Fertility and long term trend of human lifespan

Jing Chen
University of Northern British Columbia
Prince George, BC
Canada V2N 4Z9
Phone: 1-250-960-6480
Email: chenj@unbc.ca
Web: http://web.unbc.ca/~chenj/

Abstract

There has been an empirical regularity of steady human lifespan expansion for more than a century. From this regularity, many researchers suggest this trend will be extended indefinitely. We apply the inverse relation between lifespan and fertility rate to give a quantitative estimate about the possible future path of lifespan. The results suggest that the long standing pattern of steady lifespan extension will be modified in the coming decades.

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For more than one hundred years, the expected lifespan of human beings has been increasing at a steady rate. From this empirical regularity, many researchers suggest that this increase of lifespan will continue indefinitely into the future (1,2). Forecasts on lifespan change are often extended into the next half century or century (3,4). Some have suggested that due to technological progress, this rate may accelerate in the future (5).

Separately, the inverse relation between lifespan and fertility has long been observed among organisms (6,7,8). When organisms spend more resources to increase lifespan, they will have fewer resources to raise the next generation. The range of fertility varies widely, from species to species, from time to time, and from place to place. However, for all organisms that depend on sexual reproduction, the replacement fertility rates must exceed two, in order for a population to be sustainable.

Currently, a wide array of countries with the longest lifespans, including Japan and most European countries, already see a fertility rate below 2. In societies with a fertility rate far below replacement rate, the population ages over time. This requires a gradual shift of resources away from reproduction to maintain longevity. For example, when Canada first introduced the Canada Pension Plan in 1966, the deduction rate was 3.6% of income. Over the years, the deduction rate has been increased to 10.2% in 2019. This increase of pension deduction increases available resources during old age but decreases available resources during youth, the reproductive age. During this period, the fertility rate in Canada dropped from 2.75 to 1.60. The increase of the deduction rate of the Canada Pension Plan is not the only resource shift to provide for longevity. Many other measures are taken to increase lifespan, which tend to decrease fertility at the same time.

While the fertility rates of many wealthy countries are below replacement rate, the fertility rate of the whole world is still above the replacement rate. In this paper, we will apply the relation of lifespan and fertility to global population. The inverse relation between lifespan and fertility in human societies has been observed. Yet this relation is not integrated into forecasting future lifespan of human societies in current literature. Given the near constant increase of lifespan with respect to time, there seems to be no need to include another factor in forecasting future lifespan. However, suppose that current human lifespan trends apply to the future, as predicted by many researchers. If the empirically observed relation between lifespan and fertility persists, the fertility rate of the world population will significantly drop below replacement rate in the next two to three decades, rendering the global population system unsustainable. From this observation, past regularities in population dynamics, such as steady increase of lifespan, may not extend beyond the near future.

In the next section, we will provide a regression analysis to give quantitative estimates on the possible future path of human lifespan and the related time frame.

Data, regression and analysis

We will use worldwide lifespan and fertility data from World Bank. It starts at 1960 and ends at 2017, a total of 58 years. Lifespan was 52.57 years in 1960 and 72.23 years in 2017. Fertility

rate was 4.98 in 1960 and 2.43 in 2017. In this data set, lifespan increases every year. Starting from 1964, fertility rate drops every year. The patterns of change of lifespan and fertility rate are very regular.

To test the relationship between lifespan and fertility rate, we perform a regression analysis, with lifespan as a function of the logarithm of fertility rate. Without loss of generality, assume the logarithm function to be base two. In effect, we are testing a model of

$$y = a + bx \qquad (1)$$

Where y is lifespan and x is log2 (fertility rate). The results of the regression are presented in Table 1.

	Coefficients	P-value
a	89.11519005	5.44323E-68
b	-14.16241921	4.71642E-38
R Square	0.949728961	

Table 1

The regression results are highly statistically significant. The regression equation is

$$y = 89.12 - 14.16x \qquad (2)$$

There is a strong relation between the increase in lifespan and the decrease in fertility rate. We often attribute the increase of lifespan as the payoff from investments in technology and social policies. At the same time, we need to recognize the decrease of fertility rate as a cost resulting from the same investments.

We will utilize the regression equation to extrapolate the quantitative scenarios when lifespan is higher, and correspondingly, fertility rate is lower. Some numerical results calculated from (2) are presented in Table 2.

life expectancy	75	80	85	90
corresponding fertility	2.00	1.56	1.22	0.96

Table 2

From Table 2, if the global human lifespan increases to 75 years old, fertility rate will decrease roughly to the replacement rate. If the global human lifespan increases to 80 years old, fertility rate will decrease significantly below the replacement rate. Even if the global lifespan of 80 years old is attainable, it will be unlikely to be sustainable. If the global human lifespan increases to 85 years old, fertility rate will decrease to around 1.22. Is it possible for the global fertility to drop that low? At the regional level, fertility rate can certainly drop below 1. However, two reasons may prevent global fertility to stay very low over an extended period.

The first is that populations with low fertility will decline over time and populations with high fertility will increase over time. The second is that areas with low fertility, such as Europe, see net immigration whereas areas with high fertility, such as Africa, see net emigration. Due to these reasons, global fertility rate must have a lower limit, although this needs to be determined empirically. But it is generally seen that global fertility rate stays higher than 1.22. This does not mean fertility rate cannot drop to a very low level during catastrophic events, in which both fertility and lifespan plummet.

Next, we will analyze the time frame of these changes. In the past several decades, the increase of lifespan is roughly 2.5 years per decade. If this pattern persists, global human lifespan will be 75 years old around 2030 and 80 years old around 2050. The corresponding fertility rate at 2050 drops to around 1.56, which is significantly below the replacement rate.

From the above analysis, in the next several decades, the speed of lifespan increase will decline over time. Eventually, the global lifespan will start to decrease. It is unlikely that the current speed of 2.5 year per decade of lifespan extension will last for a century, or even half a century.

Concluding remarks

There is a strong inverse relation between lifespan and fertility rate. Resources have to be distributed between prolonging lifespan and increasing the number of offspring. Fertility rate has to be above replacement rate for a population to be sustainable. This puts a constraint on the upper bound of lifespan and its speed of change in a population.

In this work, we apply the regression method to establish a quantitative relation between lifespan and fertility rate. It provides a more precise understanding to the future trend of lifespan change. It is only an early attempt to integrate the information of fertility rate into a quantitative investigation on the future patterns of human lifespans.

We discuss the pattern of lifespan change of the global population. We haven't specifically discussed the lifespan problems in the countries with the longest lifespans. However, all regions are bound of the global distribution of resources. Similar changes in demographic patterns should occur in these countries as well. More detailed discussion shall be left to the future.

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