Managing longevity risk: Construction and applications of mortality indexes


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One major challenge in offering longevity insurance products is a lack of avenues for insurers and reinsurers to effectively manage and transfer longevity risk. Trading of longevity-linked securities and liabilities is still in its infancy stage. In this article, **Dr Jackie Li** of the **Insurance Risk and Finance Research Centre**, Nanyang Business School, **NTU**, and **Dr Johnny Li** of the **University of Waterloo** explore the feasibility of constructing appropriate mortality indexes and associated derivative securities to help address this issue.

The life market

The Life and Longevity Markets Association (LLMA) was set up in 2010 in the UK, with an objective to promote the development of a liquid life market, where longevity-linked securities and liabilities are traded.

It is hoped that via a deeper and more mature market, insurers and reinsurers will be able to spread their longevity risk more easily amongst one another and with investors who want to diversify their portfolios with an uncorrelated market sector. As with many successful financial markets, transparent and widely adopted market indicators and indexes are indispensable.

To date, there have been a number of attempts by the industry to create indexes.

- In 2006, Credit Suisse started a longevity index with the life expectancy at birth of the US population as its basis.
- In 2007, Goldman Sachs launched the QxX Index, which is based on the number of survivors in the reference population.
- JPMorgan introduced the LifeMetrics Index in the same year, which renders death rates and period life expectancy figures.
- In 2008, Deutsche Börse released the Xpect Cohort Index, and it is linked to the number of survivors of a certain birth cohort.

What is the use of a mortality index?

Mortality indexes provide an objective method of measuring longevity risk. They broadly indicate the pace at which the mortality of a population is changing, enabling the measurement of longevity risk by comparing the difference between the expected and actual paths of the index.

With this understanding, one can create standardised mortality-linked securities using suitable mortality indexes, such as survivor bonds and swaps. These securities can be traded between investors and insurers who seek to reduce their longevity risk exposures. Compared to over-the-counter transactions, standardised securities are easier for investors to understand and should help improve market liquidity.

What makes a good mortality index?

The mortality indexes cited earlier are all model-free – they are based on actual data without any assumptions or parameters. While this avoids the problem of model error, it limits the amount of information that an index can incorporate. For example, an index based on life expectancy reflects mortality improvement at the aggregate level, but it does not show how the underlying mortality curve moves over time.

Since changes of a mortality curve are typically not uniform, an insurer may find it hard to use such an index to construct a proper longevity hedge. To fully express the shifts of a mortality curve in a model-free way, a large number of indexes are needed, such as those that are linked directly to death rates at different ages. However, tracking too many indexes at the same time is problematic. It is also difficult to increase market liquidity when there are a large number of mortality indexes offered in the market.

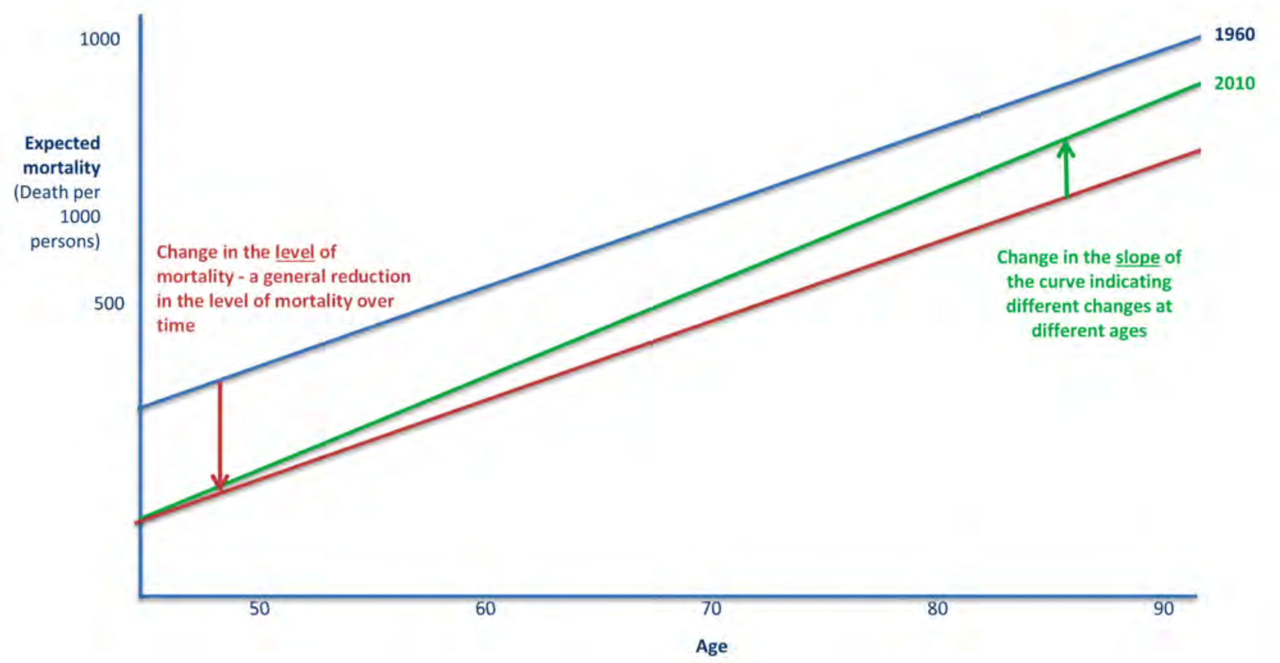
In contrast, a model-based approach has the potential to enhance the information content of mortality indexes. In the past two decades, several extrapolative stochastic mortality models have been proposed and extended. Generally, when they are applied to historical data, one or more time series of parameters are computed. The parameters are projected into the future and mortality forecasts can be made. These parameters contain a wealth of information about how a population's mortality varies with time and may be used as mortality indexes.

Criteria to be met to build an index

However not every stochastic mortality model is suitable for building indexes. There are several criteria that need to be satisfied.

- Firstly, though its dimension is small, the vector of indexes should indicate the varying levels of mortality improvement at different ages, not just the overall mortality level.
- Secondly, the model should enable updates when a further year of mortality data is available with the index values of previous years remaining unchanged – a "new-data-invariant" property. Otherwise, if past values are revised from time to time, it would not be possible to track the index.
- Thirdly, the indexes should be easily understood by risk hedgers and investors. Other criteria require that the indexes be unambiguous, transparent, objective, measurable, timely, appropriate, popular, relevant, and stable.

Figure 1: Mortality changes - simplified example (Change in the level and slope of mortality)



The CBD model

The Cairns-Blake-Dowd (CBD) model appears to be the most suitable candidate within the current literature to address these criteria. It considers both

- the change in the level of mortality over time (level(t)); and
- the changes at different age groups (slope(t)).

These two time-varying parameters can be used jointly as mortality indexes.

> The CBD model is specified as:
>
> $$\log(\text{death.rate}(x,t)/(1-\text{death.rate}(x,t))) = \text{level}(t) + \text{slope}(t) \times (x-\bar{x})$$
>
> The term death.rate(x,t) represents the death rate at age x in year t and $\bar{x}$ is the average age over the sample age range.

Figure 1 shows a simplified example of the changes in mortality with this function. As expected, the older the age, the higher the death rate.

There are two things to note:

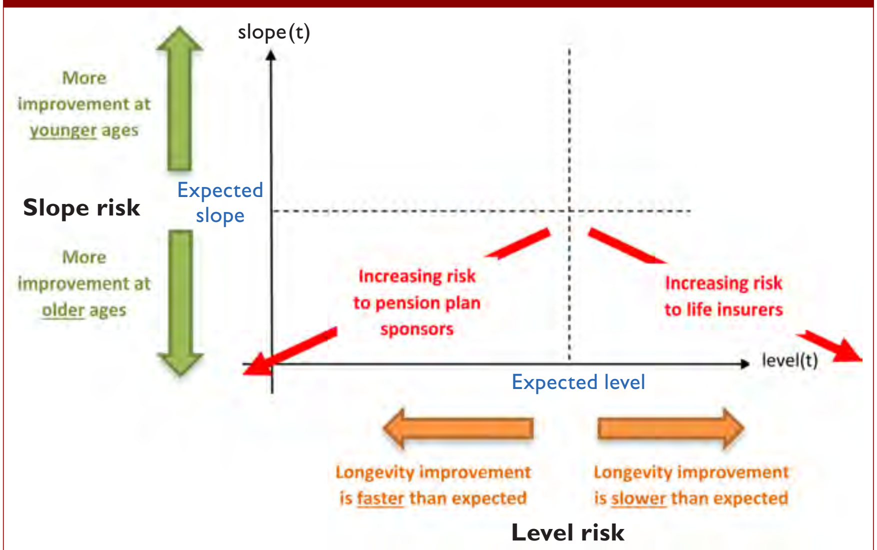
- First, the mortality curve moves down over time, which means that overall mortality (the level) decreases across time. Detailed analysis conducted on Singapore, Australia, and Hong Kong data supports this trend.
- Second, the curve becomes steeper, which means mortality declines faster at younger ages than at older ages.

The model specification is fairly straightforward for use in practice. Considering these two parameters (level and slope) jointly as mortality indexes can capture different kinds of movements in the underlying mortality curve. A curvature term, a third index, may also be added to the model structure where necessary.

Figure 2 further illustrates the model's implications, in which longevity risk is divided into two components: "level risk" and "slope risk". The dotted lines in the middle indicate the expected index values. Consider a pension plan for retirees, and an insurer selling term life insurance to young adults. The pension provider will incur a loss if the level or the slope is lower than expected, while the life insurer will suffer when the level turns out to be high or the slope turns out to be small.

In spite of all the advantages, the CBD model, like many other mathematical models, may not give a "perfect" fit to the data. What makes it stand out is mainly its new-data-invariant property, which allows an investor or risk hedger to track the index values.

Figure 2: Impact of level risk and slope risk



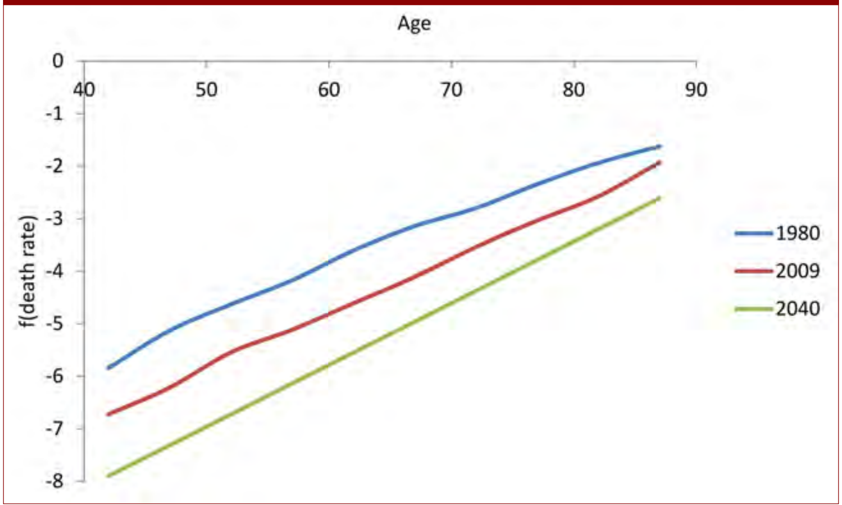
Using the CBD model to create mortality indexes can be compared with applying the Black-Scholes option pricing model to construct the Chicago Board Options Exchange (CBOE) implied volatility indexes. Both models may not be entirely accurate, but they do generate well-defined indexes that are trackable by users.

Practical applications of the CBD Model and derivatives linked to mortality indexes

The CBD model can readily be fitted to historical mortality data. The level and slope parameters are then extrapolated to the future, and mortality forecasts can be formed.

Figure 3 plots the projected mortality curve for Singapore males. It can be seen that the level of mortality is expected to continue to decrease, and the projected decrease is faster at younger ages.

Figure 3: Projected mortality curve for Singapore males



Moreover, standardised derivative securities that are associated with the two CBD mortality indexes can be written for the purpose of transferring longevity risk. We propose a security called "K-forward", which is effectively a zero-coupon swap that exchanges, on the maturity date, a pre-determined fixed amount for a random amount related to a CBD mortality index.

> The payoff to the fixed receiver from a K-forward is
> $$\$X(\tilde{\kappa}_T - \kappa_T),$$
> in which X is the notional dollar amount, T is the maturity date, κ_T is the level or slope, and $\tilde{\kappa}_T$ is the forward value.

Payouts from a combination of properly calibrated K-forward contracts can potentially offset the undesired future outcomes of an annuity portfolio or a pension plan. Further research is needed to find the best way to exploit these derivatives and to examine how a longevity hedge can be structured effectively.

The IRFRC was established in 2011 to produce research and extend the dialogue on insurance and insurance-related risk in the Asia-Pacific region. The ideas expressed in this article present the views of the named researchers. For more information, see irfrc.com.

More technical details can be found in: W.S. Chan, J. Li, and J.S.H. Li, 2012, The CBD mortality indexes: modeling and applications, Longevity 8, Waterloo, Canada.