Mortality Compression and Longevity Limits

PEOPLE ARE LIVING MUCH LONGER NOW. The life expectancies of U.S. males and females, for example, increased more than 20 years in the 20th century—from less than 50 years old in 1900 to more than 70 at the end of the century (Figure 1). This increase of approximately 30 years over the past 100 years comes out to about 0.3 year annually.

But it's not just the United States. According to the United Nations, life expectancy worldwide had an average increment of 0.25 year annually during the second half of the 20th century. A recent BBC report even predicted that about one in five citizens of the United Kingdom will live beyond age 100.

This prolongation of life is changing societal structures in both developed and developing countries. In many of these countries, the number of elderly soon will surpass the number of children aged 5 and younger. This is not just because of increasing life expectancy but also because of declining fertility rates. In the United States, 12 percent of the population was elderly in 2004—a proportion that is projected to increase to 21 percent by 2050. Life expectancy in Taiwan and the United States is about the same, but because of much lower fertility rates, Taiwan's proportion of elderly in 2050 (37.9 percent) will eclipse that of the United States.

These changes have affected retirement planning dramatically and are increasing the financial burden on individuals and governments alike. Japan, whose citizens are among the longest lived in the world (after Andorra and Macau), didn't anticipate its rapidly decreasing mortality. As a result, many Japanese insurance companies face long-term potential financial insolvency. Both the U.S. Social Security and Medicare systems anticipate funding shortfalls down the road. If the trend of reducing mortality continues its pace, there will be many more countries facing similar problems.

A Rectangular Survival Curve

Because of the rapid increase in life expectancy over a relatively short period of time, there aren't enough data to model elderly mortality rates.

But while there is no consensus about future life expectancy, mortality rates do share some common features. Rectangularization of the survival curve, or mortality compression, is one of them.

According to James Fries, a medical doctor who wrote about mortality compression in a 1980 article published in the *New England Journal of Medicine*, this is a method in which mortality from exogenous causes is eliminated—leaving genetic factors as the primary cause for the remaining variability in the age at death. Figure 2 shows the survival curves of Taiwanese females, in which the mortality rates for infants and children dropped significantly over the course of 100 years. The majority of deaths occur between ages 65 and 85, accounting for about 50 percent of deaths in 2000. Following Fries', concept of mortality compression, the burden of lifetime illness is compressed into a shorter period before death.

Some researchers have used rectangularization to determine if human life span has an upper limit. In research published in 2000, Väinö Kannisto of Germany's Max Planck Institute for

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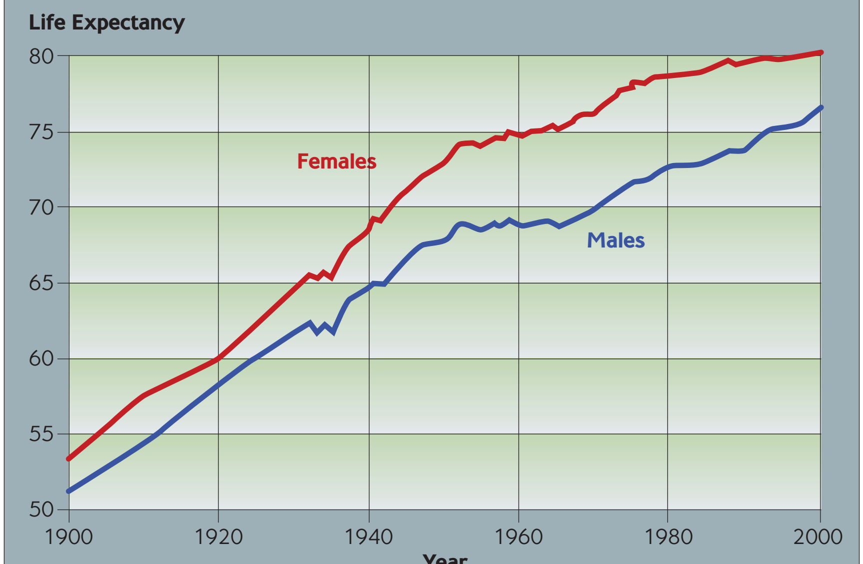
FIGURE 1

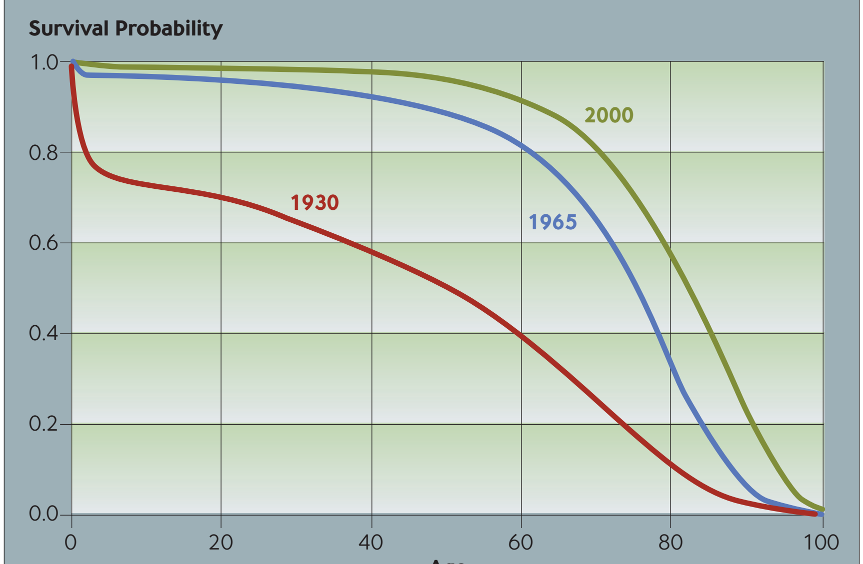
U.S. Life Expectancy in the 20th Century



SOURCE: JACK C. YUE

FIGURE 2

Survival Curves of Taiwanese Females



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Demographic Research found that while life expectancies in the United States and the European Union are continuing to increase, more deaths are occurring in a shorter age interval. Demographers Siu Lan Karen Cheung, Jean-Marie Robine, Edward Jow-Ching Tu, and Graziella Caselli in 2005 proposed three-dimensional measures for the survival curve, including horizontalization, verticalization, and longevity extension. They applied the idea to Hong Kong data, and, in addition to confirming mortality compression, they concluded that the increase in longevity is meeting resistance. These past studies, however, are all based on life table data, not raw data. The life table values usually are graduated and may vary greatly because of different graduation methods.

Evaluating Rectangularization

In my study, I evaluated this rectangularization with raw data. I used the following five elements in measuring mortality compression:

- The mode age (M) that has the largest number of deaths and is highly correlated with the life expectancy;
- The probability of premature death, similar to horizontalization;
- The smallest number of ages covering the probability of deaths, similar to verticalization (deaths are clustered at a small number of ages);
- The variance of age distribution for deaths σ^2;
- The probability of survival beyond a high age, such as $M + k\sigma$, where k is a positive number—I chose it to be 1 or 2.

The first three elements are similar to the three-dimensional measurements that demographers Cheung, Robine, Tu, and Caselli used, and the last two elements evaluate the life limit.

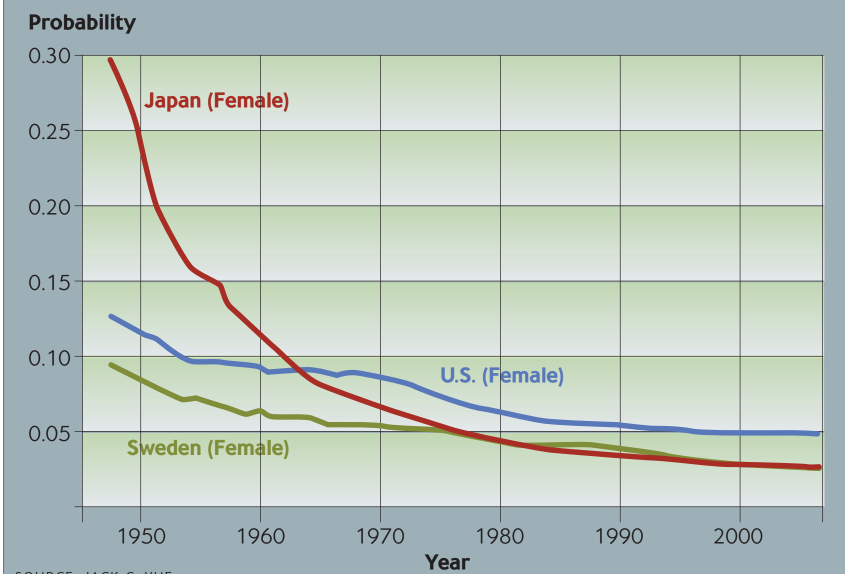
I used data from Japan, Sweden, and the United States (taken from the Human Mortality Database) for my study. The time period of the data selected for these three countries was 1947 to 2005. Since the patterns by gender were similar, I will limit my discussion to the results for females.

I found that the results from the first three elements supported the concept of mortality compression. The modes of the females are near constant before the 1980s and increase linearly after that time. Japanese females appear to have larger modes than those living in Sweden or the United States, which is consistent with Japan's pattern of longevity. It seems safe to state that human life expectancy will continue to increase.

The results of horizontalization and verticalization also support the concept of mortality compression. Figure 3 shows the

FIGURE 3

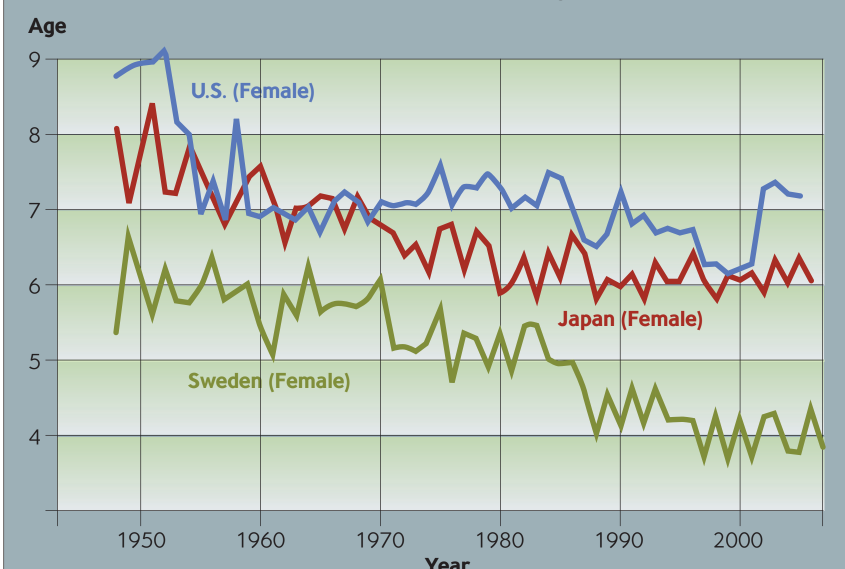
Probability of Dying Before Age 50



SOURCE: JACK C. YUE

FIGURE 4

The Standard Deviations of Age at Death



SOURCE: JACK C. YUE

probabilities of dying before age 50 (horizontalization). The probabilities aren't greater than 0.05 since 2000, indicating that at most 1 in 20 infants will die before age 50. The probability of a Japanese female dying, initially the highest, has experienced the largest decrease. Also, the probability of a U.S. female dying is greatest after 1970, and this is highly correlated to the comparatively shorter life expectancy.

Based on the preceding measurements, life expectancy seems to extend gradually and the mortality compression tends to hold. But the standard deviation of age distribution for deaths and the probability of survival beyond extreme age tell a different story. Figure 4 shows the standard deviations. There are noticeably large fluctuations since raw data are used. But unlike the results from the Hong Kong study conducted by demographers Cheung, Robine, Tu, and Caselli, the standard deviations don't always decrease. Those of Japanese and U.S. females appear to level off, while those of Swedish females decrease annually. As a result, I don't have concrete evidence supporting mortality compression.

In a similar fashion, the probabilities of surviving to an extremely old age also don't support the concept of mortality compression. Figure 5 shows the survival probabilities beyond the mode plus one standard deviation and two deviations of age distribution. The ages of these two bounds are approximately 95 and 100, and therefore can be treated as having survival probability that is extremely high. We can use these two survival probabilities as a proof of whether life extension reaches a limit. Because of the insufficient sample of the elderly, the survival probabilities have large fluctuations. It's interesting that the high survival probabilities of the three countries are quite close to one another. In general, the survival probabilities beyond M+σ of females are around 11~13 percent, and those beyond M+2σ of females are around 1~2 percent.

Future Life Expectancy

Although the measurements of horizontalization and verticalization support mortality compression, the standard deviation and the survival probability beyond extremely high ages provide another possibility for future life expectancy. The survival probabilities beyond very high age and the standard deviations of age distribution for Japan and the United States are almost constant. Coupled with the fact that the mode age (or life expectancy) continues to increase, it seems that the question of whether life expectancy has a limit is still open. I would postulate that life is without a limit, where the survival curve is likely to move to the right, as shown in Figure 6.

In the past, people tended to believe

that life expectancy would level off or reach a limit. In the 1960s, for example, the consensus was that human beings were unlikely to live beyond age 85. The life expectancies for females in certain countries, such as Japan and Hong Kong, already have surpassed 85 years.

To account for increasing life expectancies, stochastic mortality models have become a popular tool in calculating the value of annuity products. The life expectancies in these models will continue to increase, similar to what I found in my study. But doubts still exist about using them to model annuity products, particularly in relation to pricing. Because there are insufficient data samples for people aged 90 and over, modeling mortality rates of the elderly usually relies on extrapolation methods, such as the Gompertz-Makeham law of mortality. This means that we are not sure about the right tail of the survival distribution and depend on other assumptions to price annuity products. This makes it difficult to evaluate the risk of using stochastic mortality models to price annuity products.

If mortality compression does take place, we can use it to modify mortality models and evaluate the risk. But, as I found, the concept of mortality compression isn't always valid. If the variance of the death age distribution is decreasing, we would have more confidence in pricing annuity products. But for the historical data from Japan and the United States, the standard deviations and extremely high age survival probabilities behave like constants. This indicates that there is a non-negligible probability that the right tail of the survival distribution is still unknown—or without enough observations.

Other Approaches

Because the concept of mortality compression doesn't eliminate doubts about using stochastic mortality models, the results of my study might lead to other approaches. Since the survival probability beyond M+2σ is around 2 percent, for example, it's possible that the death age distribution is credible on the left-hand side of M+σ. One possibility for dealing with longevity risk is to concentrate on the components that are more credible. This would allow us to focus more on products like annuity-certain, designing annuities that are payable up to the age of M+2σ and using other tools to cope with ages beyond M+2σ. (I would note that the age of M+2σ is approximately 100 years old, and it would be sufficient for most people.)

There are several ways to tackle the coverage of survival beyond the age M+2σ, but first we need to determine the role of annuity products in planning for retirement. If annuity products aren't the primary source of income, then annuity coverage up to age M+2σ is probably enough. If the insured relies solely on annuity products, then we need to deal with estimating the probability of surviving beyond age M+2σ. It's unfortunate that at this time the data to estimate the probability remain scarce. ☐

FIGURE 5

The Probability of Survival Beyond a High Age

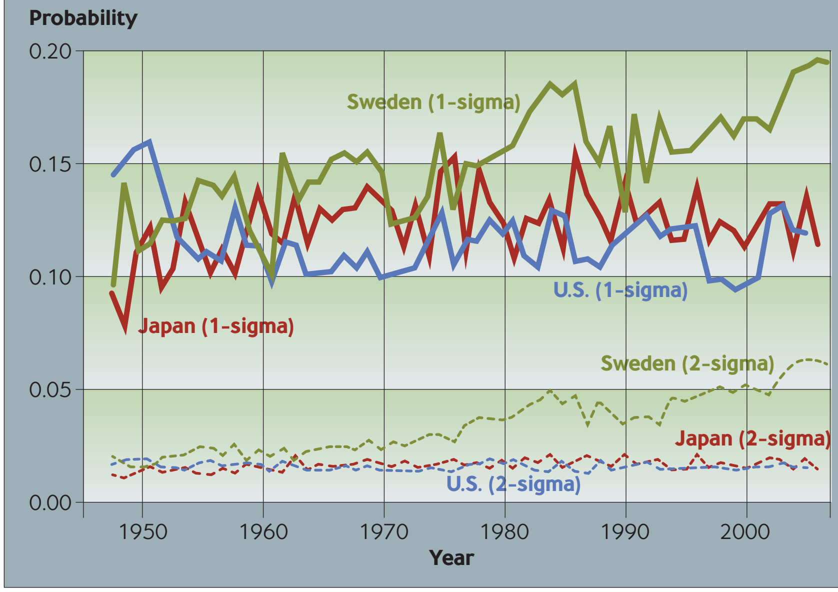
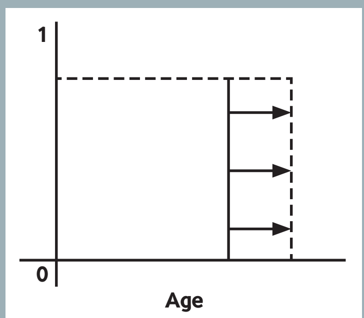


FIGURE 6

The Theory of Life Without a Limit



SOURCE: JACK C. YUE

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