Using System Dynamics to Predict Health Trends in China: A Close Look at Healthy Life Expectancy

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Abstract

We combined the Sullivan method and the System Dynamics model to simulate the trajectory of China's Healthy Life Expectancy (HALE) from 2000 to 2060. Over this period, a rising trend in China's HALE is observed. Specifically regarding the Healthy Life Expectancy for females which consistently surpasses that of males. The disparity between females and males first widens and then narrows, indicating a convergence trend. However, the extension in females' lifespan is not always synonymous with healthy years. Our goal with this model is to contribute to the creation of sound policies to support China in meeting its development goals.

Problem

China is currently at a crossroads between negative population growth and accelerated aging. The economic consequences of aging, however, depend to a large degree on whether older people will stay healthy and perhaps be able to work, or whether they will suffer from ill health at old age. Therefore, to predict China's Healthy Life Expectancy (HALE) is essential. With the aim to offer an innovative policy tool we have designed a System Dynamics (SD) HALE model to answer the following questions from 2000 to 2060:

1. Trends: What are the trends in China's Healthy Life Expectancy?

2. Comparison: How does the trend in Healthy Life Expectancy compare with that of Life Expectancy at Birth?

Healthy Life Expectancy (HALE) captures quality of life. HALE offers an average number of years that an individual is anticipated to live in "full health" from birth. HALE also summarises both mortality and non-fatal outcomes in a single indicator of average population health (Salomon et al. 2012). Conversely, Life Expectancy at Birth refers to the average number of years that a newborn could expect to live, acting as a broader gauge of a population's overall mortality level (Murray et al, 2003; WHO, 2018; Labbe, 2010; Australian Institute of Health and Welfare, 2019).

Figure 1 illustrates that the Crude Birth Rate has fallen dramatically since the early 1960s. It also shows that Life Expectancy at Birth (LEXP) has been steadily climbing each year while the Crude Death Rate has remained virtually flat. At the end of 2022 the Crude Death Rate surpassed the Crude Birth Rate. This means negative population growth and accelerated aging.

The Status of Work That Has Been Done So Far

We have developed an original System Dynamics (SD) model to capture a full picture of China's present and future Healthy Life Expectancy (for females, males, and both).

Next Steps

In the next steps of this Work In Progress (WIP), we will analyze and present predictive results of HALE by age and gender, drafting a detailed research paper.

Innovation

Our research is potentially the first to combine the Sullivan method and the System Dynamics model to calculate and simulate China's Healthy Life Expectancy (HALE).

Dynamic Hypothesis

Our working hypothesis is that China's HALE is exhibiting an upward trend. Healthy Life Expectancy (HALE) for females surpasses that of males, with the disparity gap between genders first widening, and then narrowing.

A Description of The Intended Approach & Model Structure

Sullivan's method calculates the fraction of equivalent lost healthy years, taking into account comorbidity factors, for individuals at each age within synthetic population. It is not reflective of current real population demographics. It then divides the hypothetical years of life lived by a period life table cohort at different ages into years of equivalent full health and equivalent lost healthy years (WHO, 2018; Labbe, 2010; Australian Institute of Health and Welfare, 2019). Building upon Sullivan's method, we have utilized Stella 3.3 to design a Stock Flow Diagram of the SD HALE model (Figure 2).

Preliminary Results

As illustrated in Figure 3, during the period from 2000 to 2060, Healthy Life Expectancy (HALE) and Life Expectancy at Birth (LEXP) for China's both (females and males together), females, and males, have all shown a steady increase, indicating improvements in health conditions. By 2060, HALE is expected to reach 73.56 years for both, with females at 74.23 years and males at 72.89 years. Additionally, there is a high correlation between HALE and LEXP (with the coefficient of determination R^2 being 0.9587). Despite females having a higher HALE and LEXP than males, the gap between genders first widens then narrows, exhibiting a converging trend. Not all years added to female LEXP are healthy, aligning with findings by the World Health Organization (2019). Furthermore, the gap between HALE and LEXP has been gradually widening due to significant reductions in mortality rates and the Years of Life Lost (YLL) rate since 1990, coupled with an increase in the Years Lived with Disability (YLD) rate driven by aging, which suggests that while LEXP has increased, the disparity gap between HALE and LEXP has also grown.

Data Sources and Software

We have used Stella Architect 3.3 from isee systems to build the SD HALE model in this Work In Progress (WIP). To construct the HALE SD model we have utilized various data sources including the Fifth, Sixth, and Seventh National Population Census of the People's Republic of China on the Crude Death Rate (CDR), and deaths in the years 2000, 2010, and 2020. We also considered the Global Burden Diseases (2019) on YLD and YLL in the years 2000, 2010, and 2019. To compare the trend in

Healthy Life Expectancy with Life Expectancy at Birth, we used the Global Burden Diseases findings on LEXP from 2000 to 2060. To draw Figure 1, we used World Bank database on CBR, CDR, and LEXP from 1952 to 2022.
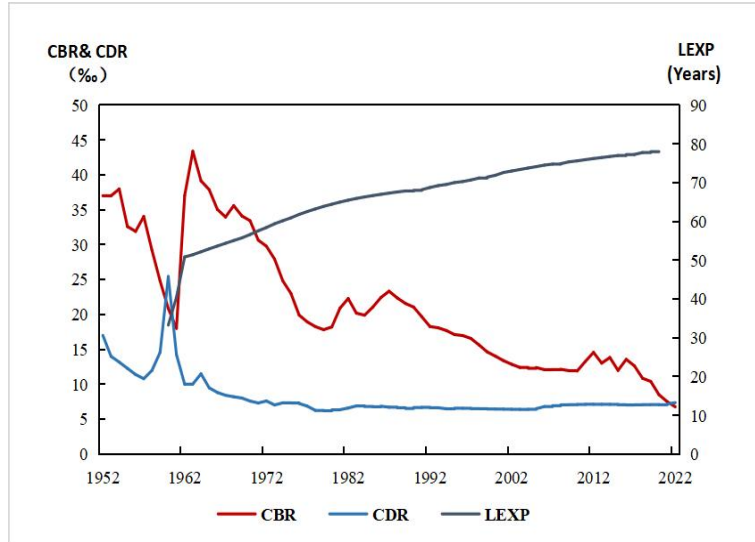
Appendix

Figure 1: Crude Birth Rate (CBR), Crude Death Rate (CDR), and Life Expectancy at Birth (LEXP) for China 1952 to 2022
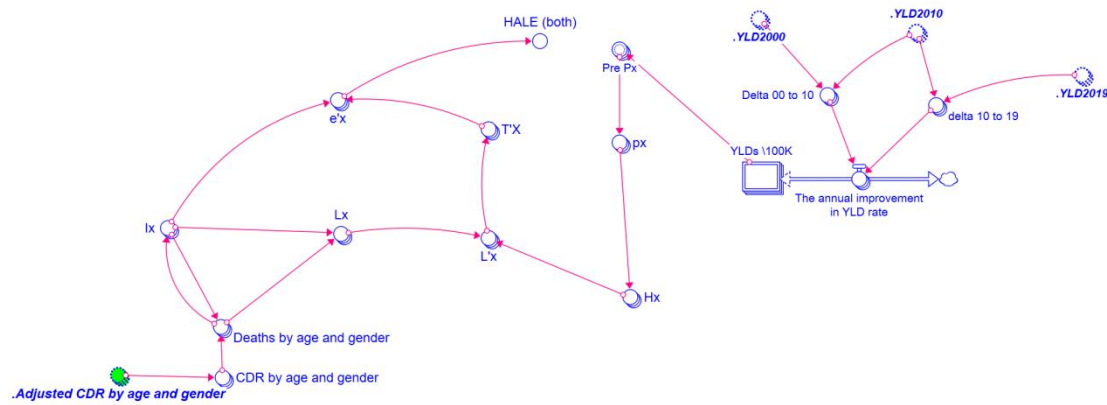
Data Sources: World Bank.

Fig. 2 Stock Flow Diagram for HALE

The steps for calculating HALE: I_x represents the number of surviving individuals at age x, q_x refers to the number of deaths divided by age group. By calculating the number of life-years in the age group x (L_x) for each age group and then applying the average YLD rate (p_x) to compute the proportion of each year lived in full health (H_x) we adjusted the number of life-years for each age group, resulting in an adjusted number of life-years (L'_x). This reflects the total time lived in full health by each age group within the cohort. Subsequently, we calculated the cumulative years from age x to the last age in the life table, considering only the time lived in full health, to obtain the total cumulative healthy years (T'_x). Finally, using the adjusted cumulative healthy years (T'_x) and the number of surviving individuals I_x at each age stage, we calculated the Healthy Life Expectancy by age and gender (e'_x), and Healthy Life Expectancy at Birth (HALE) (Australian Institute of Health and Welfare, 2019).
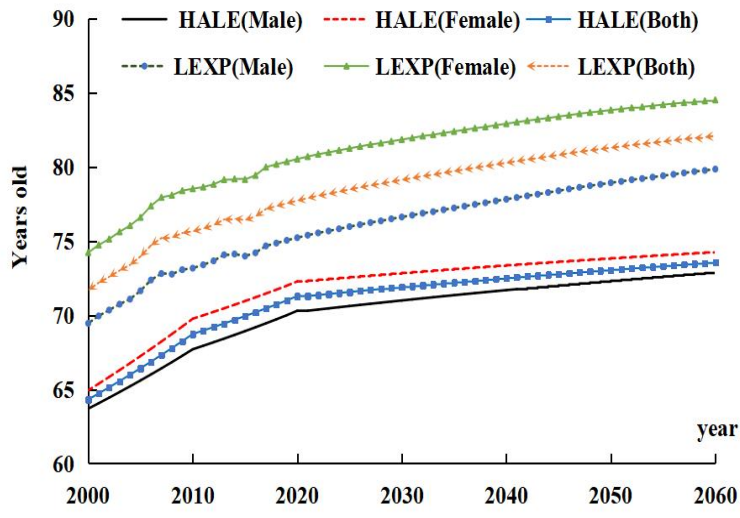
Fig. 3 Trends in LEXP and HALE

Data sources: HALE (our own calculations); LEXP (Global Burden Diseases)
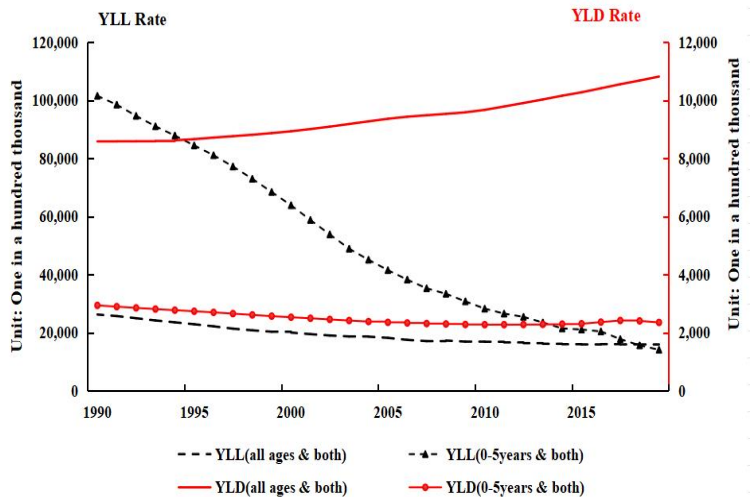

Fig. 4 Trends inYLL and YLD for All ages&both and 0-5years&both from 1990 to 2019

Data Sources: Global Burden Diseases, 2019

Sullivan's methodology employs the life table to explain that changes in Healthy Life Expectancy (HALE) stem from the changes in age-specific death rates or Years of Life Lost (YLL) rate and Years Lived with Disability (YLD) rate. As depicted in Figure 4, the YLL rate (all ages&both) exhibits a gradual decline, predominantly attributable to the substantial reduction in infant mortality rates. Meanwhile, the YLD rate (all ages&both) witnesses a progressive increase, reflecting the implications of an aging population. Initially experiencing a steady decline, the YLD rate (0-5years&both) in China stays stable briefly before a slight increase, ultimately stabilizing towards the end of the observed period. Conversely, the YLL rate (0-5years&both) for this age group shows a marked decrease, primarily due to the significant drop in infant mortality rates.

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Abbreviations

THE: Total Health Expenditure

SD: System Dynamics

SFD: Stock Flow Diagram

YLD: Years Lived with Disability

YLL: Years of Life Lost

GBD: Global Burden Disease

WHO: World Health Organization

LEXP: Life Expectancy at Birth

HALE: Healthy Life Expectancy at Birth

CBR: Crude Birth Rate

CDR: Crude Death Rate