# Catastrophic Mortality Bonds: Analysing Basis Risk and Hedge Effectiveness

Alex Huynh, Bridget Browne, Aaron Bruhn

*A Huynh, Booz & Co, Sydney, Australia*
*B Browne and A Bruhn, Australian National University, Canberra, Australia*

Phone: +61 2 6125 7373
Fax: +61 2 6125 0087
Email: bridget.browne@anu.edu.au

**Abstract**          Life insurers are exposed to catastrophic mortality risk.  Catastrophic mortality bonds are a recent market innovation that provide an alternative risk management tool to address this risk.  However there is little in the way of published studies which examine their effectiveness, given that they are subject to basis risk arising from the use of country level general population mortality in their construction.  By constructing a typical mortality risk portfolio and calibrating a bond for this portfolio, the hedge effectiveness of the instrument is analysed under a wide variety of circumstances.  We find that on a stand-alone basis, hedge effectiveness may be too low to be acceptable to small to medium insurers.  However, effectiveness of the bond increases when used in combination with surplus reinsurance and/or when pooling is used to increase portfolio size.

# 1 Introduction

Life insurers and reinsurers are exposed to the risk of future mortality uncertainty. Catastrophic mortality events pose a significant threat to the life insurance industry as they cause a sudden increase in mortality over a short period of time, which may lead to a substantial rise in claims and the potential for severe adverse financial consequences, such as breaches in regulatory solvency and capital requirements (Cox and Hu, 2004).

Although there are a range of catastrophic mortality events that may impact the life insurance industry, an influenza pandemic is considered the most serious threat. The exposure to catastrophic mortality events such as influenza pandemics has been difficult for life insurers and reinsurers to manage since the probability of such events occurring in any year is low while the potential for devastating losses is high. Catastrophic mortality bonds are a recent capital market innovation that provide an alternative risk management tool to hedge against catastrophic mortality events. In contrast to the inherent credit risk associated with traditional reinsurance, they bear essentially no credit risk for sponsors (Bagus, 2007). However, catastrophic mortality bonds are not indemnity based as the payoff trigger is based on a specified mortality index, which is calculated as a weighted average of general population mortality rates (Cowley and Cummins, 2005). Consequently, the issue of basis risk arises, resulting in imperfect hedge effectiveness as the possibility exists for gains or losses in the hedged position. In particular, the sponsor is concerned that the bond payoff will be inadequate to cover the actual loss suffered (Coughlan et al., 2011).

This article quantifies the basis risk and hedge effectiveness of catastrophic mortality bonds in order to explore the level of coverage they provide for sponsors. It examines the use of catastrophic mortality bonds in hedging against additional claims arising from an influenza pandemic using an individual fully underwritten yearly renewable term (YRT) insurance portfolio as a practical example. It does not attempt to develop a definitive catastrophic mortality model, as this is not required for our purposes here. Interested readers may use this as a guide for application to their own specific portfolios.

Overall, we find that there is significant variation in the basis risk and hedge effectiveness of catastrophic mortality bonds. The findings suggest that catastrophic mortality bonds are a viable alternative risk management tool for large portfolio sizes, for portfolios where the distribution of exposed sums insured is less spread, and where the life insurer's underlying exposure remains relatively stable. Hence the pooling of small to medium portfolios and/or the use of surplus reinsurance to homogenise the distribution of sums insured may be effective risk management strategies to adopt concurrently with implementation of a catastrophic mortality bond.

The remainder of this article is structured as follows. Section 2 briefly outlines the epidemiological characteristics of influenza pandemics in order to set the scene for the calibration of a bond issuance and discusses the life insurer's management of catastrophic mortality risk arising from an influenza pandemic. Section 3 provides an overview of the catastrophic mortality bond market, the key features of the bonds and concepts of basis risk and hedge effectiveness. Section 4 describes the methodology adopted for the analysis. Section 5 reports the results obtained and summarises key findings. Section 6 concludes.

## 2  Influenza pandemics

### 2.1  *Epidemiological characteristics*

While seasonal influenza epidemics usually occur during the autumn and winter months in temperate regions and all year round for tropical and sub-tropical regions, the emergence of influenza pandemics is not constrained by season (Nguyen-Van-Tam and Hampson, 2003) and it is reasonable to believe that influenza pandemics may appear at any time during the year.

In contrast to seasonal influenza epidemics that occur annually, influenza pandemics are rare and unpredictable events, which have occurred irregularly throughout history. To date, there is no identified chronological pattern that would allow us to predict the occurrence of future influenza pandemics (Potter, 2001).  Influenza pandemics have been characterised by multiple waves of infection with varying impact occurring over two calendar years.  A variety of patterns have been observed regarding duration and severity, which will be incorporated in later modelling.

This paper does not attempt to develop a sophisticated or micro-level approach to modelling pandemic risk, as this is not required to illustrate the issue of basis risk.

### 2.1.1  Excess mortality rate

Evidence suggests that influenza pandemics may cause considerably higher, excess mortality (defined as the difference between the observed mortality rate and the expected baseline mortality rate in the absence of an influenza pandemic (Simonsen et al., 1997)), but this impact is difficult to quantify because influenza may not be listed as a cause on the death certificate for many influenza related deaths (Woolnough et al., 2007). Consequently, the all-cause excess mortality and influenza- and pneumonia-specific excess mortality can be considered as the upper and lower bounds of mortality attributed to an influenza pandemic, respectively. The excess mortality rate has varied significantly among the influenza pandemics of the last 100 years, as illustrated in Table 1.

**Table 1: Estimated excess mortality rates for the influenza pandemics of the 20th and 21st century**

| Name | Global excess mortality rate (per 1,000) [a] | U.S. excess mortality rate (per 1,000) [a] |
|---|---|---|
| 1918-1919 Spanish Flu | 27.60 – 55.20 | 4.81 – 6.50 |
| 1957-1958 Asian Flu | 0.34 – 0.69 | 0.38 – 0.46 |
| 1968-1969 Hong Kong Flu | 0.28 | 0.14 – 0.17 |
| 2009-2010 H1N1 Flu | Not available | 0.02 – 0.14 |

*Sources: Dauer & Serfling (1961); Glezen (1996); Simonsen et al. (1998); U.S. Census Bureau (2000, 2011a, 2011b); U.S. Department of Health & Human Services (2011); United Nations (1999); Viboud et al., (2010); World Health Organisation (2005)*
[a] The excess mortality rate is calculated as the number of excess deaths divided by the average of the population over the influenza pandemic.

It is important to note that death rates during pandemic events are unlikely to satisfy the standard (and necessarily simplified) assumption of independence between lives. However, we will make this assumption in later modelling for simplicity, the implication being that the results may be somewhat understated.

### 2.1.2  Age-specific distribution of excess mortality rates

The age-specific distribution of excess mortality rates for seasonal influenza epidemics typically has a "U" shape curve representing high mortality among infants and the elderly with comparatively low mortality rates at ages in between (Nguyen-Van-Tam and Hampson, 2003). On the other hand, the age-specific distribution of excess mortality rates for influenza pandemics has tended to affect a higher proportion of persons under 65 years of age than seasonal influenza. This is often attributed to the partial immunity that many persons over 65 years of age may have retained from exposure to similar influenza infections as children or young adults (Nguyen-Van-Tam and Hampson, 2003). The age-specific distribution of excess mortality rates for the last four influenza pandemics have exhibited either "U", "V\", or "Λ" shapes and have been similar for both genders. Further details on the level and characteristics of these distributions may be found in Huynh et al. (2013).

### *2.2  Catastrophic mortality risk management*

### 2.2.1  Risk identification

For most life insurers, death benefit products constitute the majority of their risk business and as a result, they are likely to experience a significant loss from an influenza pandemic. This has the potential to severely impact the life insurer's results and may lead to breaches of solvency requirements.

### 2.2.2  Risk measurement

Life insurers assess the potential impact of influenza pandemics with risk modelling and scenario testing. Internal risk models are commonly used to assess a full range of (perceived) risks and to take into account dependencies between different risks and exposures, which can be complex. Since influenza pandemics are rare events, there is scarce data to calibrate a number of uncertain parameters required in the models. This is typically dealt with through sensitivity testing (Baumgart et al., 2007).

Several studies have examined the potential impact by estimating the additional cost based on a range of deterministic scenarios derived from historical influenza pandemics. It is apparent from Table 2 that a wide range of outcomes are considered possible. In general, the studies conclude that the life insurance industry can absorb the impact of a severe pandemic, but will incur significant decreases in profit and capital. It is also noted that the life reinsurance industry will be more heavily impacted since reinsurance is essentially pure mortality risk business, and that the advantage conferred by reinsurers' geographical diversification ceases to apply in the event of a pandemic (Dreyer et al., 2007, APRA, , 2007).

**Table 2: Summary of assumptions and results from studies examining the potential impact of an influenza pandemic on the life insurance industry**

| Author(s) | Country | Severity [a] | General population excess mortality rate (per 1,000) | Age-specific distribution of excess mortality rate | Excess mortality rate ratio of insured versus general population (%) [b] | Influenza pandemic duration (Years) | Results: additional gross claims (AGC) or additional net claims (ANC) |
|---|---|---|---|---|---|---|---|
| APRA (2007) | Australia | Severe | 1.0 | Flat | 100% | 1 | AGC: AUD 1.2 billion |
| Dreyer, Kritzinger & Decker (2007) | South Africa | Mild Moderate Severe | 0.40 1.40 20.0 | "W" "W" "W" | Group life: 70% Individual life: 40% * | 1 1 1 | AGC: ZAR 0.753 billion AGC: ZAR 2.7 billion AGC: ZAR 37.6 billion |
| Stracke (2007) | Germany | Severe | 6.4 | "W" | 100% | 1 | ANC: EUR 5.1 billion |
| Toole (2007) | U.S. | Moderate Severe | 0.70 6.5 | "U" "\/\" | 57.1% 76.9% | 1 1 | ANC: USD 2.8 billion ANC: USD 64.3 billion |
| Weisbart (2006) | U.S. | Moderate Severe | 1.07 4.81 | "_/" "U" | 100% 100% | 1 1 | AGC: USD 31 billion AGC: USD 133 billion |

[a] Severity ratings are specified by each of the authors of the study.
[b] The excess mortality rate ratio of insured versus general population reflects the potential for better mortality experience in the insured population relative to the general population in an influenza pandemic scenario.
* The excess mortality rate ratio of insured versus general population for Dreyer, Kritzinger & Decker (2007) is the same across all three scenarios, but is differentiated into group life and individual life products.

### 2.2.3 Risk management

Retention of catastrophic mortality risk is possible, but is unlikely to be economically efficient. Clearly, geographic diversification is not as effective as with other, localised, catastrophic mortality events since an influenza pandemic is likely to affect multiple geographical regions around the world. Diversification across lines of businesses is also somewhat limited because health and general insurance business may also be affected. On the other hand, annuity business may provide a natural hedge as the value of protection and annuity liabilities move in the opposite direction in response to a change in mortality (Cox and Lin, 2007). This will however depend on the age-specific distribution of excess mortality rates as life insurers primarily write protection policies to younger age groups and sell annuity policies to older age groups.

Life insurers can transfer mortality risk through reinsurance. However, this exposes the insurer to credit risk because the reinsurer may develop solvency issues due to a pandemic event causing them to default on their obligations or be slow to pay reinsurance

claims (Baumgart et al., 2007). An alternative is a catastrophic mortality bond, which essentially eliminates credit risk when well designed. These instruments offer several advantages and disadvantages compared to reinsurance, which are discussed in Huynh et al. (2013) along with an introduction to the market and key features of these instruments. A key disadvantage is the presence of basis risk, which is discussed in the following section.

## 3    Catastrophic mortality bonds – basis risk and hedge effectiveness

Basis risk arises whenever there are differences between an underlying hedged portfolio and the associated hedging instrument. Its presence implies imperfect hedge effectiveness because there is a possibility of gains or losses in the hedged position. This does not necessarily invalidate the case for hedging because basis risk can be minimised by appropriately structuring and calibrating the hedging instrument to ensure high hedge effectiveness. If the basis risk is small relative to the risk of the initial unhedged position then it is possible for the hedging strategy to be beneficial (Coughlan et al., 2011).

The issue of basis risk has been examined for several index-based insurance linked securities (ILS). In non-life, industry loss warranties, catastrophic loss index securities and catastrophe insurance linked contracts have been examined (see, for example, Cummins et al., 2004, Harrington and Niehaus, 1999, Zeng, 2000). In life, the extant literature has primarily focused on longevity linked securities (see, for example, Coughlan et al., 2011, Cairns et al., 2011, Ngai and Sherris, 2011). To the authors' knowledge, there has been no published literature on the analysis of basis risk and hedge effectiveness for catastrophic mortality bonds.

In the context of catastrophic mortality bonds, basis risk could arise from differences between general and insured populations due to initial or emerging mismatches in age, gender, geographical location and socioeconomic class (Coughlan et al., 2011)[1]. As age, gender, country and financial exposure in the form of sum assured can be calibrated to match that of the life insurer's initial underlying exposure, one important determinant of basis risk is therefore associated with mismatches of socioeconomic class (Richards and Jones, 2004).

Some historical evidence from an 1889 pandemic (Mead, 1919) and the 1918-19 pandemic in Craig and Dublin (1919) and Little (1919) suggests that the impact of underwriting and economic self-selection will continue to result in lighter mortality experience in the insured population in the event of an influenza pandemic, as compared to the general population. In addition, a study on the 1957-1958 and 1968-1969 influenza pandemics observes approximately 12% lower excess death rates in standard ordinary policyholders compared with age and gender matched general population (Woolnough et al., 2007), consistent with other findings such as Metropolitan Life Insurance Company (1976).

However, basis risk remains even if similar characteristics are shared or differences are calibrated for, simply because the two populations are not the same people.
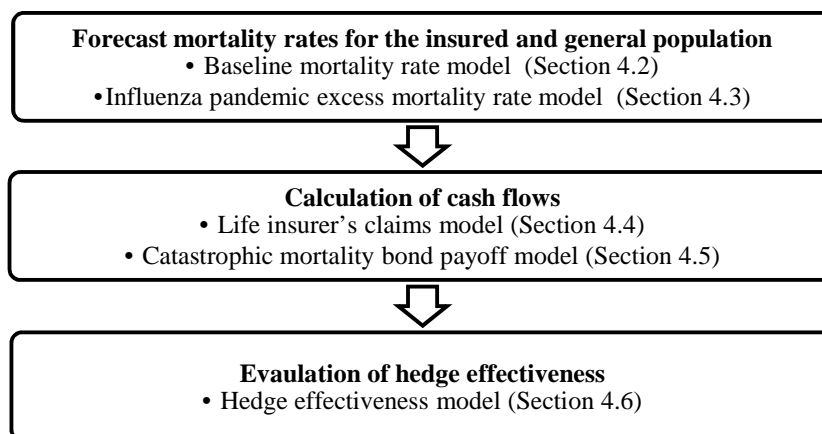
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[1] This is additional to the issue of differing overall mortality experience between general and insured populations. Insured mortality may be significantly lower than that of the general population due to the impact of underwriting and economic self-selection, with differences dependent on age, gender, smoking class, policy duration and underwriting type (Toole, 2007)

## 4 Methodology

### 4.1 Overview of framework

The framework for assessing basis risk and hedge effectiveness is adapted from Coughlan et al. (2011) and is shown in Figure 1. The life insurer's claims are determined by the insured population mortality rates while the catastrophic mortality bond payoff is determined by the general population mortality rates. The evaluation of hedge effectiveness uses simulations of the forecast mortality rates to calculate these cash flows, which are used to calculate the hedge effectiveness.

**Figure 1: Framework for assessing basis risk and hedge effectiveness**



**Forecast mortality rates for the insured and general population**
• Baseline mortality rate model  (Section 4.2)
•Influenza pandemic excess mortality rate model  (Section 4.3)

**Calculation of cash flows**
• Life insurer's claims model (Section 4.4)
• Catastrophic mortality bond payoff model (Section 4.5)

**Evaulation of hedge effectiveness**
• Hedge effectiveness model (Section 4.6)

*Source:Modified from Coughlan et al. (2011)*

### 4.2 Baseline mortality rate model

The baseline mortality model forecasts the baseline mortality rate for the general and insured population. The baseline mortality rate is defined as the future annual mortality rates assuming that no catastrophic mortality event occurs. In this paper, Australian mortality is used, however the methodology would be the same for any country or countries where an insurer may have exposure.

#### 4.2.1 Life tables and mortality improvements

The Australian Bureau of Statistics (ABS) 2007-2009 life tables are the basis for the Australian general population mortality. The mortality of the Australian insured population is based on the IA95-97 life tables published by the Institute of Actuaries of Australia.

Both life tables are assumed to improve by the Australian Government Actuary (AGA) 25 year mortality improvement trend to 2010, to establish the starting point for the bond.  For projecting beyond 2010, a divergence in the rate of change in mortality rates could have an impact on hedge effectiveness. Therefore, three possible mortality improvement trends are considered for both general and insured populations: the AGA 25 year mortality improvement trends, the 100 year mortality improvement trends, and no mortality improvement.

### *4.3 Influenza pandemic excess mortality rate model*

This component forecasts the excess mortality rate for the general and insured population in the event that an influenza pandemic occurs. The excess mortality rate is modelled explicitly and not decomposed into the clinical attack rate and case fatality rate, and is modelled only as age-specific and not gender-specific.

It is uncertain whether increases in mortality caused by a historical influenza pandemic should be treated as additive (i.e. absolute) or multiplicative (i.e. relative) to baseline mortality rates for the purpose of estimating future impact of a 'similar' pandemic.[2] In accordance with existing studies, we have modelled the pandemic as additive.

There are two broad sources from which to develop the assumption: actual historical influenza pandemic mortality data as described in Section 2.1 and assumptions used by studies examining the potential impact of an influenza pandemic as described in Section 2.2.2. The 20th century influenza pandemic mortality data is difficult to apply to today's situation, due to significant environmental changes including improvements in medical care and technology, establishment of global health monitoring and early warning systems, better communication methods and improved socio-economic conditions (Baumgart et al., 2007). On the other hand, some changes may increase the impact of future influenza pandemics such as a higher percentage of the population at older ages, increased urban population density and increased human mobility (Faulds and Bridel, 2009). There are no explicit adjustments made to account for these changes in this paper given the substantial uncertainty surrounding their impact. In any case, the range of historical influenza pandemic severities already provides a wide range of potential scenarios.

### 4.3.1 Overall general population excess mortality rate

The range of general population excess mortality rate assumptions used by the influenza pandemic studies is broadly consistent with the range of U.S. excess mortality during the past four influenza pandemics (as shown in Table 1 and Table 2). The 1918-1919 Spanish Flu is generally considered as the upper bound on future influenza pandemic mortality, even though there is evidence to prove that this represent the maximum possible mortality (Murray et al., 2006). Notwithstanding, historical experience suggests that the general population excess mortality rate may vary between 0 and 5 per 1,000.

### 4.3.2 Age-specific distribution of excess mortality rates

For the purposes of this paper, four shapes of age-specific distribution of excess mortality rates are considered: "U", "V\" and "W" and a flat curve. The first three, introduced in Section 2.1.2, are coherent with the studies shown in Table 2, and a flat shape is considered as a reference point for the other shapes. Each "shape" is calibrated to the age structure of (in this case) Australia to ensure that the overall excess mortality rate assumed to be observed is consistent with the actual overall excess mortality rate.

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[2] For example, the Spanish Flu caused an additive increase to baseline mortality rates of approximately 5 per 1,000 or a multiplicative increase of 30% of baseline mortality rates. But because baseline mortality rates have decreased over time, the two approaches produce quite different results when applied to current baseline mortality rates. To continue the above example, applying the additive increase to the Australian standardised baseline mortality rate of 5.7 per 1,000 results in a multiplicative increase of 88% instead of 30%.

### 4.3.3 Excess mortality rate ratio of insured versus general population

Potential differences in mortality between insured and general populations in the event of a pandemic are unclear since the effects of underwriting and economic self-selection may cease to apply. As a result of their higher socioeconomic status the insured population may have better access to healthcare and be more educated about the impact of influenza, but on the other hand also more likely to engage in international travel and live in high density urban areas. A lack of data exacerbates this uncertainty. Woolnough (2007) suggests an insured to general population mortality ratio of 88% from the 1957-1958 and 1968-1969 influenza pandemics, and as per Table 2 the ratio assumed by influenza pandemic studies ranges from 40% to 100%.

In this paper, the mortality ratio of the insured versus general population is assumed to vary from 40% to 120% to capture the uncertainty regarding this relationship.

### 4.3.4 Duration of the influenza pandemic and severity of waves each year

Historical evidence from Section 2.1 suggests influenza pandemics may begin at any time during the year, and also indicates that influenza pandemics have varying severity of waves over two calendar years. In contrast, influenza pandemic studies assume that the duration is one year as shown in Table 2. We assume that the influenza pandemic occurs with varying severity of waves each year over one, two or three calendar years.

### *4.4 Life insurer's claims model*

The life insurer's claims model simulates the aggregate annual claims for a typical life insurer's portfolio of individual fully underwritten YRT insurance. This requires assumptions about the number of policies, average sum insured and distribution of sum insured by age and gender.

The aggregate annual simulated claims include sampling risk, which is the risk that the "realised" mortality is different from the "intrinsic" mortality due to a small population size. A Bernoulli distribution is used to model the death process of each policyholder where the policyholder dies if a simulated random number between 0 and 1 is less than the policyholder's mortality rate. This is likely to be an understatement of the true pandemic mortality risk, since, as identified in 2.1.1, death rates during pandemics are almost certainly not independent events, however this is acceptable to demonstrate the minimum basis risk that may present.

The portfolio is assumed to be comprised of 20,000 policies. A relatively small portfolio size is chosen for ease of calculation and because it is more effective in illustrating the relative impacts on hedge effectiveness from varying key parameters. The portfolio composition by age and gender is as shown in Table 3. The smoker status of policyholders was not considered as baseline mortality and influenza pandemic excess mortality rates are not subdivided by smoker status (although this may also contribute to basis risk).

**Table 3: Portfolio composition by age and gender**

| Age band | Male | Female | Age band | Male | Female |
|----------|------|--------|----------|------|--------|
| 15-24[*] | 0.6% | 0.8% | 55-64 | 6.2% | 1.5% |
| 25-34 | 10.6% | 9.1% | 65-74 | 0.0% | 0.0% |
| 35-44 | 22.9% | 16.7% | 75+ | 0.0% | 0.0% |
| 45-54 | 21.7% | 9.9% | *Subtotal* | *62.0%* | *38.0%* |

*Source: Hayes (2008), as per IA95-97 life tables* [*]A minimum age of 18 is assumed.

The portfolio composition remains static over the risk period. The average sum insured is assumed to be $365,000, based on a 2007 YRT average sum insured of approximately $330,000 (Palmer, 2009). Table 4 provides the gender-specific distributions of sum insured by age.

**Table 4: Male and Female distribution of sum insured by age band**

| Male / Female Age band | Sum insured bands | | | | |
|---|---|---|---|---|---|
| | $20k - $150k | $150k-$500k | $500k - $1m | $1m - $3m | $3m - $5m |
| 34 and less | 55% / 65% | 33% / 26% | 10% / 8% | 2% / 1% | 0% 0% |
| 35 – 54 | 40% / 60% | 29% / 24% | 20% / 12% | 9% / 3% | 2% / 1% |
| 55 & greater | 70% / 80% | 20% / 13% | 8% / 6% | 2% / 1% | 0% / 0% |

### 4.5 Catastrophic mortality bond payoff model

#### 4.5.1 Construction of contingent claim payoff mechanism

The catastrophic mortality bond payoff component models the contingent claim payoff mechanism, as described in the appendix and constructed following Swiss Re Capital Markets (2008).

#### 4.5.2 Calibration of the catastrophic mortality bond

The catastrophic mortality bond must be calibrated according to the life insurer's hedging objective, which for this paper is to protect against significant additional claims arising from a one year influenza pandemic causing a general population excess mortality rate of 1 to 2 per 1,000 with a "V" age-specific distribution. That is, we do not expect the insurer to want to pay for protection against every additional claim arising, they will only require protection once additional claims reach a financially stressful level.

Assuming an excess mortality rate ratio of insured versus general population of 80%, this equates to an insured population excess mortality rate of 0.8 to 1.6 per 1,000. The life insurer intends to retain the loss from claims caused by all baseline mortality plus excess mortality up to 0.8 per 1,000, referred to as 'retained claims'.

A general population excess mortality rate of 1 to 2 per 1,000 is chosen as this results in attachment and exhaustion points that are consistent with the range observed in the market. The "V" shape is chosen because this shape has the highest impact on insured lives.

The start of the risk period is assumed to be 1st January 2011, the maturity of the bond is five years, and the influenza pandemic is arbitrarily assumed to occur in 2013 and last for on year . We assume that the general and insured population mortality improvement follow the AGA 25 year trend.

For simplicity, there is only one tranche. The attachment and exhaustion point are chosen to be 122.33% and 151.77% as this is equal to the expected mortality index values with the given mortality assumptions at an excess mortality rate of 1 and 2 per 1,000. The size of age bands is set to five years consistent with previous transactions, while the age and gender weightings were fit to the portfolio. The principal amount is $6,466,841, set to the

expected aggregate claims between an excess mortality rate of 1 and 2 per 1,000. It should be noted that in reality the characteristics of a bond are also influenced by investor demand.

It is assumed that there is no sampling risk in the general population (in contrast to the life insurer's claims model).

## 4.6 Hedge effectiveness model

Hedge effectiveness can be defined as the degree of risk reduction of the unhedged exposure for a given risk metric (Cummins et al., 2004, Li and Hardy, 2011, Coughlan et al., 2011, Cairns et al., 2011). The unhedged and hedged exposures are defined as the value of the liability and the value of the liability plus the value of the hedging instrument, respectively. In this paper we define the hedge effectiveness (hereafter HE) realised for any specific simulation outcome in a given scenario as follows:

$$HE = 1 - \frac{AC - RC - \text{Bond Payoff}}{AC - RC}$$

Where:

| HE | The hedge effectiveness measure; |
|---|---|
| AC | Actual aggregate claims incurred; |
| RC | Retained claims, ie those the insurer was prepared to accept for their own account, caused by an general population excess mortality rate of 1 per 1,000; |
| Bond Payoff | The bond payoff |

The numerator is the hedged exposure and the denominator is the unhedged exposure. This means HE will be 100% when the bond payoff is exactly equal to the excess claims incurred (ie AC − RC): those against which the bond was intended to protect. Under-hedging occurs when HE is less than 100% indicating that the bond payoff is insufficient to cover the excess claims incurred. Over-hedging, when HE is greater than 100%, occurs when the bond payoff exceeds the excess claims incurred. HE cannot be less than zero as the bond payoff cannot be negative.

Estimated HE is examined at the median is as well as the mean. A key measure is the effectiveness of the hedge under more extreme circumstances, hence HE at the 5th percentile is examined as it indicates the minimum level of coverage with high probability.

We run 10,000 simulations at a general population excess mortality rate of 1 and 1.5 per 1,000 to obtain an empirical distribution of the retained claims and actual aggregate claims, respectively. An experienced excess mortality rate of 1.5 per 1,000 is chosen as it corresponds to the middle of the range of protection targeted. Each simulation generates a value for the actual aggregate claims and retained claims, which are used to calculate a value for the HE. The bond payoff is constant for a given set of assumptions, as it is determined by observation at population level

## 4.7 Sensitivity analysis

A sensitivity analysis is conducted on the characteristics of the life insurer's portfolio. In performing this analysis, the bond issuance is recalibrated for scenarios (A) 1. and (A) 2. below but not for scenario (A) 3. The changes that are considered include:

(A) 1.  Increasing the number of policies in the portfolio to 40, 60, 80 and 100 thousand, produced by replicating the original portfolio;

(A) 2.  A flat distribution of sum insured with an equivalent average sum insured; and,

(A) 3.  A portfolio composition with the age of policyholders increased and decreased by 5 years.

Given the inherent uncertainty surrounding future mortality, a sensitivity analysis is also conducted on the mortality assumptions. The changes that are considered include:

(B) 1.  Combinations of the AGA 25 year mortality improvement, 100 year mortality improvement, and no mortality improvement for each of the general and insured populations;

(B) 2.  An overall general population excess mortality rate (per 1,000) of 1.00, 1.25, 1.75, 2.00 and 2.25;

(B) 3.  An age-specific distribution of excess mortality rates of "U", "W" and flat;

(B) 4.  An excess insured to general population mortality rate ratio of 40%, 60%, 100% and 120%;

(B) 5.  The influenza pandemic occurs in 2011, 2012, 2014, or 2015; and,

(B) 6.  An influenza pandemic duration of 2 and 3 years with different severity of waves each year. The scenarios examined include a 2 year influenza pandemic with an excess mortality rate of 1 and 0.5 per 1,000 in the first and second year, respectively; a 2 year influenza pandemic with an excess mortality rate of 0.5 and 1 per 1,000 in the first and second year, respectively; and, a 3 year influenza pandemic with an equal excess mortality rate of 0.5 per 1,000 in each year.

The bond is not recalibrated for scenarios (A) 3. and (B) 1. through (B) 6. as the purpose is for potential issuers to examine the effect on HE of various possible outcomes once the bond has been put in place.  Given that actual outcomes will differ from those assumed in calibrating the bond, the question of interest is the extent to which the protection provided by the bond is impaired or possibly improved over a range of possible scenarios.


## 5   Results

### *5.1   Base scenario*

The base scenario represents the situation where actual mortality experience exactly matches the mortality assumptions used to calibrate the bond. Table 5 shows the estimated mean and variance of net claims, where net claims are defined as the aggregate claims minus the bond payoff. The mean and variance of the net claims increase when a pandemic occurs as the higher than expected mortality causes the death of more policyholders with varying sum insured amounts. The difference between the mean of net claims for the pandemic with no bond and pandemic with bond scenarios is equal to the bond payoff, which is constant under each deterministic scenario as no sampling risk was assumed in the general population. For this reason, the estimated variance of net claims is also the same for these two scenarios.

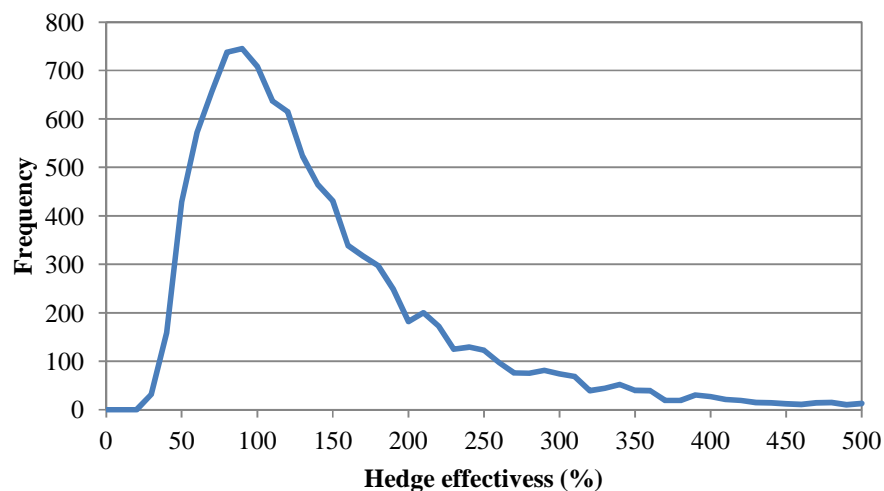**Table 5: Estimated average and variance of life insurer's net claims**

| Scenario | Estimated mean of net claims ($ Millions) | Estimated variance of net claims ($ Millions) |
| --- | --- | --- |
| No pandemic with no bond | 6.77 | 7.77 |

| | | |
|---|---|---|
| Pandemic with no bond | 16.38 | 18.35 |
| Pandemic with bond [a] | 13.15 | 18.35 |

[a] In this scenario, the bond payoff is is equal to $3.23 million or equivalently half the principal amount because the excess mortality of 1.5 per 1,000 assumed corresponds to the middle of the range of excess mortality rate targeted in the specified hedging objectives.

The distribution of HE under the base scenario is shown in Figure 2. While the peak frequency measure is near 100%, the median HE is 115%, the mean HE is 153%, and the HE at the 5th percentile is 48%. Despite the bond being calibrated on an expected value approach, the estimated mean HE is actually 153% and not 100% as intended which indicates intrinsic over-hedging. Here the bond provides on average 53% more coverage than required. The distribution of HE shows significant skewness, with a long right tail indicating the possibility of gains. This is caused by the combination of an HE measure floored at zero, a relatively small portfolio size and a non-uniform distribution of sums insured, and is key to the effectiveness or otherwise of catastrophic mortality bonds as an alternative risk management tool. Potential bond issuers should consider using simulation to assist in the design of an appropriate hedge instrument, but need to be aware of the risk that targeting a mean HE of 100% may lead to poorer HE at the 5th percentile. The impact of portfolio size and sum insured distribution is considered further in the scenarios chosen for the sensitivity analysis.

**Figure 2: Estimated distribution of HE under the base scenario**



### 5.2  Sensitivity analysis on the characteristics of the life insurer's portfolio

In the following analysis, the HE is considered to have improved when the HE at the 5th percentile increases and the mean and median HE remain above 100%. This indicates an adequate coverage on an expected value basis, with improved protection when the outcome is significantly adverse for the insurer.

### 5.2.1 (A) 1. Number of policies

Table 6 shows that as the number of policies increases, the estimated HE at the 5th percentile improves, and both the estimated median and mean HE decrease towards 100%. The latter result suggests that an expected value approach for calibrating the bond may result in a perfect mean HE for larger portfolio sizes.
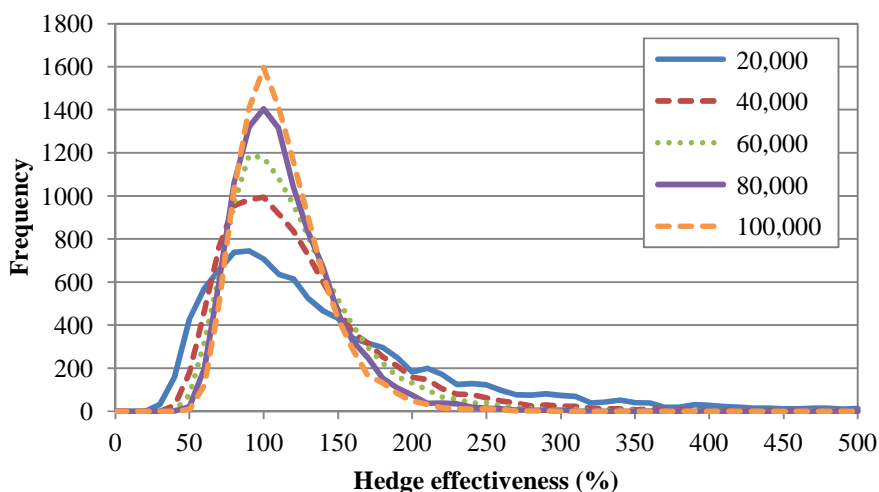
**Table 6: Estimated HE when varying the number of policies**

| Number of policies | Estimated HE (%) | | |
| --- | --- | --- | --- |
| | Mean | Median | 5th percentile |
| 20,000* | 153 | 115 | 48 |
| 40,000 | 119 | 107 | 57 |
| 60,000 | 114 | 106 | 62 |
| 80,000 | 109 | 103 | 65 |
| 100,000 | 107 | 102 | 68 |

In this and all further Tables, * indicates the base scenario.

Figure 3 shows that the estimated distribution of HE becomes less spread, less positively skewed and more peaked as the number of policies increase. Overall, this confirms that the HE is substantially improved as portfolio size increases and clearly demonstrates the potential beneficial effect for insurers of considering pooling their portfolios when seeking protection via these instruments.

**Figure 3: Estimated distribution of HE when varying the number of policies**



### 5.2.2 (A) 2. Flat sum insured distribution

Table 7 shows that a flat sum insured distribution has improved HE compared with the base scenario. The estimated mean HE is far closer to 100% while the estimated median

HE also falls towards 100%. In addition, the estimated HE at the 5th percentile increases significantly.
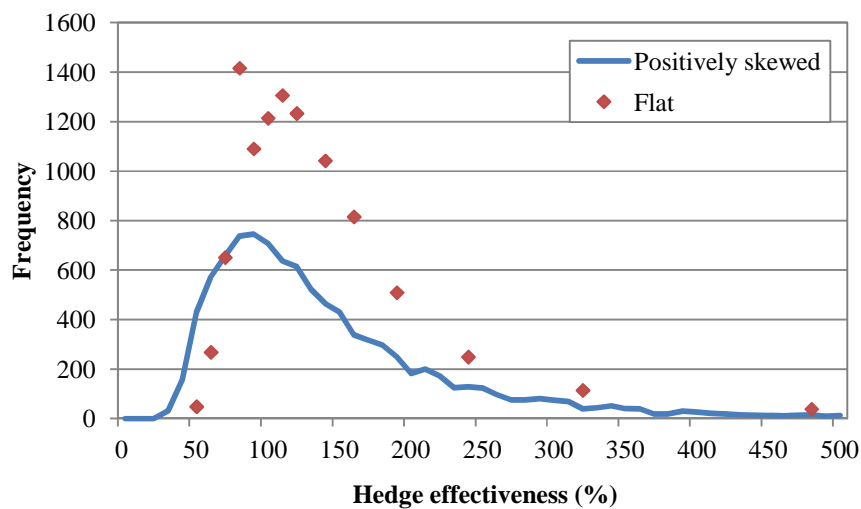
**Table 7: Estimated HE for a flat sum insured**

| Distribution of sum insured | Estimated HE (%) | | |
|---|---|---|---|
| | Mean | Median | 5th percentile |
| Positively skewed* | 153 | 115 | 48 |
| Flat | 114 | 105 | 63 |

Figure 4 shows that the estimated distribution of HE with a flat sum insured distribution has a higher peak than the base scenario. The estimated HE distribution is shown as points for the flat sum insured distribution. The HE takes only several specific values because the actual aggregate claims minus the retained claims is always a multiple of the assumed, uniform $365,000 sum insured for all policyholders, and the bond payoff is constant under each deterministic scenario.

The results suggest HE is improved when the catastrophic mortality bond is used as a hedge for a portfolio that has a flat sum insured distribution, and this demonstrates the potential for effective use of a bond in combination with a surplus reinsurance arrangement.

**Figure 4: Estimated distribution of HE when varying the distribution of sum insured**



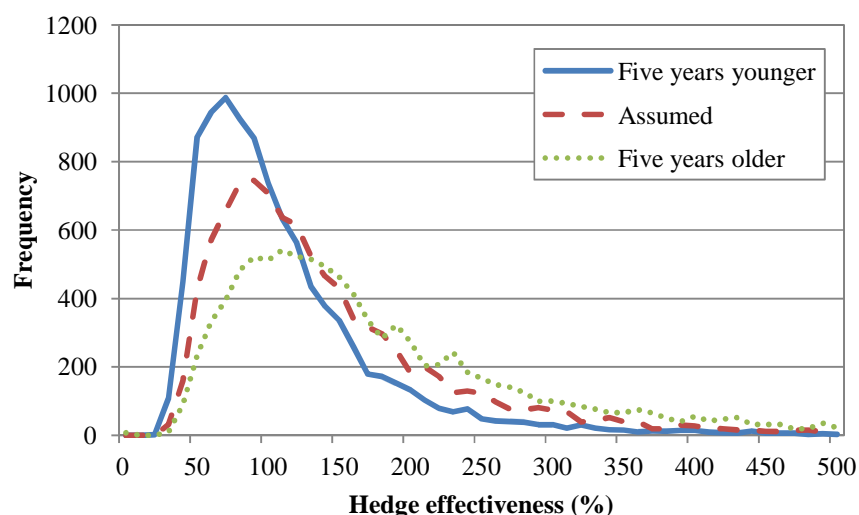### 5.2.3 (A) 3. Portfolio composition by age

Table 8 indicates that a change in the portfolio composition by age without a change in the calibration of the bond may significantly impact the HE. When the portfolio is five years younger, all the HE measures decrease in comparison to the base scenario. This is because the bond payoff remains the same while claims increase since policyholders on aggregate have increased excess mortality due to the "∨∨" shape affecting younger policyholders more. This represents a deterioration in HE. In comparison, all the HE measures increase with respect to the base scenario when the portfolio is five years older.

**Table 8: Estimated HE when varying the portfolio composition by age**

| Portfolio composition by age and gender | Estimated HE (%) | | |
|---|---|---|---|
| | Mean | Median | 5th percentile |
| Five years younger | 110 | 88 | 39 |
| Assumed* | 153 | 115 | 48 |
| Five years older | 217 | 147 | 55 |

Figure 5 illustrates. This finding demonstrates that the inflexibility of the bond to adjust the age (and gender) weightings for the mortality index over time may have significant consequences for the HE if the portfolio composition changes during the term of the bond. This suggests a future improvement for the structurers of such bonds could be to alter the design of bonds to better allow for this potential drift.

**Figure 5: Estimated distribution of HE when varying portfolio composition by age**



## 5.3 Sensitivity analysis of mortality assumptions
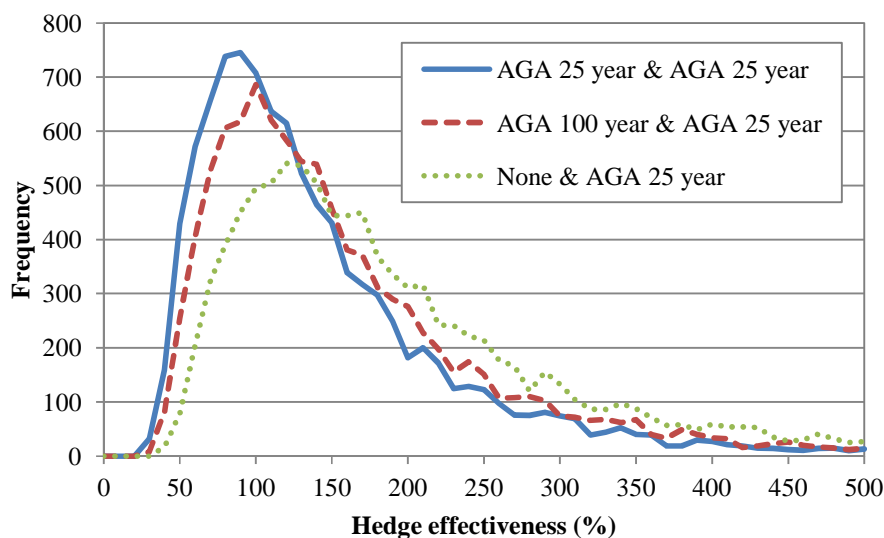
### 5.3.1 (B) 1. Mortality improvements

Table 9 shows that the HE is sensitive to changes in the general population mortality improvements but not those in the insured population. As the general population mortality improvements decrease progressively in aggregate from the AGA 25 year trend to the AGA 100 year trend and then to no trend, all the examined measures of HE increase significantly as the bond payoff increases while the claims remained unchanged. The bond payoff increases as the mortality index is higher than in the base scenario. The changes in the insured population mortality improvements do not materially affect the HE as the chosen measure only considers the claims caused by influenza pandemic excess mortality and not baseline mortality.

**Table 9: Estimated HE when varying the general and insured population mortality improvements**

| General population mortality improvement | Insured population mortality improvement | Estimated HE (%) | | |
|---|---|---|---|---|
| | | Mean | Median | 5<sup>th</sup> percentile |
| AGA 25 year* | AGA 25 year* | 153 | 115 | 48 |
| AGA 25 year | AGA 100 year | 153 | 115 | 48 |
| AGA 25 year | None | 154 | 114 | 47 |
| AGA 100 year | AGA 25 year | 174 | 131 | 54 |
| AGA 100 year | AGA 100 year | 174 | 131 | 54 |
| AGA 100 year | None | 175 | 130 | 54 |
| None | AGA 25 year | 214 | 161 | 67 |
| None | AGA 100 year | 214 | 161 | 67 |
| None | None | 215 | 160 | 66 |

Figure 6 demonstrates that the estimated distribution of HE becomes more spread as the mortality improvements weighted by the bond's age and gender calibration decrease.

**Figure 6: Estimated distribution of HE when varying the general population mortality improvements**



### 5.3.2 (B) 2. Overall general population excess mortality rate

Table 10 reports the estimated HE when varying the overall general population excess mortality rate. The measures are 0% in the scenario with an excess mortality rate of 1 per 1,000 because the bond is not triggered. When the excess mortality rate increases above 2 per 1,000, the bond has already paid the entire original principal amount to the life insurer so the HE measures decrease substantially at an excess mortality rate of 2.25 per
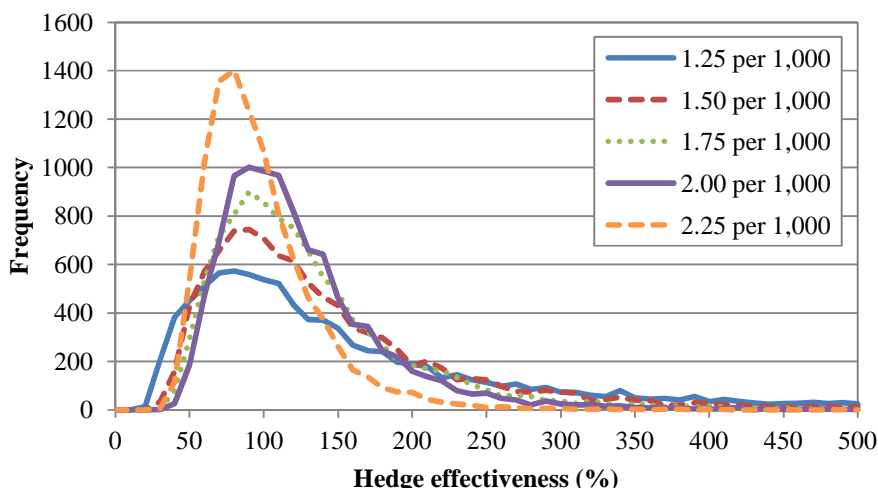
1,000 (compared to 2 per 1,000) as the increase in claims is no longer offset by an increase in the bond payoff. These results are consistent with the intended hedging objectives of hedging against claims caused by an excess mortality rate of 1 to 2 per 1,000. As the excess mortality rate increases from 1 to 2 per 1,000, the estimated mean and median HEs decrease while the estimated HEs at the 5th percentile increase.

**Table 10: Estimated HE when varying the overall general population excess mortality rate**

| Overall general population excess mortality rate (per 1,000) | Estimated HE (%) | | |
| --- | --- | --- | --- |
| | Mean | Median | 5th percentile |
| 1.00 | 0 | 0 | 0 |
| 1.25 | 250 | 125 | 37 |
| 1.50* | 153 | 115 | 48 |
| 1.75 | 129 | 110 | 53 |
| 2.00 | 120 | 107 | 57 |
| 2.25 | 93 | 84 | 48 |

Figure 7 demonstrates that the estimated distribution of HE becomes less spread, less positively skewed and more peaked as the excess mortality rate increases from 1 to 2 per 1,000. After the excess mortality rate exceeds 2 per 1,000, the estimated distribution of HE shifts to the left and becomes more peaked. Overall, this suggests the HE is improved when the excess mortality rate is closer to the upper bound of the range used to calibrate the exhaustion point.

**Figure 7: Estimated distribution of HE when varying overall general population excess mortality rate**



### 5.3.3   (B) 3. Age-specific distribution of excess mortality rates
Table 11 indicates that the HE is highly sensitive to changes in the age-specific distribution of excess mortality rates. As the "U", "W" and flat shapes with the same overall general
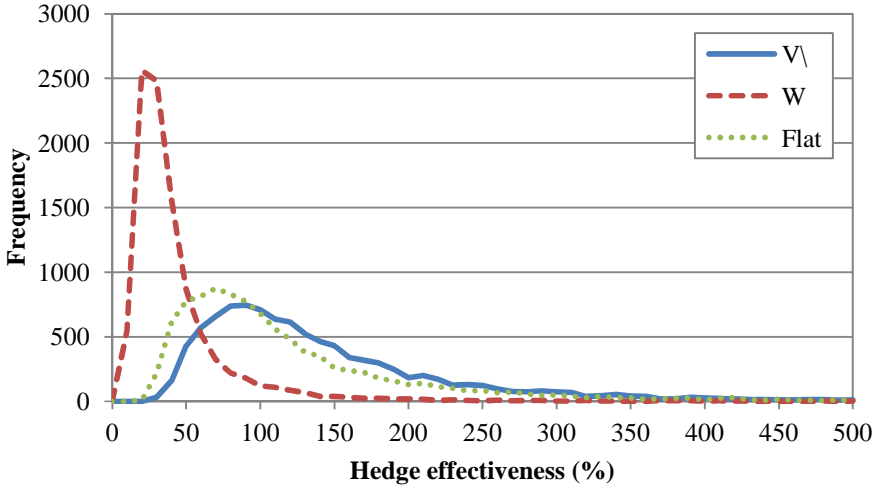
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population excess mortality rate result in an increase in the mortality index less than that for the "VΛ" shape, the bond payoffs for these scenarios are comparatively smaller than the "VΛ" shape. In addition, the claims for these scenarios are also smaller, but the decrease in bond payoff is proportionally greater than the decrease in claims. This explains the lower estimated HE measures for the "U", "W" and flat shapes in comparison to the "VΛ" shape. In particular, the estimated HE measures for the "U" shape are 0% because the bond is not triggered in this scenario as the "U" shape primarily affects infants and the elderly, who are given a small weighting in the mortality index.

**Table 11: Estimated HE when varying the age-specific distribution of excess mortality rates**

| Age-specific distribution of excess mortality rates | Estimated HE (%) | | |
|---|---|---|---|
| | **Mean** | **Median** | **5th percentile** |
| VΛ * | 153 | 115 | 48 |
| U | 0 | 0 | 0 |
| W | 42 | 27 | 10 |
| Flat | 134 | 91 | 35 |

Figure 8 shows that the estimated distribution of HE is fairly similar between the "VΛ" and flat shape while it differs considerably between the "VΛ" and "W" shape. Overall, this indicates the HE of the bond is highly sensitive to the shape of age-specific distribution of excess mortality rates in a pandemic event.

**Figure 8: Distribution of HE when varying the age-specific distribution of excess mortality rates**



### 5.3.4 (B) 4. Excess mortality rate ratio of insured versus general population
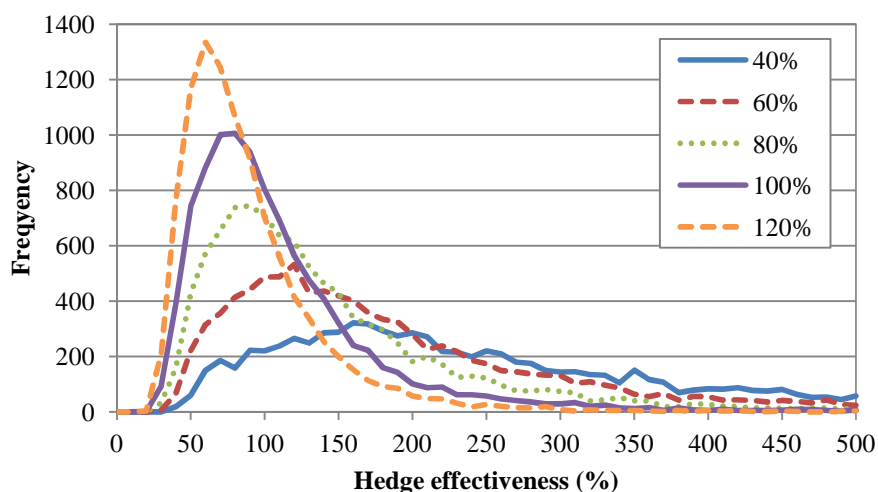
Table 12 demonstrates that the estimated HE measures fall as the excess mortality rate ratio increases since higher insured mortality rates result in a greater number of policyholder deaths causing claims to increase while the bond payoff remains unchanged.

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However the rise in the HE metrics from higher than assumed excess mortality rate ratio is small relative to the rise in those metrics when there is lower than assumed excess mortality rate ratio. Figure 9 illustrates.

**Table 12: Estimated HE when varying excess mortality rate ratio of insured versus general population**

| Excess mortality rate ratio of insured versus general population | Estimated HE (%) | | |
|---|---|---|---|
| | **Mean** | **Median** | **5th percentile** |
| 40% | 521 | 250 | 76 |
| 60% | 245 | 160 | 57 |
| 80% * | 153 | 115 | 48 |
| 100% | 110 | 89 | 40 |
| 120% | 86 | 72 | 35 |

**Figure 9: Estimated distribution of HE when varying excess mortality rate ratio of insured versus general population**



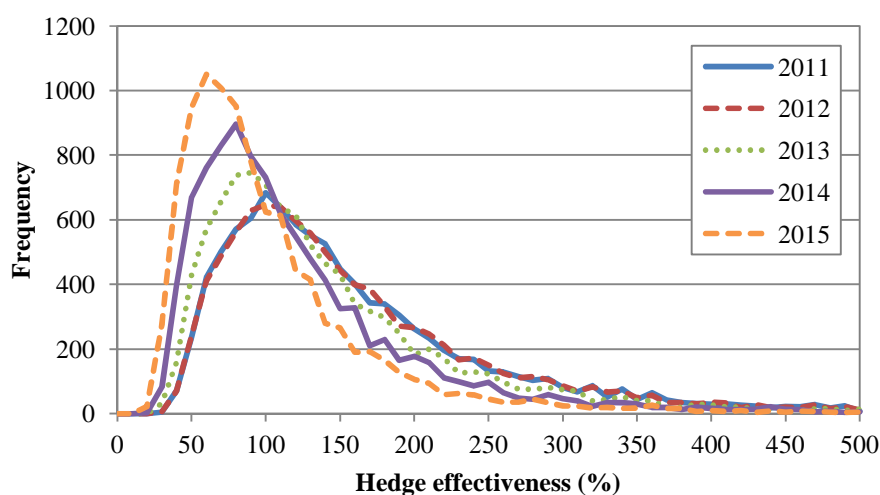### 5.3.5  (B) 5. Timing of the influenza pandemic

Table 13 reports the estimated HE when varying the timing of the influenza pandemic. The HE measures for an influenza pandemic occurring in 2011 or 2012 are broadly the same. The bond payoff is made at the end of 2012 in both these scenarios since the construction of the mortality index requires two years of mortality experience. Thereafter, the estimated HE measures decrease approximately linearly every year after 2012 since the assumed positive mortality improvements decrease the general population mortality rates every year, which reduces the bond payoff. The fall in insured population mortality rates due to mortality improvements does not affect the HE as the chosen HE measure only considers the claims caused by influenza pandemic excess mortality.

**Table 13: Estimated HE when varying the timing of the influenza pandemic**

| Timing of the influenza pandemic | Estimated HE (%) | | |
|---|---|---|---|
| | Mean | Median | 5th percentile |
| 2011 | 177 | 132 | 55 |
| 2012 | 178 | 133 | 55 |
| 2013 * | 153 | 115 | 48 |
| 2014 | 130 | 98 | 40 |
| 2015 | 107 | 80 | 33 |

Figure 10 illustrates. Altogether, the findings suggest there is improved HE when the influenza pandemic occurs earlier than assumed for calibration.

**Figure 10: Estimated distribution of HE when varying the timing of influenza pandemic**



### 5.3.6  (B) 6. Duration of the influenza pandemic and severity of waves each year

Table 14 demonstrates that the HE is sensitive to changes in the duration of the influenza pandemic and severity of waves each year, but not the order of these waves. A two year influenza pandemic results in lower estimated mean, median and 5th percentile HE compared to a one year influenza pandemic. This is because a two year influenza pandemic has a lower bond payoff since the mortality index has decreased by one more year of mortality improvements. When the impact of influenza pandemic is spread equally over 3 years, the bond payoff is not triggered and consequently, the estimated HE measures are 0%.
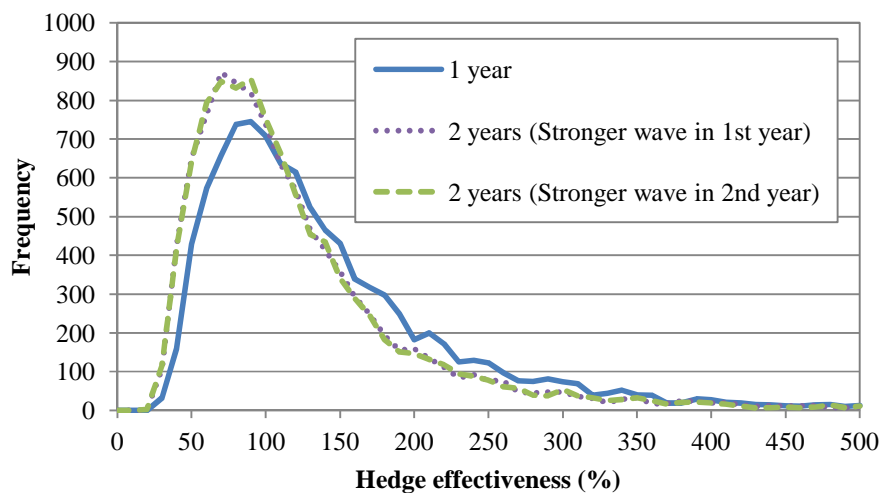
**Table 14: Estimated HE when varying duration of influenza pandemic and severity of waves each year**

| Duration of the influenza pandemic and severity of waves each year | Estimated HE (%) | | |
|---|---|---|---|
| | Mean | Median | 5th percentile |
| 1 year * | 153 | 115 | 48 |
| 2 years (Stronger wave in 1st year) | 128 | 97 | 40 |

| | | | |
|---|---|---|---|
| 2 years (Stronger wave in 2nd year) | 128 | 97 | 39 |
| 3 years (Equal waves each year) | 0 | 0 | 0 |

Figure 11 indicates that the estimated distribution of HE for a one year influenza pandemic varies somewhat from the two year influenza pandemic scenarios. The two year influenza pandemics with unequal waves have similar distributions. This suggests that the order of the waves does not affect HE in this case. In conclusion, it appears that the HE deteriorates for a two year influenza pandemic of equivalent total severity as the base scenario.

**Figure 11: Estimated distribution of HE when varying the duration of the influenza pandemic and severity of waves each year**



## 6    Discussion and Conclusion

The analysis of the base scenario finds that the hedge effectiveness of catastrophic mortality bonds is highly variable.  Although the bond is intended to provide strong hedge effectiveness for that scenario the actual estimated mean hedge effectiveness implies substantial over-hedging. This is primarily attributed to the positively skewed distribution of sum insured and the relatively small portfolio size assumed in the base scenario.

The sensitivity analysis on the characteristics of the life insurer's portfolio suggests that catastrophic mortality bonds have improved hedge effectiveness under certain circumstances. Catastrophic mortality bonds appear to be viable alternative risk management tools for large portfolio sizes particularly where the distribution of sum insured is more uniform, and when the life insurer's underlying exposure remains relatively stable.

As the number of policies in the portfolio increases, the overall hedge effectiveness improves significantly. In addition, the estimated mean hedge effectiveness converges to 100% as intended when using the expected value approach for calibrating the bond. This is coherent with the current use of catastrophic mortality bonds as a risk management tool for large, globally diversified insurers and reinsurers. In comparison, reinsurance or

retrocession coverage is likely to remain a significantly better risk management tool compared to catastrophic mortality bond for smaller insurers or reinsurers since there is significant basis risk and variation in the hedge effectiveness at smaller portfolio sizes. However, it may be possible for smaller insurers or reinsurers to pool their exposures and issue a catastrophic mortality bond for the aggregated portfolio.

Although age, gender, country and financial exposure in the form of sum insured can be calibrated for catastrophic mortality bonds to match the life insurer's underlying exposure, the hedge effectiveness is highly sensitive to changes in the portfolio composition. As the age and gender weightings of the bond are fixed at issuance, any change in the composition of the life insurer's portfolio could have a substantial impact on the hedge effectiveness. In particular, a change in the age composition is likely to have a greater impact than a change in gender composition because historical influenza pandemic mortality experience suggests excess mortality rates vary considerably across age, but not by gender. Consequently, factors that may affect the portfolio composition such as a change in marketing and advertising strategy will have serious ramifications for the hedge effectiveness of catastrophic mortality bonds.

Catastrophic mortality bonds provide lower variation in hedge effectiveness for portfolios where the distribution of sum insured is more uniform. A possible hedging strategy stemming from this result is the combined implementation of surplus reinsurance and catastrophic mortality bonds. Firstly, surplus reinsurance should be used to transfer the volatility in the sum insured exposure above a specified retention. Secondly, a catastrophic mortality bond should be used to cover the life insurer's retention. The surplus reinsurance effectively reduces the spread of the distribution of sum insured for which the catastrophic mortality bond is used to provide coverage.
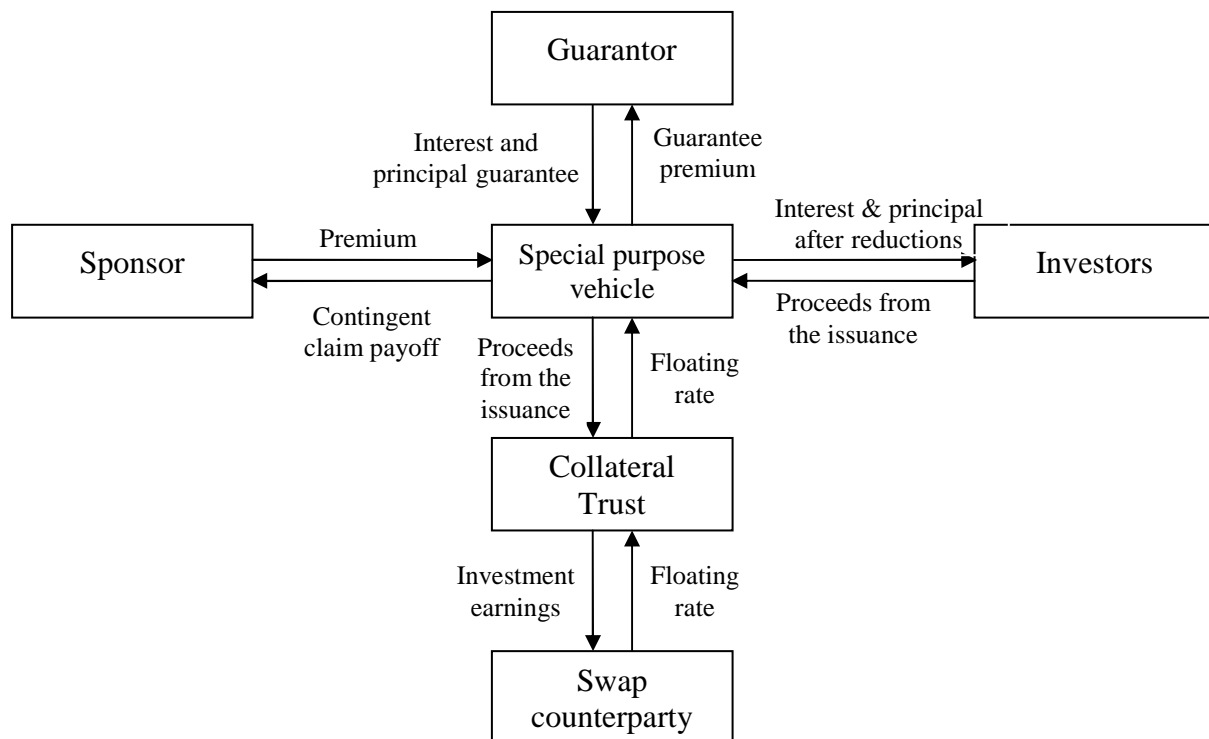
The sensitivity analysis on the mortality assumptions highlights the significant uncertainty surrounding the basis risk and hedge effectiveness of catastrophic mortality bonds. This is due to the inherent uncertainty regarding future mortality rates, particularly in a pandemic scenario where the actual epidemiological characteristics are impossible to predict. In general, catastrophic mortality bonds provide improved hedge effectiveness when: the general population mortality improvements are lower than assumed; the overall general population excess mortality rate is at the upper bound of the range used to calibrate the exhaustion point; the age-specific distribution of excess mortality rates follows the assumed shape; the excess mortality rate ratio of insured versus general population is lower than assumed; the influenza pandemic occurs at the start of the risk period; and, the duration of the influenza pandemic is one or two years.

The research could be extended to analyse the hedge effectiveness for aggregate mortality exposure across a range of life insurance products. For example, traditional products, retirement income products and other risk products could be examined. Other methods of calibrating the characteristics of catastrophic mortality bonds could also be explored as there seems to be minimal existing literature regarding this area. A detailed investigation into the calibration of catastrophic mortality bonds should provide a better understanding of how to optimise the hedge effectiveness.

Furthermore, a holistic approach to enterprise risk management may consider the interaction of catastrophic mortality bonds with existing risk management strategies such as reinsurance. For example, the previously suggested hedging strategy of pooling portfolios for a bond issuance and/or using both surplus reinsurance and catastrophic mortality bonds to hedge against catastrophic mortality events could be explicitly investigated.

# Appendix

**Figure 12: Basic catastrophic mortality bond transaction structure**



*Source: Linfoot (2007)*

**Additional technical notes:**

The general and insured population excess mortality rate for five year age group *i*, $GPEMR_i$ and $IPEMR_i$, that are applied over the assumed duration of the influenza pandemic are calculated as follows:

$$GPEMR_i = OGPEMR * R_i$$
$$IPEMR_i = GPEMR_i * EMRR$$

Where:

| | | |
|---|---|---|
| $GPEMR_i$ | = | The general population excess mortality rate for five year age group *i*; |
| $OGPEMR$ | = | The overall general population excess mortality rate; and, |
| $R_i$ | = | The ratio of general population excess mortality rate for five year age group *i* to the overall general population excess mortality rate. |
| $IPEMR_i$ | = | The insured population excess mortality rate for five year age group *i*; |
| $EMRR$ | = | The excess mortality rate ratio of insured versus general population. |

The catastrophic mortality bond payoff at the end of measurement period in calendar year *t*, $CMBP_t$, can be expressed as followed:

$$CMBP_t = P \times R_t^C$$

$$R_t^C = Max \left( \frac{Index_t^C - A^C}{E^C - A^C} - R_{t-1}^C, 0 \right)$$

Where:

| | | |
|---|---|---|
| $CMBP_t$ | = | The catastrophic mortality bond payoff at the end of measurement period in calendar year *t*; |
| $P$ | = | The original principal amount; |
| $R_t^C$ | = | The principal reduction factor for measurement period ending in |

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calendar year $t$ and country $C$ where $R_t^C = 0$ for the start of the risk period and $0\% \leq \sum_t R_t^C \leq 100\%$;

$Index_t^C$ = The mortality index for measurement period ending in calendar year t and country $C$;

$A^C$ = The attachment point for country $C$; and,

$E^C$ = The exhaustion point for country $C$.

The mortality index for measurement period ending in calendar year $t$ and country $C$, $Index_t^C$, can be expressed as:

$$Index_t^C = \frac{\overline{q}_t^C}{\overline{q}_{\text{reference years}}^C}$$

$$\overline{q}_t^C = \frac{1}{2} * (q_t^C + q_{t-1}^C)$$

$$q_t^C = \sum_x (w_{x,m}^C * q_{m,x,t}^C + w_{x,f}^C * q_{f,x,t}^C)$$

Where:

$Index_t^C$ = The mortality index for measurement period ending in calendar year $t$ and country $C$;

$\overline{q}_t^C$ = The two year average mortality rate over measurement period ending in calendar year $t$ for country $C$ where the reference years correspond to the two years before the start of the risk period;

$q_t^C$ = The annual mortality rate for country $C$ in calendar year $t$;

$q_{m,x,t}^C$ = The mortality rate for males of country $C$ and age group $x$ in calendar year $t$;

$q_{f,x,t}^C$ = The mortality rate for females of country $C$ & age group $x$ in calendar year $t$;

$w_{x,m}^C$ = The weight applied to male mortality rates of country $C$ and age group $x$;

$w_{x,f}^C$ = The weight applied to female mortality rates of country $C$ and age group $x$.

The future average sum insured in year $t$, $ASI_t$, can be expressed by the following formula:

$$ASI_t = ASI_s * \prod_{x=s}^{t-1} (1 + TUR * AIR_x)$$

Where:

$ASI_t$ = The future average sum insured in year $t$;

$ASI_s$ = The past average sum insured in year $s$, where $s < t$;

$TUR$ = The take up rate; and,

$AIR_x$ = The annual inflation rate in year $x$.

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