.

This is like the curve (logistic function) in the middle of Fig. 4 of the main text, in its normalized form.

Further, the derivative of this equation with time *t* is the normalized Hubbert function:

$$\frac{dy}{dt} = \frac{\exp(t)}{(1+\exp(t))^2}$$

This equation will be illustrated as seen below:

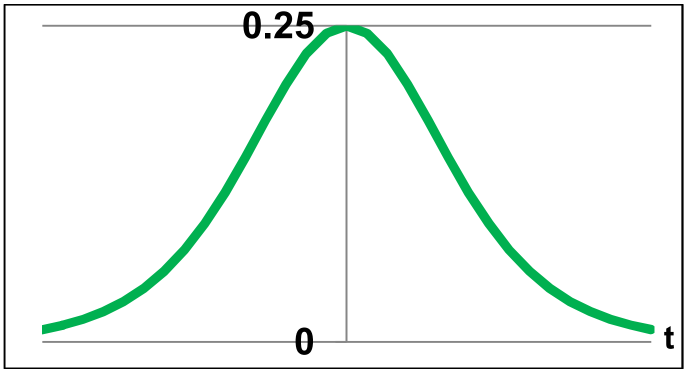

Figure B

This is like the curve (Hubbert function) in Fig. 2 of the main text, in the normalized form.

Since Hubbert's theory has been explained in the main text, here we supplement a mathematical interpretation of the Hubbert function.

As already mentioned, the Hubert function is a derivative of the logistic function:

$$\mathrm{h(t)} = \frac{K\exp(-\alpha t)}{(1+\exp(-\alpha t))^2}$$

The parameters *K* and α can be directly read from the actual data (tables and graphs). Let us regress these actual demographic dynamics of Japan to the Hubbert curve in reference to the above formula.

The population of Japan reached its peaked 128,084 thousand people in 2008.

This corresponds to the peak value h (0) of the Hubbert function h (t). This is,

$$\mathrm{h(0)} = \frac{K}{4} = 1.28[\mathrm{Billion}] \;\square\; K = 1.28 \times 4[\mathrm{Billion}]$$

This coefficient *K* is determined by the function value at *t* = 0, independently of the coefficient α, the time factor; and corresponds to the height of the Hubbert curve (the size in the vertical direction).

On the other hand, the time coefficient α determines the breadth of the curve (the horizontal size). There is a simple method for estimating the α; of which the first step is to find a time point *t* at which the function value h(*t*) becomes the half of the peak value (= the half height value).

The half of the maximum population, 128,084 thousand people, is 64,042 thousand: this population lies just midway between 63,461 thousand in 1929 and 64,450 thousand in 1930, therefore, the half maximum population may correspond to the population in 1929.5. Thus, the distance u (= half value width) from the peak year can be estimated as:

$$\mathrm{u} = 1929.5[\mathrm{year}] - 2008[\text{the peak year}] = -78.5[\mathrm{years}]$$

$$\mathrm{h}(-78.5) = \mathrm{h(0)}/_2 = K/_8 = K\mathrm{h}_0(\tau)$$

Here,

$$\frac{\exp(\tau)}{\left(1+\exp(\tau)\right)^2} = \frac{1}{8}$$

To solve $\exp(\tau)$, one can substitute x for $\exp(\tau)$ to obtain:

$$\frac{x}{(1+x)^2} = \frac{1}{8}$$

$$\square\ 8x = (1-x)^2 = 1 + 2x + x^2$$

$$\square\ x^2 - 6x + 1 = (x-3)^2 - 8 = 0$$

$$(x-3)^2 = 8 = \left(\pm\sqrt{8}\right)^2 \rightarrow \quad (x-3) = \pm\sqrt{8} = 2\sqrt{2}$$

$$x = 3 \pm 2\sqrt{2} = \exp(\tau)$$

This τ must satisfy the formula: $\tau = \ln(3 \pm 2\sqrt{2})$

(It is enough to take one of + or -)

Here, this constant τ for $1/_8 = h_0(\tau)$ is an informative factor to represent the half width of the normalized Hubbert curve.

By directly assigning $t = -78.5$ to the Hubbert function h(t),

$$h(-78.5) = \frac{K\exp(78.5\alpha)}{\left(1+\exp(78.5\alpha)\right)^2} = K/_8$$

On the other hand, the function value on the normalized Hubbert curve at t = τ is,

$$h_0(\tau) = \frac{\exp(\tau)}{\left(1+\exp(\tau)\right)^2} = 1/_8$$

A comparison of the numerator and the denominator of the above two formulas will give,

$$78.4\alpha = \tau \quad \square \quad \tau = \ln\left(3+2\sqrt{2}\right), \quad \text{i.e.,} \quad 78.4\alpha = \ln\left(3+2\sqrt{2}\right)$$

Therefore,

$$\alpha = \frac{\ln\left(3+2\sqrt{2}\right)}{78.5} = 0.022455$$

Although this value of α is estimated by a simplified method by using the half-value width, the h (t) curve (calculated value) using this α correlates to the actual demographic dynamics with high accuracy (Fig. C).

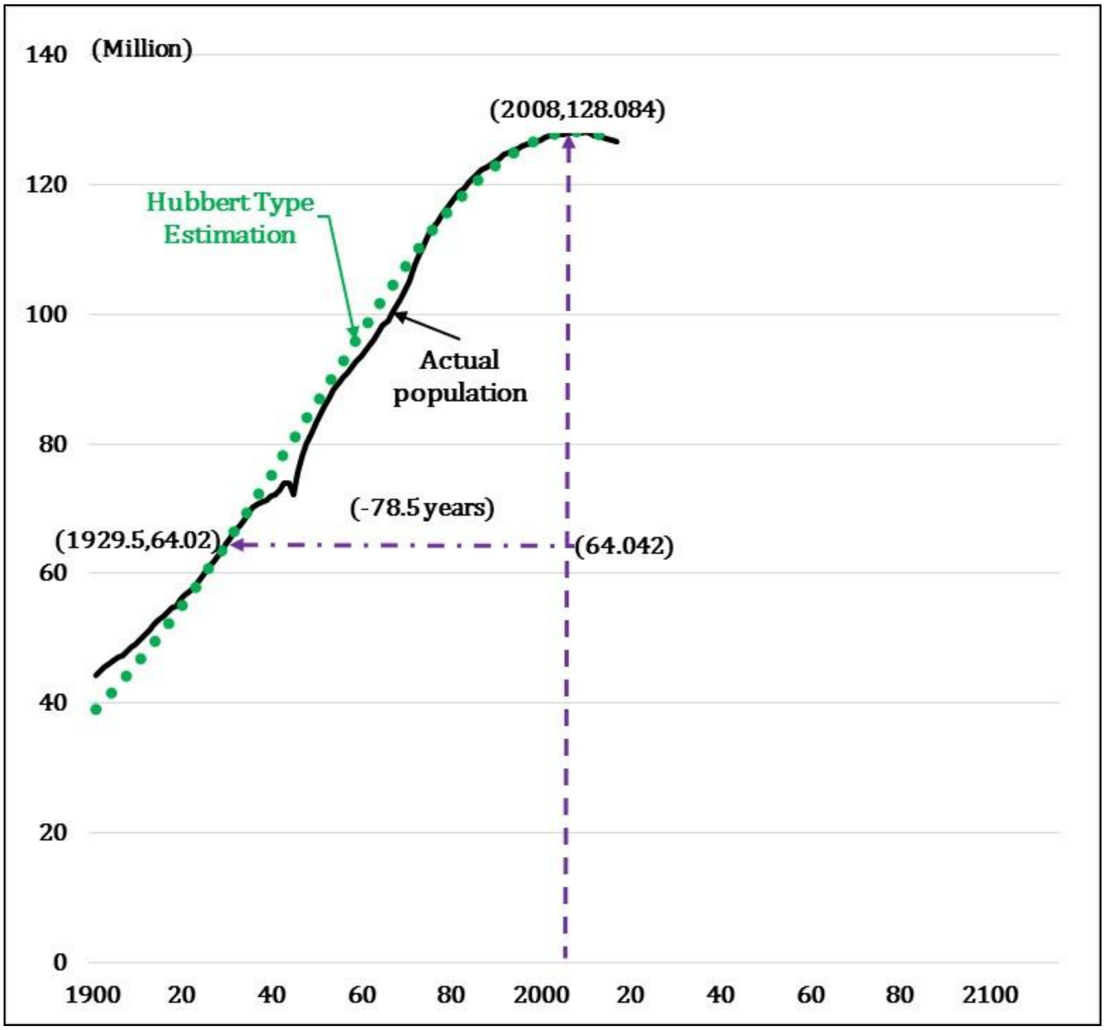

Figure C

Some supplements to Figure C:

The observation period: 1901 - 2015, Data points: $n = 114$

The correlation coefficient between the data and the calculated values is: $r = 0.99478$

The correlation coefficient after the correction for the degree of freedom (= 2) will be:

$Q = 0.99469$

Formula for correcting the degree of freedom is:

$$Q^2 = 1-(1-r^2)(n-1)/(n-2) = r^2-(1-r^2)/(n-2)$$

The correlation coefficient (> 0.99) is highly accurate in the descriptive statistics. Therefore, further adjustment (optimization) of α value will be unnecessary. In fact, if we try to minimize the squared deviation of (actual value - computed value) for optimization, it must bring the anomalous phenomenon of population decline during World War II into the theoretical equation, which should rather be arrested.