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Quantifying the Mortality–Longevity Offset

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Life insurance and annuities have opposite sensitivity to changes in life expectancy. If life expectancy increases, life insurers will experience a loss on their annuity portfolios because they must make benefit payments for a longer period. However, increased life expectancy will have an opposite effect on the value of life insurance portfolios—they will gain in value because they will receive premiums longer, and the death benefit payment will be further in the future, reducing its present value. The exact amount of the hedge benefit from maintaining these two classes of business has not been easy to assess using statistical methods. The typical age profiles of the two classes of business are very different (a typical life insurance policyholder is 30–50, whereas a typical annuitant is 60–90), and there can be great disparity between the amounts at risk. Other differences, including portfolio country, gender balance, policy term structures, and other issues make the two business lines quite dissimilar.

Many life insurers understand this offset in concept, but have a difficult time factoring it into business decisions because of the lack of ability to quantify it. This article introduces a robust framework for quantifying the offset between mortality and longevity risk, and illustrates how it can be applied to assessing the risk of a longevity risk transfer transaction.

LIFE INSURANCE AND ANNUITIES CREATE OFFSETTING RISKS

To understand the offset between life insurance and annuities, we will examine the simplest version of these contracts: a term life insurance policy and a single-premium immediate annuity:

- Term life insurance policy
  - Receive level premiums over the life of the policy
  - Pay out death benefit upon death of the insured
- Single-premium immediate annuity
  - Receive a single premium at the start of the annuity
  - Pay out level payments until the death of the annuitant

To illustrate the mortality–longevity offset, let’s imagine that we had a portfolio of life insurance policies on a pool of 60-year-old U.S. males, and a portfolio of annuity contracts also on a pool of 60-year-old U.S. males. This is an unrealistic scenario, since we expect the holders of life insurance policies to typically be much younger than the holders of annuities, but we are using this example to illustrate the “best case” for the mortality–longevity offset. As life expectancy increases in this population, we would expect...
a gain in the value of the life portfolio, as the insurers would receive more premiums and defer the payment of the death benefit. The annuity portfolio would suffer a loss in value, as the insurer would need to make more annuity payments than expected. Given that the underlying populations are the same, you would expect that we could construct a “hedge ratio” that represents the best hedge between the life insurance contract and the annuity.

When simulating 10,000 hypothetical paths of future mortality improvement, we find that the two portfolios have a correlation of $-94\%$. That is, they are almost a perfect hedge for one another. We can see this by looking at a scatterplot of present value of the annuity portfolio against the present value of the life insurance portfolio (see Example 1). Each dot on the graph represents a different hypothetical path of future mortality improvements. Note that the dots on the graph lie on a nearly straight line; the deviations from a pure line are due to differences in the durations of the portfolios.

The optimal hedge ratio is reached when the standard deviations of the liability values for the two portfolios are equal. For this portfolio, we offset $24.55$ of face amount of the life portfolio against $12.80$ present value

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**Example 1**

Stylized “Perfect Hedge” Portfolio

**Assumptions**

- Two portfolios of 60-year-old U.S. males, one for term life, one for annuities
- Fully correlated mortality—this assumes that the portfolios consist of identical individuals; otherwise, there would be some breakdown in mortality correlation
- Term length of 20 years, lapsing at 3% per annum
- Interest rate of 5%
- No escalation on the annuity benefits
of the annuity portfolio, for a hedge ratio of roughly 2 to 1 (see Exhibit 1).

Note that for a more realistic portfolio (e.g., one where the typical age for the term life portfolio is 40 years old), we typically see the optimal hedge ratio between the face amount of the life portfolio and the present value of the annuity portfolio to be 10 to 1.

HOWEVER, QUANTIFYING THE MORTALITY–LONGEVITY OFFSET IS COMPLEX

If the world were as simple as the stylized example in the previous section, the task of constructing offsetting portfolios of life policies and annuities would be simple—and we would see many more life insurers using hedging to manage their mortality risk (as they currently do for interest rate risk). Unfortunately, the stylized example of the mortality–longevity offset in the previous section is far from reality for life insurers. The effectiveness of the offset that insurers experience is reduced by several factors:

- **Different ages:** The typical age range for life insurance policyholders is 45–55; the typical age range for an annuitant is 65–75.
- **Different countries:** Many life insurers and reinsurers are now global, requiring the calculation of the mortality–longevity offset across different countries.
- **Different products:** Different life and annuity products have different cash-flow characteristics. For example, the offset between term life and individual annuities could be very different from the offset between whole life and group annuities.

It’s intuitive to think that each combination of age band, country, and product (let’s call this a “cell”) will be subject to its own distinct set of possibilities for future mortality improvements. For example, a country where a high percentage of the population are smokers will have a bigger potential gain from improvements in lifestyle than a country where fewer people smoke. Therefore, to understand the mortality–longevity offset more broadly, we need to have a model of future mortality improvement for each cell.

How, then, can we model future mortality improvement for each cell? While it’s tempting to try to measure historical correlation of mortality improvements, and assume that the future will resemble the past, this approach does not work for this problem. The reason is that “catastrophic” changes in longevity come from regime shifts, rather than year-on-year volatility. Exhibit 2 illustrates the historical regime shifts that changed the prevailing level of mortality improvement trend. Any effective ex ante risk model would need to model the potential for these regime changes to impact mortality improvement.

Each cell’s relationship to these regime shifts determines how much its mortality improvements will be correlated with other cells. For example, the cardiovascular disease revolution caused more mortality improvement in countries where the prevalence of unhealthy diets and other risk factors was higher to begin with.

Therefore, we first need a model of the future drivers of mortality risk; then we need to understand the correlations among these drivers; finally, we need to understand how each population sub-segment is impacted by each driver. Only then can we create a set of correlated future mortality paths that we can use to evaluate the mortality–longevity offset.

THE SOLUTION: A STRUCTURAL MODEL OF THE DRIVERS OF MORTALITY IMPROVEMENT

To meet the needs of quantifying the mortality–longevity offset, Risk Management Solutions (RMS) built its model around five drivers of mortality improvement, or “vitagions”:

- **Lifestyle**—behaviors that influence life expectancy, such as smoking, diet, and exercise
- **Health environment**—sanitation, pollution, housing quality, knowledge of and awareness of healthcare issues
- **Medical intervention**—current and future medical treatments that can impact life expectancy, such as statins and aspirin for cardiovascular disease
Regenerative medicine—techniques for repairing and renewing cells and organs, including stem-cell therapy and nanomedicine

- Anti-aging processes—therapies that involve changing the “biological clock” of cells to delay the speed at which they accumulate damage

We model two important characteristics of each vitagion. The first is that there is a limit to the speed of progress or new innovations within each vitagion. This is driven, for example, by the regulatory environment (e.g., the multi-year FDA approval process in the U.S.). The second is the “burnout” of each vitagion: Over time, the impact of a given vitagion declines as more and more of the population receives the mortality improvement benefit from that vitagion. See an example of the vitagion “waves” in Exhibit 3.

The risk model for each vitagion is a constrained version of the Lee–Carter model, a common statistical model used by the actuarial community to model lon-
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The parameters that drive the risk models are:

- Mortality improvement trend
- Mortality improvement limit ($V_{\text{max}}$)
- Path volatility
- Trend volatility
- Correlations.

We parameterize one of these constrained statistical models for each “cell” that represents the combinations of the following categories:

- Country
- Age band
- Vitagion
- Gender.

Now that we have a risk model for each of the five “vitagions,” we can develop correlations among each of the cells by using the following approach (see Exhibit 5):

1. Measure historical correlations in mortality improvement (over 5-year periods) between aggregate population indices in developed countries.
2. Analyze how the correlation varies by age, gender, and country.
3. Distribute the correlation among the vitagions, such that the 5-year target correlation values are maintained, while obeying the following medically driven constraints:

   - $\rho_{\text{path}} < \rho_{\text{trend}}$
   - $\rho_{\text{health environment}} < \rho_{\text{lifestyle}} < \rho_{\text{medical intervention}}$

Although the 5-year correlation at the aggregate population level is pegged to the historical data, Step 3 in the process is a forward-looking view based on medical analysis and expert judgment.

The output from the RMS longevity model is a set of tables that describes the future path of mortality for a given cell. These are called $q_x$ tables, where $q_x$ is the probability that someone age $x$ will die before reaching age $(x + 1)$. The tables generated are also correlated; that is, simulated changes in mortality across cells obey the correlation assumptions outlined in the previous section of this article.

**Model Results: The Mortality–Longevity Offset Is Significant and Variable**

Now that we have a set of correlated $q_x$ tables by cell, we can calculate the correlations across various books of business. We do this for each simulated sce-
Recall that the stylized example that we analyzed earlier had the unrealistic assumption that the insured population for a term life portfolio was the same 60-year-old male population as the insured population for the annuity portfolio. This portfolio had a negative correlation of $-94\%$—a nearly perfect offset. When we look at a more realistic term life portfolio (average age of 50 years) offset against a realistic annuity portfolio (average age of 70 years), we see a correlation of $-82\%$. (Example 2). This is a somewhat lower but still significant offset.

The main reason that this offset is weaker is that we are dealing with different insured populations in different socioeconomic circumstances who may be impacted by medical treatments or lifestyle advances at different rates.

Moving to a third example, we can look at the strength of an offset between different countries: a U.S. term life portfolio versus a U.K. annuity portfolio (Example 3). These portfolios have a correlation of $-58\%$. While this still represents a sizeable offset, it is lower than the previous example of term life versus annuity, both in the U.S. The main driver behind this is the breakdown in vintagion correlation across countries. For example, government investment to reduce smoking or obesity may be quite different between the U.S. and the U.K.
ADDING LONGEVITY RISK CAN REDUCE MORTALITY TREND RISK

The implication of strong negative correlations between life insurance and annuities is profound. This means that a life insurer that has only mortality risk (writing only life insurance policies and no annuities) can reduce its overall risk by taking on longevity risk (see Exhibit 7). The fact that life insurers typically get paid a risk premium for taking on longevity risk gives rise to the following unusually attractive financial proposition:

Adding longevity risk reduces risk (and associated risk capital) while paying a positive return.

It is important to note that as an insurer accumulates longevity risk, the strength of the negative correlation declines. At some point, longevity risk accumulates to the point that the marginal dollar of annuity risk begins to add to overall mortality trend risk. However, we estimate that most diversified life insurers have a long way to go until longevity risk begins to add trend risk to the balance sheet.

EXAMPLE 2
U.S. Term Life vs. U.S. Annuity

Assumptions

- Term life portfolio for U.S. males, average age 50 years
- Annuity portfolio for U.S. males, average age 70 years
- Term length of 20 years, lapsing at 3% per annum
- Interest rate of 5%
- No escalation on the annuity benefits
THE LOGICAL CONCLUSION: LONGEVITY RISK FINDS OFFSETTING MORTALITY RISK

Modeling the mortality–longevity offset provides a quantitative foundation for financial logic that has been shaping the market over the past several years. The logic is

- Life insurers with mortality risk and little longevity risk reduce their risk by adding annuities;
- Pension funds have no mortality offset, so are willing to pay to get rid of longevity risk;
- Earning a premium while reducing risk (and required capital) creates value for these life insurers; and
- The invisible hand continues to push longevity risk out of pension funds into life insurers.

**Example 3**

**U.S. Term Life vs. U.K. Annuity**

**Assumptions**

- Term life portfolio for U.S. males, average age 50 years
- Annuity portfolio for U.K. males, average age 70 years
- Term length of 20 years, lapsing at 3% per annum
- Interest rate of 5%
- No escalation on the annuity benefits

**Exhibit 7**

**Mortality Trend Risk**
A small number of large life insurers and reinsurers have recognized this and have already built significant operations to source longevity risk. As more insurers adopt structural models that allow them to quantify the mortality-longevity offset, more will realize the attractiveness of taking on longevity risk, thus creating a larger, more active market for longevity risk. As the vehicles for transferring longevity risk mature, longevity risk should flow more smoothly from pension funds onto the balance sheets of all life insurers, thereby creating firms with an efficient balance of mortality and longevity risk.

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