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Modeling longevity and chronic illness risks in retirement annuity pricing for older Malaysians

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Abstract

As Malaysia's population ages, understanding the financial implications of longevity risk and chronic illnesses among the older population is increasingly important. This study investigates how longevity risk interacts with selected chronic illnesses among older Malaysians using a multiple-state annuity model. First, the study explored the mortality and morbidity risks of selected chronic illnesses affecting older Malaysians. This research employed actuarial modeling techniques, including the Markov chain model, the Lee–Carter model, and the age-period-cohort (APC) model. The Markov chain model estimated the likelihood of health transitions, while the Lee–Carter model and the APC model were employed to project mortality and morbidity rates. These models offer a comprehensive framework to assess the longevity risk and financial pressures associated with managing chronic illnesses in aging populations. Second, the projected rates were utilized in the retirement annuity pricing models. There were two multiple-state annuity pricing models considered, one with only healthy and dead states, and the other included chronic illness states. Overall, increased longevity resulting from ongoing improvements in mortality will raise the cost of annuities for a predetermined annuity payment at the compulsory retirement age. By contrast, the inclusion of chronic illness risk in annuity pricing reduces the cost of an annuity for retirees. Hence, the risks of longevity and chronic illness will be taken into account to fairly price retirement-linked products such as annuities.

Keywords: Longevity risk; Chronic illness; Aging population; Retirement annuities

1. Introduction

In Malaysia, mortality rates have improved significantly, leading to an increase in the old-age dependency ratio (Asmuni *et al.*, 2020). Future projections from the Department of Statistics Malaysia (DOSM) indicate that the population is aging rapidly due to rising life expectancy and declining fertility rates. The total fertility level has fallen below the replacement level of 2.1 since 2013, while life expectancy is projected to increase from 69.2 years in 1991 to 77.2 years by 2060. By 2030, 13.3% of the population is predicted to be over 60, and this share will grow to 24.2% by 2060 (DOSM, 2025).

The aging phenomenon will influence the demographic transition, which in turn will affect future retirement expenditures, as retirees are expected to spend more time in retirement (Asmuni *et al*., 2020). As Malaysia's population ages, the number of working people will decrease, while the number of older adults will increase. This can result in poorer productivity and a smaller workforce, reducing national income. This is a challenge for the nation, as the government needs to implement appropriate laws and allocate funds to meet the pension payments for prospective retirees (Ismail *et al*., 2021). In relation to this aging issue, the Malaysian government has raised the retirement age for both private and public sector employees from 55 years and 58 years, respectively, to 60 years in 2014. These changes reflect the longevity risk, which is the risk that people will live longer than expected due to uncertainties in mortality patterns (Ibrahim *et al*., 2020). Hence, the sustainability of pension funding for future retirees is becoming a greater challenge.

Older adults generally experience higher morbidity risks associated with chronic diseases, and the treatment of such diseases is costly. The escalation of chronic illnesses has been recognized as a worldwide crisis, with a hefty burden falling on developing nations, resulting in a surge in healthcare expenses (Beaglehole *et al*., 2011. Malaysia has a rapidly expanding economy and is seeing a swift transformation in disease epidemiology. According to the Institute for Health Metrics and Evaluation (IHME) datasets, the leading chronic illnesses in Malaysia are cardiovascular diseases, followed by neoplasms and diabetes (IHME, 2024). A neoplasm is a profoundly severe ailment that significantly impacts one's quality of life and is ranked as the second-highest contributor to mortality in Malaysia. The challenges posed by chemotherapy or radiation therapy in neoplasm treatment often disrupt normal daily functioning.

As outlined in the National Cancer Institute (2021), the most prevalent cancers among males include lung and nasopharyngeal cancers, while cervical and breast cancers are predominant among females. In 2021, COVID-19 emerged as the primary cause of death, followed by ischemic heart disease among Malaysians. Cardiovascular diseases have numerous contributing factors, such as smoking, genetic predisposition, high blood pressure, and cholesterol levels. A sedentary lifestyle can also significantly increase people's susceptibility to these critical illnesses. Meanwhile, diabetes is another significant contributor to mortality in Malaysia, and if not treated properly, it can cause complications and reduce the quality of life.

In light of Malaysia's aging population and the prevalence of chronic illnesses, it is crucial to address the vital issue of the sustainability of the country's retirement plans. In particular, for private sector employees in Malaysia, the primary retirement funding is their savings in the Employees Provident Fund (EPF) scheme. According to the World Bank (2020), the majority of EPF members can only sustain a monthly income of less than Malaysian Ringgit (MYR) 1,050, equivalent to USD 249, on retirement. For public sector retirees, however, pensioners expect to receive a monthly income of 60% of their final drawn salary. For its part, the government faces funding challenges to support this public provision retirement program. The Bank Negara Malaysia (BNM), through the economic, monetary, and financial developments in 2022 (BNM, 2022), also underscores the urgent need for critical policy interventions to ensure that Malaysians will be protected adequately during retirement without overburdening fiscal funding or significantly increasing personal contribution rates at the expense of current disposable incomes. Among prospective retirees who depend solely on drawing down savings through contributory schemes, low-income and informal sector workers will be at a greater risk of falling into poverty on retirement. Therefore, the risk of old-age poverty is significant in the aging phenomenon.

To address this challenge, Malaysia should shift from a traditional charity-based approach to a more inclusive system, such as annuity (Rabi *et al*., 2019). An annuity safeguards personal finances by providing steady payments at regular intervals throughout retirement (James, 2016). Advancements in life annuities that consider the effects of disease on benefits can provide older people with a more comprehensive and personalized retirement planning tool. This approach uses the policyholder's age, sex, and other pricing factors to help determine their annuity payments. Retirees with reduced life expectancy due to chronic illness may receive modified annuity payments, ensuring that their living costs remain covered.

The following sections review the existing literature on the impact of increasing longevity and chronic disease prevalence on pension systems' sustainability. They also outline methodological insights relevant to the development of the new approach proposed in this study. Finally, the sections elaborate on the history of pension reforms related to annuities as a part of Malaysia's voluntary retirement schemes, which represent the third pillar of the national retirement system.

1.1. Literature review

The sustainability of pension systems has been a concern due to demographic shifts, particularly rising life expectancy and the growing prevalence of chronic diseases among aging populations. Studies such as those by Lee &

Mason (2017) and Bloom & McKinnon (2014) emphasized that prolonged longevity significantly extends the duration of retirement, thereby increasing the financial burden on pension funds. Lee & Mason (2017), for example, quantified that, in high-income countries, every additional year of life expectancy adds 3–4% to the lifetime pension cost per retiree, assuming retirement age remains constant. Similarly, Bloom & McKinnon (2014) estimated that population aging could lead to approximately 5% increase in pension expenditures as a share of gross domestic product (GDP) in developing countries by 2050 if policy reforms are not implemented.

The economic burden is further amplified by the higher incidence of chronic illnesses later in life, escalating healthcare costs. In many developing countries, healthcare costs at older ages are partially subsidized through public pension or social security schemes. According to the World Health Organization (2022), about 75% of individuals aged 60 and above live with at least one chronic illness. These conditions significantly impact government expenditure, where the health-related costs for individuals aged ≥65 are estimated to be 2–4 times higher than for younger adults, with a substantial portion absorbed by public funds, retirement-linked products, and social security systems.

In the Malaysian context, research studies by Asher & Bali (2015) and BNM (2022) highlighted the strain placed on the EPF and other retirement schemes due to inadequate savings and longer retirement periods. These challenges are compounded by a low annuitization rate and limited coverage of informal sector workers. Recent studies also point to the lack of integration between healthcare and pension planning as a critical gap in current policy frameworks. According to the World Bank (2020), the distribution of balances for active EPF contributors at age 54 suggests that a majority of retirees will receive very low benefits in retirement from their EPF accounts. Notably, over half of the members at age 54 have balances under MYR 150,000, and almost three-quarters have balances under MYR 250,000.

Comparative research from Japan provides useful insights into how to modify pension plans to accommodate aging populations. For example, Japan's experience with supporting private annuity markets and tying pension payouts to life expectancy highlights the significance of policy flexibility toward the aging phenomenon (Kai Lit, 2006). Within the context of annuity provision in the market, a recent study by Olivieri & Tabakova (2024) concludes that the provider's goal, while issuing special-rate annuities, is to expand the size of the pool. In fact, since typical annuities are priced based on the lifestyles of healthy individuals, people with poor health or unhealthy lifestyles may reject them. Instead, they may opt for annuities that are assessed according to their characteristics, such as higher mortality risk. The rise in annuity demand should therefore be facilitated through the provision of special-rate annuities. Similarly, Pitacco & Tabakova (2022) investigated the insurance portfolio risks consisting of special-rate annuities, including standard annuities and annuities for impaired individuals. They asserted that future extensions of their study should consider diverse trends and varying degrees of uncertainty for the various special-rate annuities.

In terms of methodology, actuarial models have been extensively employed to evaluate the viability of pension funds under diverse health and demographic scenarios (Bravo *et al.*, 2023). Nonetheless, there is increasing interest in creating more dynamic, data-driven models that take into account patterns of health decline as well as the effects of longevity. Building on these methodological developments, this research proposes a retirement annuity pricing approach that incorporates the risks of chronic illness and longevity among aging populations to avoid the underestimation of long-term pension liabilities. This method seeks to offer a more accurate and fairer pricing of retirement-linked products.

1.2. Brief history of pension reforms in Malaysia

Malaysia is experiencing an aging trend that is faster than that of many other countries (Tai & Sapuan, 2018). Moreover, increasing longevity worsens the situation, as pensions based on the earnings of previous generations are struggling to keep up with rising prices (Hussein, 2019). Many Malaysians lack sufficient retirement savings, underscoring the importance of focused strategies to improve financial preparation for the future (Tai & Sapuan, 2018). Moreover, defined contribution and defined benefit schemes, which form the first and second pillars of Malaysia's retirement system, have adequacy issues. In a public defined benefit system, the sustainability of pension systems has become a recent issue as longevity places a heavy burden on the government's funding (Hussein, 2019).

For the defined contribution scheme, many EPF members in Malaysia earn less than MYR 5,000 per month. In percentage terms, 88% fall into this category. Since its establishment in 1951, the EPF, a government-guaranteed organization that oversees the retirement accounts of workers in Malaysia's private sector, has delivered reasonable annual returns to its members. Over the past 50 years, the EPF's investment returns have averaged between 4% and 8% annually (EPF, 2010). However, there remains a risk that members outlive their assets during the decumulation phase. Given that members have the option to take a lump-sum withdrawal once they reach retirement age, this risk is even higher. Since members are allowed to withdraw up to 40% of their pre-retirement savings to pay for housing and schooling, Thillainathan (2004) argued that there might be a shortage of members' retirement funds. These features collectively increase the risks of longevity-related shortfall in the EPF context.

In 2000, a group of private insurance companies, known as the Konsortium Annuiti Malaysia, launched the EPF Annuity Schemes in an attempt to provide members with a better decumulation plan. Members can use the funds in their EPF account to purchase an annuity product under this plan. The launch of this program has generated controversy. It was criticized by a number of organizations, including the Malaysian Trade Union Congress, a group that represents Malaysian workers, as EPF members were at risk of losing all their savings if the insurers failed and were exposed to uncertain investment returns. This controversy constrained public confidence in the initiative.

If the program had been offered by a government-funded organization or by the EPF, it might have gained more momentum. By the time the plan was halted, over 200,000 EPF members had contributed a total of over MYR 4 billion in single premium income, demonstrating a high level of participation (Mohd Kassim, 2003). Following the EPF Annuity Schemes' cessation, single-premium business declined by 48.2%, and the insurance industry suffered a significant loss compared to the prior years' impressive growth of 171.7% in 2000 and 131.5% in 2001 (Aziz, 2002). To date, only private, fixed-term annuities are offered in the market to support the third pillar of Malaysia's retirement scheme.

Given the current aging trend, annuities offered in the market can potentially be revisited to provide secure, sustainable income for retirees and to strengthen retirement planning. For example, enhanced annuities or enhanced life annuities can be described as immediate annuities that only exist in certain countries (Gatzert & Klotzki, 2016). These products use the policyholder's age, sex, and other pricing factors to determine annuity payments. Consequently, individuals with reduced life expectancy receive higher payments, and people with myocardial infarction (heart attack), cancer, diabetes, obesity, and other conditions are strong candidates for these annuities. In addition, enhancements are based not only on health states but also on lifestyle and place of residence.

In the United Kingdom (UK)'s insurance market, enhanced annuities are more prominent than in most markets (Gatzert & Klotzki, 2016). The enhanced annuity product was introduced in 1995, and since then, it has grown remarkably. In the last quarter of 2014, this product accounted for approximately 28% of all enhanced annuity products sold by the 12 providers. The payments are based on the policyholder's lifestyle and health. Although longevity risk exists as the population ages, the risk of chronic diseases also affects the lifestyles and financial circumstances of older adults. Hence, it is crucial to incorporate these elements when pricing retirement products such as annuities. This international experience motivates the model choices assessed in the present study. Building on this policy background, the next section details the data sources and models used to analyze mortality and morbidity trends for annuity pricing.

2. Data and methods

2.1. Data sources

This study conducted an analysis based on secondary data obtained from reputable and authoritative sources to ensure accuracy and reliability. The secondary data sources are as follows:

(i) Government data: Official statistics on mortality rates by age group and sex for the Malaysian population were collected from the DOSM's yearly publication of the Abridged Life Table Malaysia from 1990 to 2023 (DOSM, 2023)

(ii) Global health database: The incidence rates and the mortality rates of selected chronic illnesses, consisting of cardiovascular diseases, neoplasms, and diabetes, from 1990 to 2021 were collected from the IHME database (IHME, 2025)

(iii) Other published sources: The mortality rates of a group of annuitants who were considered as the retirement-linked insurance scheme policyholders were collected from the a(90)m and a(90)f life tables for males and females, respectively. These are standard mortality tables used for valuing products for retirement or annuities. They were published by the professional body, namely the Institute and Faculty of Actuaries (IFoA), UK (BNM, 2018; IFoA, 2025).

In this study, data collected from all sources above were in the form of incidence rates for mortality and illness cases rather than the raw number of each case. Hence, the data have already been published in the form of the rate of events per specific Malaysian population. These rate-based measures facilitate consistent integration across sources for subsequent modeling.

2.2. Projecting mortality and morbidity rates

The mortality rates of the healthy population from the DOSM data have been adjusted by comparing the data to tables a(90)m and a(90)f. The data were rated down by two years, as assumed by Malaysia's Risk-based Capital policy. This method enabled us to establish a comparative ratio to compute a new mortality rate for the healthy population. The mortality rates for the healthy population and for people with selected chronic illnesses were then projected using the Lee–Carter model and age-period-cohort (APC) model, while morbidity rates for selected chronic illnesses were projected using the APC model.

2.2.1. Lee–Carter model

According to Kamaruddin & Ismail (2018), the Lee–Carter model is a statistical time series model combined with a demographic model to project mortality rates. It is widely used for mortality projection due to its simplicity and robustness. Kamaruddin & Ismail (2019) conducted a statistical comparison on the performance of the original Lee–Carter model and its extension, namely the Hyndman-Ullah model, using Malaysian mortality data. The original Lee–Carter model had the lowest values for both the Akaike information criterion and the Bayesian information criterion, indicating that this model provides the best fit for Malaysian mortality data. The Lee–Carter model has also been found to perform well in forecasting mortality rates in Malaysia; for example, Redzwan *et al.* (2023) reported a forecast error of nearly zero based on the mean squared error and the mean absolute percentage error. This model is a two-factor model with age and time as factors, and it can be defined as follows:

$$\ln(m_{x,t}) = a_x + b_x k_t + \varepsilon_{x,t} \qquad (1)$$

where $m_{x,t}$ is the central mortality rate of a person aged x at time t, a_x is an average age-specific mortality rate, b_x is the rate of improvement of the level of mortality at age x, k_t captures the time factor of mortality rate changes at time t, and $\varepsilon_{x,t}$ is the random error for a person aged x at time t.

2.2.2. APC model

A modeling instrument known as the APC model can be employed to condense the data regularly gathered in cancer registries and registries for other diseases (Rutherford *et al.*, 2010). The APC model has historically identified trends, patterns, and potential risk factors associated with a disease by assessing individual contributions to APC effects. The primary purpose of an APC analysis is to deduce the cultural and social changes that led to a particular result by isolating the roles played by the three APC variables (Fosse & Winship, 2019).

According to Rutherford *et al.* (2010), the APC model is an appropriate statistical technique for analyzing data commonly collected from cases of neoplasms and other diseases. The model considers APC effects as separate components, allowing researchers to distinguish between their effects on disease patterns. Moreover, this approach provides a more thorough understanding of how each factor influences the incidence of disease and offers a systematic means of separating cohort effects from age and period effects. Typically, the standard APC model assumes that counts of illness events follow a Poisson distribution and that the incidence or mortality is a multiplicative function of APC, while the logarithm of the rates is an additive function of the parameters (Wang *et al.*, 2022. The general APC model is defined as follows:

$$\ln\{\lambda(a,p)\} = \alpha_a + k_p + \gamma_c + \varepsilon_{ap} \qquad (2)$$

where λ is the mortality or morbidity rate, a is the age variable, p is the period variable, and c is the cohort variable. The model is specified in Poisson log-linear form with a random error of ε. To ensure consistency of age groups and period intervals across the study period, the data were transformed from a year-age format into a birth cohort format.

Nevertheless, it is impossible to uniquely ascertain this model's elements due to the direct correlation between variables: the value of c is obtained by subtracting a from p. To address this identification problem, penalization terms were applied within the P-spline and cubic spline smoothing framework, which impose smoothness constraints on the APC effects while reducing model overfitting.

2.3. Markov chain model

The Markov chain model describes stochastic processes in which the likelihood of a policyholder transitioning to the next health state depends only on the current state, regardless of the sequence of previous events. The transitions of individuals from a healthy state to a state with a chronic disease condition or to death were characterized in this study using a multiple-state Markov chain model. The mortality rates represent the transition rates from a particular chronic disease to the death state for those specific chronic illnesses and are based on the projected rates. By applying this multiple-state model approach, a strong basis was established for valuing and pricing complex insurance contracts. According to Pasaribu *et al.* (2019), the cash flows of premiums and benefits are determined by an event that corresponds to each state in the Markov chain. These transition probabilities serve as inputs to the annuity pricing models, as outlined in Section 2.4.

2.4. Comparing two-state and five-state annuity models

An annuity provides a series of payments to the annuitant, returning the premiums paid to the insurance company, conditional on the annuitant's survival. Hence, annuities are well-suited for providing retirement income to prospective retirees. The two-state annuity model provides only basic financial support. By contrast, the five-state annuity model allows retirees, especially those expected to have health issues, to receive better financial support for their healthcare. Typically, individuals with heart attacks, cancer, diabetes, obesity, and other diseases are the most suitable candidates for this annuity product, as it provides a higher income to help fund necessary medical expenses. This study focused on selected chronic illnesses and compared the two-state and five-state models for annuity pricing. Both annuity pricing models are discussed below.

Figure 1 shows the application of the discrete-time multiple-state model that was used in this study. The limitation of this multiple-state Markov chain model is the scarcity of data with regard to recovery from chronic illnesses. However, in prior actuarial modeling involving critical illness insurance coverage, as described by Macdonald *et al.* (2005) and Ozkok *et al.* (2014), most insurance coverages pay at the time of diagnosis, with no change in payments thereafter due to the low probability of recovery. Similarly, under the enhanced annuity product considered here, income payments increase upon the diagnosis of a chronic illness and remain unchanged thereafter, as the chances of a full recovery are small.

2.4.1. Annuity pricing model structure

In the two-state framework, pooling arrangements, such as the alive-dead models, are analogous to the regular annuity plan, as the model shows that individuals share both systematic and idiosyncratic mortality risks. In addition, a similar structure, though not in a multi-state context, was considered by Piggott *et al.* (2005). This two-state model derives the payouts of an annuity from the two-state process and serves as an analogy for it.

At time t, a person is in one of the two states: alive (1) or dead (2). They can only move from state 1 to 2 and not from 2 to 1. We denoted the probability of an individual who is in state 1 at age x still in state 1 at age $x + t$ as ${}_t p_x^{11}$, and the probability that the individual has transitioned to state 2 as ${}_t p_x^{12}$. Next, we illustrate how the general two-state annuity framework can be applied to calculate enhanced annuity products for a five-state model, including a chronic illness model.

Figure 2 illustrates the five-state transition model to describe the state of an individual insured under a policy. It extends the two-state model by adding the possibility of common chronic illnesses faced by the elderly. Based on the Markov chain state space, the transition probability notation used in this study is as follows:

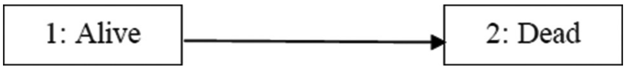

Figure 1. Two-state alive–dead model

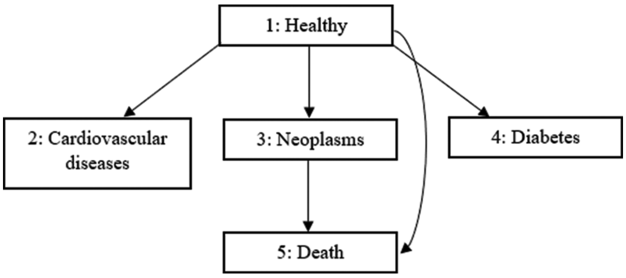

Figure 2. Five-state annuity model

(i) ${}_t p_x^{11}$: Probability of an individual age x currently in the healthy state, at age $x + t$ remaining in the healthy state
(ii) ${}_t p_x^{12}$: Probability of an individual age x currently in the healthy state, at age $x + t$ transitioning to the cardiovascular disease state
(iii) ${}_t p_x^{13}$: Probability of an individual age x currently in the healthy state, at age $x + t$ transitioning to the neoplasms state
(iv) ${}_t p_x^{14}$: Probability of an individual age x currently in the healthy state, at age $x + t$ transitioning to the diabetes state
(v) ${}_t p_x^{15}$: Probability of an individual age x currently in the healthy state, at age $x + t$ transitioning to the death state
(vi) ${}_t p_x^{25}$: Probability of an individual age x currently in the cardiovascular disease state, at age $x + t$ transitioning to the death state
(vii) ${}_t p_x^{35}$: Probability of an individual age x currently in the neoplasms state, at age $x + t$ transitioning to the death state
(viii) ${}_t p_x^{45}$: Probability of an individual age x currently in the diabetes state, at age $x + t$ transitioning to the death state.

The data on historical mortality and morbidity incidence rates for the Malaysian population were collected from the DOSM and the IHME, as mentioned in Section 2.1. The fitted and projected mortality and morbidity incidence rates acquired from the Lee–Carter and the APC models provide the transition probabilities between various states in 1 year for a particular person aged x, such as healthy to death, healthy to cardiovascular diseases, neoplasms, or diabetes, as well as the transition from these illnesses to death. Hence, the transition rate estimation varies by age and year according to the projected mortality and incidence rates. The probability of remaining in each state equals one minus the sum of the probabilities of transitioning to all other states, and this computation is repeated for each state:

$$ {}_t p_x^{ii} = 1 - \sum_{j \neq i} {}_t p_x^{ij} \quad (3) $$

where ${}_t p_x^{ii}$ denotes the probability of remaining in state i for a person aged from x to $x + t$.

2.4.2. Deferred annuity pricing

A deferred annuity is a type of annuity designed for policyholders who want to pay an annual premium for several years before benefits commence from an agreed date. This annuity accumulates premiums paid by the policyholder over a specified period. The accumulated amount is then converted into annuity payments each year beginning at a specified age. This annuity product guarantees a fixed income for the policyholder, especially for those nearing retirement.

In this study, both deferred and immediate annuities were considered, with the latter requiring a lump-sum premium at the purchase age of 60. Several factors influence pricing, and one of the most important is the interest rate. Premiums are driven primarily by the investment return assumption and the mortality risk factor. A shorter investment horizon for immediate annuities results in higher premiums compared with those of deferred annuities. Regarding mortality risk, it is crucial to study the mortality pattern by age, sex, and cohort to investigate the implications of different demographic profiles on annuity pricing. The assumptions of annuity product features used in this annuity pricing analysis were based on an issuance age of 50–59 years old, policy benefit term of 40 years (starting from aged 60 to 100), and annuity annual payment of MYR 1,000. These features are similar to typical retirement annuity plans that were introduced in Malaysia back in the year 2000 (Mohd Kassim, 2003).

2.4.3. Premium calculation for two-state annuity model

The two-state annuity model consists of the states "healthy" and "dead," and is typically used to calculate annuity premiums. This model calculates the premiums that the policyholders must pay by incorporating their mortality rates and interest rates. Mortality rates are taken from standard life tables. The premium formula for the two-state annuity model is as follows:

$$ P = \frac{B \; {}_{n|}a_x}{\ddot{a}_{x:\overline{n}|}} \quad (4) $$

where P is the annual premium for the retirement annuity plan, B is the annual income received from the annuity plan that is payable upon the survival of the retiree, ${}_{n|}a_x$ is the actuarial unction of the expected present value of annuity payments payable at the end of each year, starting at the age of $x + n$, and $\ddot{a}_{x:\overline{n}|}$ is the actuarial function of the expected present value of premium payments payable at the beginning of each year for a person aged x for a term period of n years. Based on the annual premium rate above, the premium rate increases with purchase age. The annuity function in Equation 4 utilizes the transition probabilities described in Section 2.4.1 and is calculated as follows:

$$ \ddot{a}_{x:\overline{n}|} = 1 + v \; {}_1 p_x^{11} + v^2 \; {}_2 p_x^{11} + \ldots + v^{n-1} \; {}_{n-1} p_x^{11} \quad (5) $$

$$ {}_{n|}a_x = v^n \; {}_n p_x^{11} (v \; {}_1 p_{x+n}^{11} + v^2 \; {}_2 p_{x+n}^{11} + \ldots + v^{\omega-x-n} \; {}_{\omega-x-n} p_{x+n}^{11}) \quad (6) $$

where v, which is equal to $(1 + i)^{-1}$, denotes the discount factor based on an annual investment rate (i) of 5%, and ω (set at 100) is the assumed limiting age for a maximum of 40 years annuity coverage, starting from age 60 to 100.

2.4.4. Premium calculation for five-state annuity model

The five-state annuity model consists of the states "healthy," "cardiovascular diseases," "neoplasms," "diabetes," and "dead." It is used to calculate the premium for an annuity that explicitly accounts for health complications. This model requires estimating premiums that incorporate policyholder mortality rates and interest rates, with a particular focus on people who are at or near retirement. Mortality rates were taken from life tables, and premiums were computed using the estimated transition probability matrices. The premium formula for the five-state annuity model is as follows:

$$ P = \frac{B[\, {}_{n|}^{1}a_x + {}_{n|}^{2}a_x + {}_{n|}^{3}a_x + {}_{n|}^{4}a_x \,]}{\ddot{a}_{x:\overline{n}|}} \quad (7) $$

Where ${}_{n|}^{j}a_x$ is the actuarial function of the expected present value of annuity payments payable at the end of each year, starting at the age of $x + n$, as in Equation 4, but it specifies the state of health (j = 1, 2, 3, or 4). In comparison to the two-state annuity model, the annuity function in this model modifies the formulation in Equations 5 and 6 to allow for the possibilities of all surviving states: state 1 (healthy), state 2 (cardiovascular diseases), state 3 (neoplasms), and state 4 (diabetes). The basis of annuity pricing formulation described for both the two-state and the five-state annuity models was based on the actuarial premium calculation, as formulated in Dickson *et al.* (2020).

2.5. Statistical analysis

In this study, the data were collected from publicly available sources, specifically the IHME and the DOSM. The data were quantitative, comprising the variables year, age, and sex. This extensive dataset was divided into male and female categories to enhance the accuracy of incidence and mortality rates for the selected chronic illnesses, including cardiovascular diseases, diabetes, and neoplasms. Due to the different age categorizations in both data providers (DOSM and IHME), the data were presented in five-year age groups. The P-spline and cubic-spline models were applied to harmonize the grouping structure prior to comparative analysis. This cleaning and restructuring process was conducted using Microsoft Excel and RStudio software. These steps ensure reproducibility and provide a stable foundation for analyses.

3. Results

3.1. Mortality rates forecast using the Lee–Carter model

The Malaysian population mortality rates were modeled and forecasted using the Lee–Carter model. This method uses DOSM data covering 18 age groups for males and females from 1990 to 2023. In addition, mortality rates for selected illnesses were examined from 1990 to 2021 using IHME data, covering 20 age groups for both sexes. By forecasting both databases until 2063, a thorough examination of mortality trends and projections for the Malaysian population is possible. The goal is to provide insight into future mortality trends. This information is crucial for actuarial applications, healthcare resource allocation, and policy planning.

An examination of the generated rainbow graph showed that violet represents the latest year, while red represents the earliest year. Figures 3 and 4 provide numerous important insights concerning Malaysia's mortality rates between 2022 and 2063. Figure 3 presents projected mortality rates for the healthy population, whereas Figure 4 shows the mortality rate projections for those diagnosed with cardiovascular diseases, neoplasms, and diabetes.

The data exhibited a smooth and continuous trend over the whole age range after cubic-spline interpolation from grouped ages to single years. The x-axis, which was originally displayed in five-year age intervals, has been scaled into single ages for data ranging from 30 to 85. Based on historical trends, the interpolation and subsequent extrapolation beyond age 80 indicate consistent increases in the mortality rate among older adults. In particular, for the healthy population's forecast results, there exists a significant improvement in mortality rates over the years for the younger ages, and this improvement starts shrinking from age 80 and above. By contrast, mortality patterns for people with chronic diseases differ by illness type. Though in general, the rate increases similarly as people age, the improvement in mortality is rather small for neoplasms and diabetes. Given that the mortality rates of older populations continue to rise, this trend draws attention to the greater health concerns that these people face. However, generally for most ages, the projected mortality rates decrease with time, indicating mortality improvements over time.

3.2. Forecasting morbidity data using the APC model

The APC model was used to fit the chronic illness data for the purpose of forecasting the morbidity risk associated

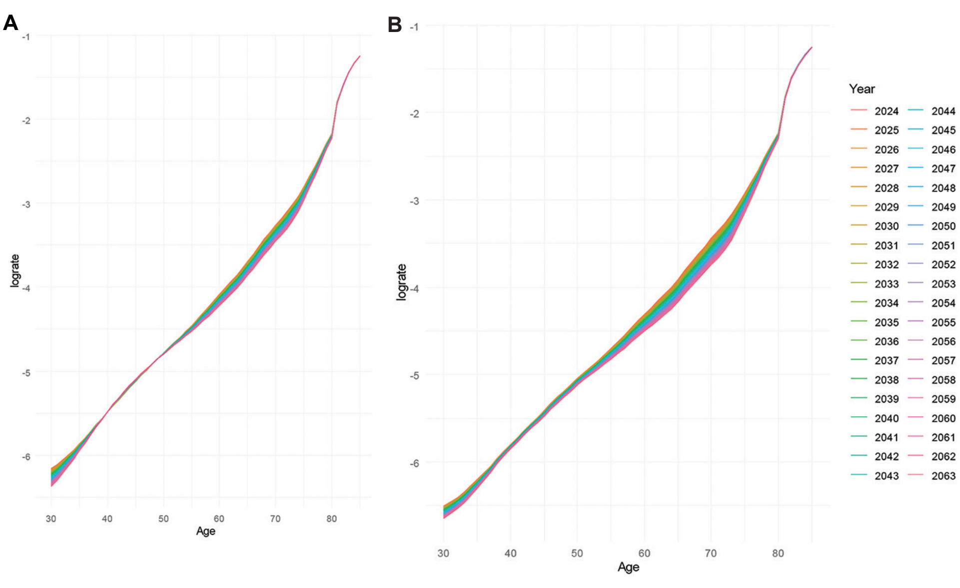

Figure 3. Spline graphs showing the mortality rates of healthy (A) male and (B) female populations from 2024 to 2063
Source: Based on the data from Abridged Life Tables Malaysia (DOSM, 2023).

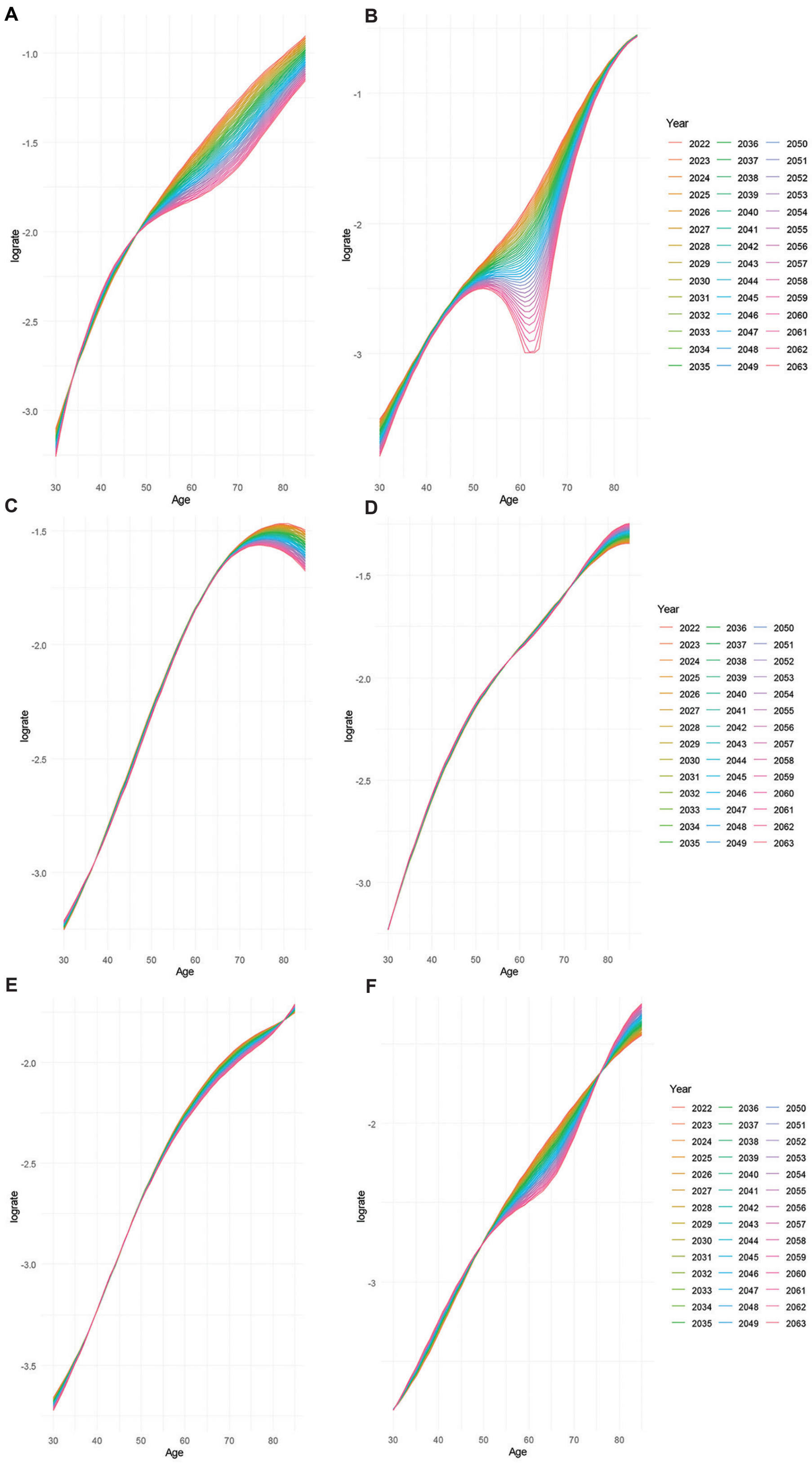

Figure 4. Spline graphs showing the mortality rates of cardiovascular diseases for (A) males and (B) females, neoplasms for (C) males and (D) females, and diabetes for (E) males and (F) females from 2022 to 2063
Source: Based on the data from the Global Burden of Disease Study (IHME, 2024).

with the diseases. Data on the number of cases and the rate of incidence due to cardiovascular diseases, neoplasms, and diabetes in Malaysia were extracted from the IHME. The extracted data needed cleaning to guarantee accurate processing in Microsoft Excel. Then, the data were arranged, where the first column represents the year, followed by the age group interval and the number of cases that were used to calculate the exposure of the incidence rate.

After P-spline interpolation from grouped ages to single-year ages, the data exhibited a smooth and continuous trend across the entire age group. The x-axis, initially presented in five-year age intervals, is now detailed by single ages from 0 to 100 for IHME data. The interpolation and subsequent extrapolation to age 100, based on past trends, indicate a steady rise in morbidity rates among older adults. Across all graphs, the incidence rates for different years (2022–2063) are closely clustered, indicating stable and consistent predictions over the forecast period. For all conditions, there is a clear age-related pattern where incidence rates tend to increase, reach a peak, and then either plateau or decline slightly. The use of the P-spline method has effectively smoothed the data, providing clear and continuous incidence rate estimates for every single year of age. Thus, the method captures the overall trends while reducing the impact of minor data fluctuations.

3.3. Generate transition probability matrix

To compare the premium values from the two-state and five-state annuity models through a thorough analysis, the projected mortality and morbidity rates estimated earlier were used to develop a transition probability matrix (TPM) for each cohort group, showing the likelihood of transitions between health states over time. This is one of the crucial parts of annuity modeling. Cohort groups were divided by sex and age at issue to reflect potential differences in mortality and morbidity that affect premium values and overall annuity estimates.

3.3.1. Cohort arrangement

Based on Table 1, the data were organized into groups of individuals who share common characteristics, specifically their age at the time of purchasing the annuity product. This rearrangement focused on extracting mortality and morbidity rates over time. Furthermore, this approach enhanced the understanding of trends and patterns among customers, allowing us to tailor products and services to the identified cohort groups. The longitudinal forecasted data on mortality and morbidity were then rearranged into age cohorts using a loop function in R software. Given that the target market for the product consists of older individuals approaching retirement, we focused on the cohort aged 50–60 years old in the purchasing year of 2023. As a result of the cohort arrangement by age and sex, several groups with different sets of TPMs were formed.

Table 1. Transition probabilities of the cohort

Ages	H-D	H-C	H-N	H-Db	C-D	N-D	Db-D
50	0.0035	0.0094	0.0044	0.0107	0.0143	0.0063	0.0026
60	0.0084	0.0227	0.0078	0.0204	0.0250	0.0160	0.0063
70	0.0174	0.0418	0.0120	0.0290	0.0358	0.0292	0.0112
80	0.0633	0.0638	0.0158	0.0191	0.0676	0.0280	0.0157
90	0.0633	0.0923	0.0145	0.0123	0.1149	0.0086	0.0336
100	0.0633	0.1298	0.0100	0.0142	0.1100	0.0124	0.0702

Abbreviations: H-D: Healthy-dead state; H-C: Healthy-cardiovascular disease state; H-N: Healthy-neoplasm state; H-Db: Healthy-diabetes state; C-D: Cardiovascular disease-dead state; N-D: Neoplasm-dead state; Db-D: Diabetes-dead state.

3.3.2. Transition probability matrix

This study used Markov models to illustrate changes in an older person's health, with a focus on the states of health, diabetes, neoplasms, cardiovascular diseases, and death. We assumed no recovery probability, meaning once individuals transition from healthy to a sick state, they cannot return to healthy or switch between different illnesses. These assumptions are particularly relevant for our target demographic of the older population, who are generally more susceptible to chronic conditions that are less likely to be cured or reversed. Furthermore, evidence by Boyd *et al.* (2008) indicates poor recovery prognoses after new disability among hospitalized older adults. This framework supports the assessment of life expectancy and healthcare needs in the context of the annuity product.

In our model, we assumed that transitions between different illnesses are not possible. Accordingly, this can be represented as three separate three-state models, each consisting of healthy, a specific illness (cardiovascular diseases, neoplasms, or diabetes), and death. However, as the market annuity product was designed for the general public, we decided to combine these into a single five-state model rather than concentrating on a particular chronic illness. The five-state model captures morbidity risk across major chronic illnesses over retirees' lifespans and is therefore more suitable for annuity funding. In addition, we chose these three illnesses because they are commonly covered by existing enhanced annuity products overseas, along with other significant conditions, such as asthma and kidney failure (Standard Life, 2023). This highlights the importance of including these illnesses in our model to better meet the needs of older Malaysians.

Next, we developed the TPMs for the two-state and five-state models to facilitate the calculation of net present value and premiums for model analysis. Based on the annuity pricing calculation, the two-state model includes only the "healthy" and "dead" states, necessitating only the mortality rate of healthy individuals' data. In contrast, the five-state model, which is an enhancement of existing annuity products, requires both the mortality and morbidity rates of healthy individuals, as well as rates for selected chronic illnesses. To transform the collected and forecasted data into a TPM, we started by gathering probabilities between different states. This involves calculating the probabilities of remaining in the same state, such as staying healthy or remaining in the chronic illnesses state, by subtracting the transition probabilities to other states from one. For example, the probability of staying healthy is derived by subtracting the probabilities of transition to illnesses or death from one, as explained in Section 2.4.1.

3.3.3. Results of annuity premium calculation

The two-state and five-state annuity models can be distinguished by their risk classification. For the five-state annuity model, pricing can be adjusted by the insurer because the model explicitly accounts for the health conditions of the annuitants to reflect their mortality and morbidity risks. For example, healthy people have lower mortality rates compared to people with chronic illnesses. Therefore, pricing should differ between these groups. Incorporating the mortality and morbidity risks into the pricing model improves pricing precision and reduces overall risk exposure. Theoretically, the five-state annuity model yields lower premiums based on the risks incorporated. The transition probabilities between healthy and the other states inform accurate premium allocation to avoid underestimation or overestimation of the costs to the insurer.

In summary, risk assessment is enhanced as the insurer considers both mortality and morbidity risks in the annuity pricing. This typically results in the five-state model having lower premiums than the two-state model, making it suitable for individuals who face health complications.

In this study, we set the entry age to 50–59 years old, focusing on purchases by individuals nearing retirement. Thus, payments commence at age 60, ensuring continued income after retirement. Based on the annual premium rates above, premiums for both models increased with purchase age. As the annuity income payments started on retirement at 60, a later purchase age shortened the investment horizon and raised premiums. For both models, premiums for females were slightly higher than for males. This reflects lower female mortality relative to male mortality. Across all ages and both sexes, premiums for the two-state model were higher than for the five-state model. Table 2 reports the net annual premiums by age and sex.

Table 2. Net annual premium for the annuity pricing model

Age	Two-state model (MYR)		Five-state model (MYR)	
	Male	Female	Male	Female
50	947.61	1,094.44	740.49	760.92
51	1,082.06	1,248.53	860.17	885.78
52	1,250.94	1,441.88	1,012.46	1,044.61
53	1,469.03	1,691.32	1,212.73	1,252.69
54	1,760.99	2,024.90	1,484.81	1,534.85
55	2,171.21	2,493.15	1,870.98	1,934.68
56	2,788.50	3,197.08	2,455.88	2,539.30
57	3,820.03	4,372.43	3,438.26	3,553.27
58	5,887.19	6,726.28	5,416.10	5,592.22
59	12,095.47	13,793.37	11,379.58	11,735.81

4. Discussion

This study explored the longevity and chronic illness risks among older Malaysians. Our findings revealed that the mortality rates for the healthy population improved over time, aligning with an increasing life expectancy as shown in the DOSM report (DOSM, 2025). By contrast, the mortality rate projections for populations with chronic disease generally improved for most ages but varied beyond age 80. The rates were improving over the years for the population with cardiovascular diseases and for the population with neoplasms. Conversely, the rates were worsening for the age group beyond 80 for both the male and female populations with diabetes. Generally, female mortality rates were lower than those for males for most age groups. Taken together, these patterns suggest disease-specific survivorship dynamics, which are consistent with a heterogeneous risk profile for older-aged populations.

These findings contribute to our understanding of the presence of longevity risk associated with retirement funding. In particular, the pricing of a retirement-linked product, such as retirement annuities, should ideally incorporate this longevity risk to ensure that the life-long annuity payments are secured. Past studies emphasized that longevity risk must be estimated accurately to avoid life offices from paying out for much longer than was anticipated, thereby shifting unforeseen longevity costs onto insurers (Mircea *et al.*, 2014). Numerous results of mortality projections used in the literature showed that the Lee–Carter model provides the best fit for many countries' mortality data, such as those by Richards & Currie (2009). Similarly, our findings show the lowest error measurement for the Lee–Carter model for all mortality type projections in Malaysia. Consequently, this implies that policy evaluation and pricing exercises anchored on Lee–Carter forecasts may reduce model-driven mispricing relative to alternatives.

In addition, incorporating morbidity risk, such as chronic illnesses, is crucial for appropriately pricing the cost of retirement annuities, as morbidity risk increases as people age. Ignoring this might produce inequitable pricing for prospective retirees and cross-subsidization between health groups. Graphical outputs from the study illustrate these trends and show a clear upward trajectory in the prevalence of chronic illnesses as age increases. The graphs highlight that individuals over the age of 70 are particularly vulnerable, experiencing the highest rates of chronic illness. This demographic shift necessitates urgent reforms in financial and healthcare systems to accommodate the evolving needs of older people. This study also underscores the importance of considering the risk of health within the older population in determining the cost of retirement plans, such as annuities, offered in the insurance industry.

As seen in the European Union, where pricing by sex is forbidden, pensioners in many nations have few options when it comes to buying life annuities, frequently priced simply on age or age and sex (European Council, 2004). Special-rate life annuities are one example of how certain countries have enhanced their annuity markets through sophisticated risk-underwriting techniques. According to Pitacco & Tabakova (2022) and Olivieri & Tabakova (2024), these annuities take into account variables including residency, lifestyle, and health states. Special-rate life annuities reflect a shorter anticipated life expectancy for the insured by taking these considerations into account and offering larger periodic payouts than ordinary annuities (Gatzert & Klotzki, 2016). Interpreting our results through this lens, the Malaysian market would price more fairly if impairment-based adjustments were permitted alongside existing regulatory constraints, thereby aligning benefits with health-adjusted life expectancy.

In accordance with the concept of special-rate life annuities, our pricing model compared the two-state and the five-state annuity pricing models. The former one only includes the states of healthy and dead, while the latter consists of the possibility of chronic illness diagnosis over the lifecycle of retirees. This structure mirrors impairment-based pricing by aligning benefits with health-adjusted life expectancy.

Overall, the pricing of annuities consisting of mortality and morbidity risks of chronic illness produces lower premiums, as higher risks reduce the expected duration of payments relative to healthy individuals. Accordingly, the five-state model explicitly recognizes elevated risk when determining premium rates. This contrasts with the two-state model, which includes only the healthy and dead states. Since people in this model do not experience health complications, their mortality risk is lower, leading to longer expected lifetimes and, therefore, higher premiums for the same benefit level. Interpretively, the observed premium differentials are a direct consequence of risk classification within the annuity pricing model.

This research expands current knowledge by addressing the implications of risk of chronic illness and longevity among the older population in pricing retirement annuities. Particularly for the Malaysian population, the difference in the cost of retirement annuities is approximately 21% and 30% cheaper for males and females aged 50 at purchase, respectively, when the risk of chronic illness is taken into account in comparison to a model with only healthy and dead states. This underscores the importance of risk-based pricing that considers health state to fairly price the retirement-linked products for future retirees.

In practice, the evidence points to a coherent policy architecture for Malaysia's annuity market. First, regulators could enable morbidity-adjusted pricing and permit carefully regulated medically underwritten or lifestyle-rated pathways to reduce cross-subsidization across health groups. Second, default partial annuitization should be incorporated into EPF decumulation paths upon retirement. This would provide a health-dependent option benefit in addition to consistent disclosure of impaired-life loadings. Collectively, these measures would align annuity pricing with health-adjusted life expectancy while maintaining equity, solvency, and consumer protection.

Despite its contributions, this study has several limitations. First, the pricing model assumes no recovery from a chronic illness. The income payments payable under the enhanced annuity product would effectively be increased on diagnosis of chronic illness. No changes in payment occur afterward since the chances of full recovery are small according to other actuarial modeling for critical illness insurance provision (Macdonald *et al*., 2005; Ozkok *et al*., 2014). Second, the number of chronic illnesses incorporated in the model may include other diseases, according to the critical illness insurance provision. Instead, this study focused on three of the top major causes of chronic illness for the Malaysian population to evaluate the impact on retirement annuities pricing. Future research may incorporate all other possibilities of chronic illnesses in the model; however, the implication on pricing will be minimal if the rate of illness is not significant for the population. Third, we have assumed a predetermined starting age for receiving annuity payments, based on the current compulsory retirement age for most Malaysians in both the public and private sectors. A potential extension of this study could involve modeling the impact of postponing the retirement age to reflect potential future policy changes. While such a postponement may reduce the cost of annuities, other important factors must be considered, such as the feasibility of extending work beyond age 60 across various occupations, and individual preferences between continued employment and leisure beyond the official retirement age.

5. Conclusion

This study offers crucial insights into how lifespan and the risk of chronic illness interact among older Malaysians, and this directly affects the actuarial pricing of products related to retirement, such as retirement annuities. Our results validate the trend of rising national life expectancy accompanied by declining mortality rates among healthy populations. However, the trends varied for people with chronic conditions, especially for the oldest groups, emphasizing how crucial it is to include mortality and morbidity risks in annuity pricing models. Overall, mortality improvements are shown for most age groups in all mortality types considered for both healthy and non-healthy populations.

Risk-based pricing models in retirement planning are pivotal, as evidenced by the reported differences in mortality rates between sexes and health states, including diabetes, neoplasms, and cardiovascular diseases. Our comparison of the five-state and two-state annuity models shows that including chronic illness risks leads to more equitable pricing in addition to reflecting a more realistic aging trajectory. In particular, when chronic illness risk is taken into consideration, premiums are shown to be 21–30% lower, making annuities more accessible for high-risk persons who might otherwise be at a disadvantage.

This study contributes to the current literature by addressing risk-based elements in retirement product pricing that consider health heterogeneity in older populations. As Malaysia's population continues to age, and as chronic illnesses become more prevalent, there is a pressing need for the insurance and pension industries to adapt through more sophisticated and inclusive risk underwriting methods, such as those seen in the development of special-rate life annuities in other countries.

While our model is limited to three major chronic illnesses, it sets the foundation for more comprehensive frameworks that can accommodate a wider range of health states. Future research may expand on this by integrating additional illnesses and considering transitions between health states. Nevertheless, our findings strongly support the integration of both longevity and morbidity risks into retirement annuity pricing, not only to ensure financial sustainability for providers but also to promote equity and adequacy in retirement income for an increasingly vulnerable aging population.

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Conflict of interest

The authors declare that they have no competing interests.

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Writing–review & editing: Nurin Haniah Asmuni

Ethics approval and consent to participate

Not applicable.

Consent for publication

Not applicable.

Availability of data

Data used in this study can be obtained from the national statistical database. In particular, the mortality rates for Malaysia's general population were obtained from the Department of Statistics, Malaysia (https://www.dosm.gov.my/portal-main/online-services?data=8), and the mortality rate and morbidity rates associated with chronic illnesses were obtained from the Institute for Health Metrics and Evaluation database on the Global Burden of Disease Study (https://vizhub.healthdata.org/gbd-results/).

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