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Demographic Consequences of Defeating Aging

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Abstract

A common objection against starting a large-scale biomedical war on aging is the fear of catastrophic population consequences (overpopulation). This fear is only exacerbated by the fact that no detailed demographic projections for radical life extension scenario have been conducted so far. This study explores different demographic scenarios and population projections, in order to clarify what could be the demographic consequences of a successful biomedical war on aging. A general conclusion of this study is that population changes are surprisingly slow in their response to a dramatic life extension. For example, we applied the cohort-component method of population projections to 2005 Swedish population for several scenarios of life extension and a fertility schedule observed in 2005. Even for very long 100-year projection horizon, with the most radical life extension scenario (assuming no aging at all after age 60), the total population increases by 22% only (from 9.1 to 11.0 million). Moreover, if some members of society reject to use new anti-aging technologies for some religious or any other reasons (inconvenience, non-compliance, fear of side effects, costs, etc.), then the total population size may even decrease over time. Thus, even in the case of the most radical life extension scenario, population growth could be relatively slow and may not necessarily lead to overpopulation. Therefore, the real concerns should be placed not on the threat of catastrophic population consequences (overpopulation), but rather on such potential obstacles to a success of biomedical war on aging, as scientific, organizational, and financial limitations.

Introduction

A common objection against starting a large-scale biomedical war on aging is the fear of catastrophic population consequences, i.e., overpopulation. This fear is only exacerbated by the fact that no detailed demographic projections for radical life extension scenario have been conducted so far. What would happen with population numbers if aging-related deaths are significantly postponed or even eliminated? Is it possible to have a sustainable population dynamics in a future hypothetical nonaging society? This study explores different demographic scenarios and population projections, to clarify what could be the demographic consequences of a successful biomedical war on aging.

Demographic Methods

Let us start with the worst-case scenario (for overpopulation)—physical immortality (no deaths at all). What would happen with population numbers then? Common sense and intuition suggest that there should be a demographic catastrophe if immortal people continue to reproduce. However, a deeper mathematical analysis leads to paradoxical results. Consider a situation, when parents produce less than 2 children on average, so that each next generation is smaller than the previous one:

$$\frac{generation\ (n+1)}{generation\ n} = r < 1.$$

Then even if everybody is immortal, the final size of the population will not be infinite, but just $1/1-r$ times larger than the initial population. For example, one-child practice ($r=0.5$) will only double the total immortal population, because $1/(1-0.5)=2$. In other words, a population of immortal reproducing organisms can grow indefinitely in time, but not necessarily indefinitely in size, because asymptotic growth is possible. This conclusion does not require any complex calculations and questionable assumptions, but follows directly from the calculus, and the property of infinite geometric series to converge when the absolute value of the common ratio, r, is less than one:

$$1 + r + r^2 + r^3 + \cdots + r^n + \cdots = \frac{1}{1-r}.$$

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So, the fears of overpopulation based on lay common sense and uneducated intuition are in fact grossly exaggerated. In fact, immortality, the joy of parenting, and sustainable population size, are not mutually exclusive.

After this very general theoretical consideration, let us consider traditional methods of demographic projections. Analysis of the existing literature on this topic revealed that the cohort-component method is the most popular and widely used method of demographic projections used by World Bank and statistical offices of many countries.[1,2]

Analysis of already existing computer programs for population projections revealed that many of them are based on cautious assumptions of small incremental changes in human life span, and they do not allow making detailed projections for the oldest age groups of the population (which are often collapsed into one single 85+ year category). For this reason, many already existing computer programs of population projections were not well suited for the purpose of this study. Therefore, with the support of the Methuselah Foundation and SENS Foundation, new demographic projection software has been developed in this study, which was then validated for consistency of results with traditional approaches. This new demographic software is based on the generally accepted cohort–component method of population projections. A number of different demographic projections are considered in this software, assuming several scenarios of life extension.

Specifically, we applied the cohort–component female-dominant projection method for population closed to migration, as presented by Preston et al.[2] In our study, we slightly modified the projection method, which was initially presented by Preston et al. for 5-year age/time intervals, and adapted it to single-year age groups and single-year time projection increments.

The projection method used in our study and applied in the new population projection software is as follows. First, we use the following notations in the formulas of the cohort-component method.

$N_x^F(t)$ = number of women aged x to $x+1$ at time t.
L_x^F = number of person-years lived by women from age x to $x+1$ (obtained from life table).
F_x = age-specific fertility rate in interval x to $x+1$.

Initially all calculations are made for female population. The main formula for population projection calculating age-specific population numbers of females for all ages except for the first and the last age groups is:

$$N_x^F(t+1) = N_{x-1}^F(t) \cdot \frac{L_x^F}{L_{x-1}^F}.$$

For the last age group ω the following formula is applied:

$$N_\omega^F(t+1) = (N_{\omega-1}^F(t) + N_\omega^F(t)) \cdot \frac{L_\omega^F}{L_\omega^F + L_{\omega-1}^F}.$$

Note that in the case of significant life extension scenario, the last age group is getting older with time, so it is different for different time periods. To calculate number of female in the first age group at time $t+1$, we need to take into account the age-specific fertility. First, the number of births to women aged x to $x+1$ between time t and $t+1$ is calculated:

$$B_x[t, t+1] = F_x \cdot \frac{N_x^F(t) + N_x^F(t+1)}{2}.$$

Age-specific fertility is usually calculated for age interval 15–50 years. Total births between t and $t+1$ are obtained by the formula:

$$B[t, t+1] = \sum_{x=\alpha}^{\beta-1} B_x[t, t+1].$$

Assuming that the sex ratio at birth (SRB) is 1.05, we obtain the number of female births between t and $t+1$:

$$B^F[t, t+1] = B_x[t, t+1] \cdot \frac{1}{1+1.05}.$$

Using this information, the number of women in the first age group at time t is given by formula:

$$N_0^F(t+1) = B^F[t, t+1] \cdot \frac{L_0^F}{l_0}.$$

Calculations for male subpopulation are similar to those for female population with the following notations:

N_x^M = number of men aged x to $x+1$ at time t.
L_x^M = number of person-years lived by men from age x to $x+1$ (taken from life table).
$B^M[t,t+1]$ = number of male births between t and $t+1$.

The formulas for obtaining population numbers for male subpopulation are as follows.

$$N_x^M(t+1) = N_{x-1}^M(t) \cdot \frac{L_x^M}{L_{x-1}^M}$$

$$N_\omega^M(t+1) = (N_{\omega-1}^M(t) + N_\omega^M(t)) \cdot \frac{L_\omega^M}{L_{\omega-1}^M + L_\omega^M}$$

$$B^M[t, t+1] = B_x[t, t+1] \cdot \frac{1.05}{1+1.05}$$

$$N_0^M(t+1) = B^M[t, t+1] \cdot \frac{L_0^M}{l_0}.$$

These formulas were used in our calculations of population projections for different scenarios of life extension. Age-specific fertility was assumed to remain unchanged over time to study mortality effects only. No migration was assumed because of the focus on natural increase or decline of the population. More details on the cohort–component method are presented in the corresponding textbook.[2]

Taking into account that no existing population projection software takes into account opportunities of radical life extension and survival of individuals beyond age 120 years, new population projection software was developed in this study using Microsoft Excel macros. This software allows users to make projections under several scenarios of life extension:

1. Negligible senescence. Under this scenario, life extension interventions result in negligible senescence or no senescence at all. This scenario assumes that after certain age mortality levels off (no further aging, the start of negligible senescence) in the whole population: $\mu(x) = \text{const}$, where $\mu(x)$ designates the hazard rate (or mortality force).

2. Aging slow down. According to this scenario, life extension interventions result in declining the slope of mortality growth with age. This scenario assumes that mortality after certain age slows down so that the actuarial aging rate (parameter α in the Gompertz function) is lower as compared to the initial situation in the whole population. The program allows users to select the degree of aging slow down using proportion of parameter α decline. It is assumed that mortality is growing according to the Gompertz–Makeham formula:

$$\mu(x) = A + R \cdot e^{\alpha x},$$

where $\mu(x)$ is a hazard rate, x is age, and A, R, and α are parameters of the formula.

3. Continuous rejuvenation. According to this scenario, life extension interventions result in continuous decline of mortality with age, which results in the negative parameter α in the Gompertz–Makeham formula. In this case, mortality declines with age until it reaches its lowest value, which is equal to mortality achieved at age 10 when mortality is at the lowest possible level in the studied population.
4. One-time rejuvenation. According to this scenario, life extension interventions result in a one-time decrease in mortality, so that individuals become certain years younger according to their risk of death. As a result, 60 year olds may have mortality as low as they had at age 40 years (the degree of rejuvenation can be selected by the user). After this rejuvenation, mortality continues to grow with age with the same pace as before the intervention, so that the mortality dependence (in semilog coordinates) parallels mortality of the remaining population but at the lower level.

For all of these scenarios, there is an opportunity to select several additional options. First, it is possible to select the projection horizon (how long is projection in years), time lag before the start of life extension interventions, and age at which life extension interventions start. Also it is possible to consider situation when only a fraction of the population risks undergoing novel life extension interventions (users of our software can select the proportion of these individuals themselves). Another option is to consider the opportunity of growing acceptance of life extension procedures, so that every year certain percent of population (selected by software user) joins the club of people taking risks of life extension interventions until there remains only certain percent (also selected by software user) of the most stubborn individuals.

Population Projection Scenario Results

Here we consider some of these scenarios using existing data on population distribution, fertility, and mortality for population of Sweden in 2005 obtained from the website of Swedish statistical office (www.ssd.scb.se). Sweden is a typical developed country with relatively high fertility (for Europe) and low mortality. So we may expect that our population projections do not underestimate the projected population due to too-low fertility assumption values. All projection scenarios considered here assume unchanged age-specific fertility and absence of migration, because the focus of this study is on projections of the rates of natural increase or decline of the studied populations.

If we consider a simple population projection assuming unchanged fertility and mortality schedules without life extension interventions, then it turns out that population of Sweden may face a significant population decline over the next 100 years (Table 1). That is why life extension in developed countries is a part of the solution of demographic problems rather than a problem itself. Many developed countries (like the studied Sweden) face dramatic decline in the native-born population in the future, and also a risk of losing their cultural identity due to massive immigration. Therefore, extension of healthy life span in these countries may in fact help to prevent, rather than create, a demographic catastrophe.

Here we consider the result of population projections assuming some of the described scenarios of life extension. In all of these scenarios, we assumed that antiaging interventions start at age 60 years with 30-year time lag from now. These assumptions are made for illustrative purposes and could be modified by other researchers if needed.

Scenario 1: Negligible senescence after age 60

According to this scenario, mortality rates remain unchanged after age 60 years. As a result of such longevity

Table 1. Expected size of Swedish Population in 2105 under Different Projection Scenarios

Population projection scenario	*Projected population size in year 2105*	*Population change over a century*[a] *2105/2005*
No life extension interventions	6,064,750	0.6703
Negligible senescence after 60	10,998,418	1.2156
Negligible senescence accepted by 10% of population	6,558,104	0.7248
Negligible senescence initially accepted by 10% of population with growing acceptance	7,833,616	0.8658
Continuous rejuvenation after age 60 years (Gompertz $\alpha = -0.005$ per year)	11,032,385	1.2194
Continuous rejuvenation after age 40 years (Gompertz $\alpha = -0.005$ per year)	13,321,983	1.4724
Aging slow down (Gompertz α is decreased by one half)	6,942,963	0.7674

[a]The size of Swedish population in 2005 is equal to 9,047,752.

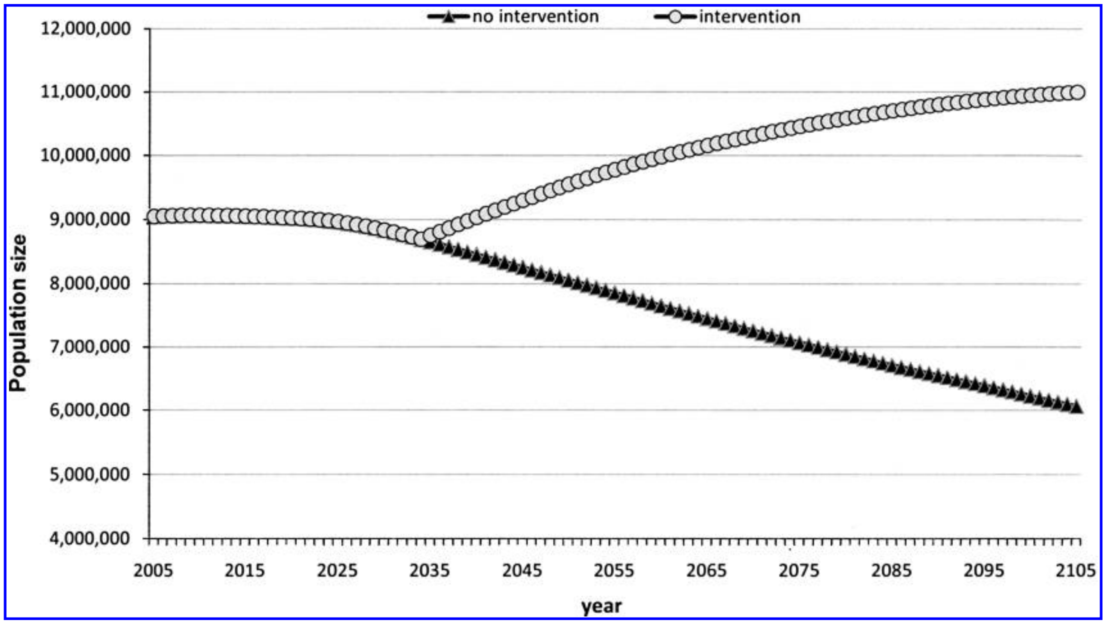

FIG. 1. Projection of the Swedish population until year 2105, assuming the negligible senescence scenario. Life extension interventions start at age 60 years, with a 30-year time delay from now.

intervention, median lifespan increases from 84 to 134 years for men and from 88 to 180 years for women. With this scenario, it is anticipated that out of 100,000 persons born alive , the longest-living men could potentially survive to 1550 years, while the longest-living women can potentially reach 2350 years of age. Thus, this is quite a radical scenario of life extension never considered in traditional population forecasts before. Table 1 shows that according to this scenario the population of Sweden will not decline, but the degree of population increase is relatively small: By the end of 100-year time period, a population will increase by only 22%. Figure 1 compares the changes in population dynamics under two scenarios—without life extension interventions and with life extension interventions resulting in negligible senescence. The conclusion on this radical scenario of life extension is that even in the case of defeating aging (no aging after 60 years) the natural population growth is relatively small (about 20% increase over 70 years). Moreover, defeating aging helps to prevent upcoming natural population decline in developed countries.

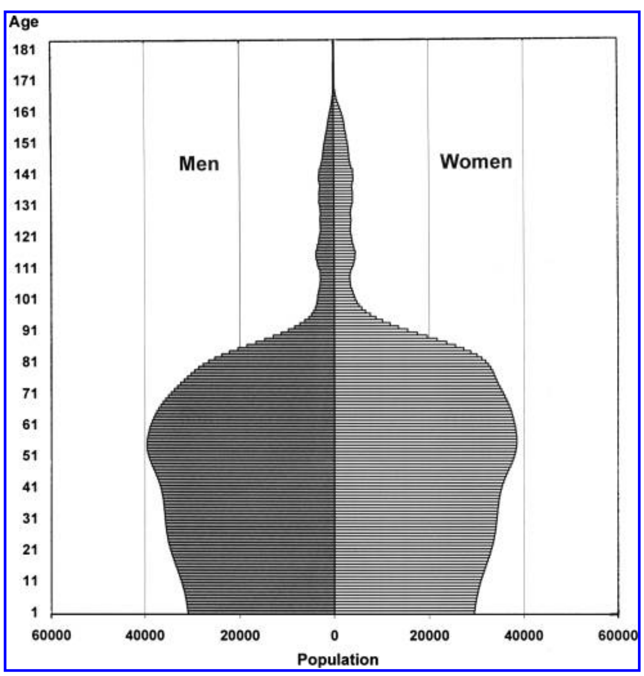

FIG. 2. Population pyramid of Sweden projected for year 2105, when only 10% of a population initially accepts interventions leading to negligible senescence.

Scenario 2: Negligible senescence for a part of the population (10%)

A situation in which all individuals simultaneously start using life extension methods does not sound realistic. So we considered a situation when only a small fraction of population (say, 10%) initially accepts antiaging interventions. According to this scenario, even such radical measures of life extension as negligible senescence after age 60 does not prevent the population from declining rapidly: At the end of a 100-year period, the population declines by 28% (see Table 1). In the case in which only part of the population accepts life extension intervention, the population pyramid may take very peculiar shape (see Fig. 2).

Scenario 3: What happens in the case of growing acceptance of antiaging interventions?

It is reasonable to assume that antiaging technologies may spread in population over time as more and more people will see their real benefits. So the next scenario is negligible senescence for a part of population (10%) with growing acceptance (1% added to negligible senescence group each year). It was also assumed that the last remaining 5% of the

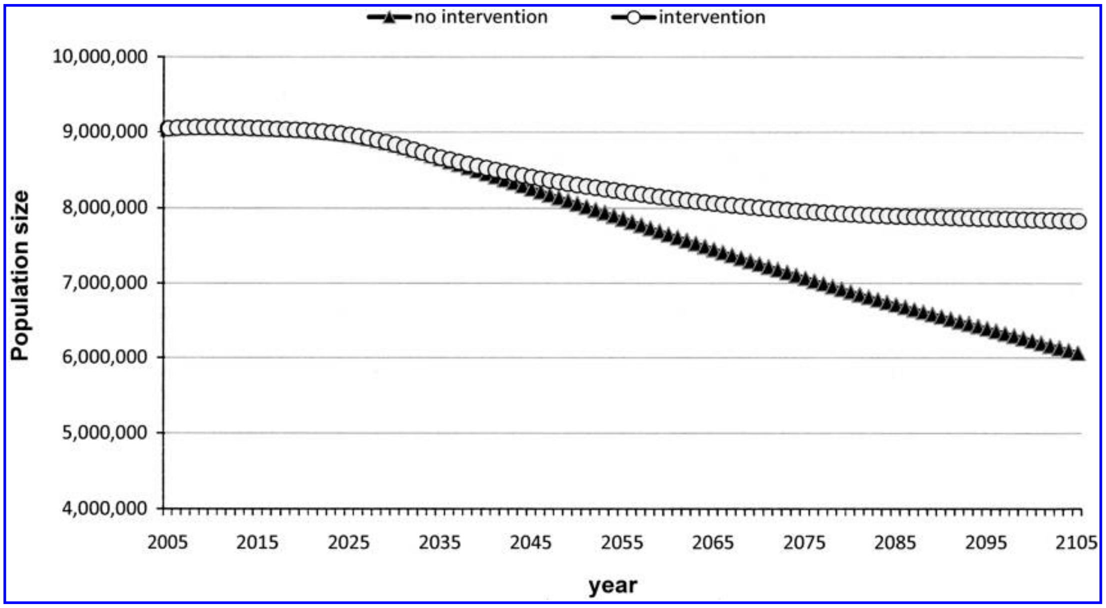

FIG. 3. Population projection for a scenario of growing acceptance of antiaging interventions. Projection of the Swedish population until year 2105, assuming the negligible senescence scenario for initially small proportion of population (10%), with growing acceptance rate over time. Life extension interventions start at age 60 years, with 30-year time delay from now.

population refuse to apply these technologies in any circumstances (because of religious beliefs or neglect to their lives). Figure 3 shows that growing acceptance of antiaging interventions slows down the anticipated population decline but cannot completely prevent it.

To summarize, Scenarios 2 and 3 demonstrate that even very radical measures of life extension do not prevent future population decline if only part of population accepts these methods.

Scenario 4: Continuous rejuvenation scenario

According to this scenario, mortality continues to decline after age 60 years until it reaches the levels observed at age 10, and then mortality remains constant thereafter. With this scenario, we assumed that the Gompertz parameter α (mortality slope) is negative rather than positive and is equal to -0.0005 per year. It can be seen from Table 1 that according to this scenario population grows by 22% only by the end of 100-year time period. The conclusion regarding this rejuvenation scenario is that even in the case of rejuvenation (aging reversal after 60 years) the natural population growth is still small (about 20% increase over 70 years of using antiaging technologies). Moreover, rejuvenation interventions will help to prevent future natural population decline in developed countries.

Of course, population growth may be larger if antiaging interventions are started at younger ages. So we considered what happens when rejuvenation starts at age 40 instead of age 60. In this case population increase at the end of 100-year period was 47% rather than 22%, but still not particularly dramatic (Table 1).

Scenario 5: Aging slow down

Finally we considered a more modest scenario when mortality after age 60 slows down but continues to grow. With this scenario, the Gompertz parameter α decreases by one half. It seems reasonable to suggest that the initial antiaging interventions coming into practice will not be too radical and correspond better to this modest scenario rather than the more dramatic ones considered earlier. According to this scenario, population continues to decline with a similar pace as in the case of no interventions at all (Table 1). Thus, simple deceleration of aging using life extension interventions does not prevent modern developed countries from future depopulation.

Conclusions

A general conclusion of this study is that population changes are surprisingly slow in their response to a dramatic life extension. For example, we applied the cohort–component method of population projections to the 2005 Swedish population for several scenarios of life extension and a fertility schedule observed in 2005. Even for the very long 100-year projection horizon, with the most radical life extension scenario (assuming no aging at all after age 60), the total population increases by only 22% (from 9.1 to 11.0 million). Moreover, if some members of the society reject the use of new antiaging technologies for religious or any other reasons (inconvenience, noncompliance, fear of side effects, costs, etc.), then the total population size may even decrease over time. Thus, even in the case of the most radical life extension scenario, population growth could be relatively slow and may not necessarily lead to overpopulation. Therefore, the real concerns should be placed not on the threat of catastrophic population consequences (overpopulation), but rather on such potential obstacles to the success of a biomedical war on aging, such as scientific, organizational, and financial limitations. To see a further discussion of this study and to make comments, visit: http://longevity-science.blogspot.com/

Acknowledgments

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