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Analysing the impact of rising mortality in adult ages on financial and actuarial products

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ABSTRACT

A reversal in the trend seen since 2010 of a reduction in adult mortality holds significant economic and financial implications. Mortality and longevity models applied in 2010 projected central death rates that have not materialized, resulting in measurable economic effects. This study examines the economic consequences of two financial-actuarial products— a year-term life insurance and life annuities— in light of the worsening central death rates within the 55–70 age bracket. Conducted across twelve countries (Australia, Canada, Denmark, France, Greece, Germany, Italy, Japan, Spain, Sweden, the United Kingdom, and the United States), the research demonstrates substantial cost savings in annuity products and cost overruns in risk insurance products.

1. Introduction

Since the 1950s, a persistent reduction has been seen in central death rates in developed countries, leading to a consistent rise in life expectancy (WHO, 2000; Oeppen and Vaupel, 2002). This phenomenon has captured the interest of economists and actuaries, who, employing widely acknowledged longevity models, have strived to forecast future mortality trends (Lee and Carter, 1992; Renshaw and Haberman, 2003). Nevertheless, recent research (Welsh et al., 2021) has uncovered a noticeable deceleration in the reduction of central death rates, particularly in the age groups approaching retirement. This deceleration carries significant economic implications for financial and actuarial products, such as annuities and life insurance, and thus warrants further analysis.

By examining the economic implications of increased central death rates, the aim of this study is twofold. Firstly, the study sets out to critically assess the underestimation of mortality by several dynamic mortality models employed in actuarial practice, particularly for the age group nearing retirement. Secondly, in a novel contribution to economic literature, the study aims to quantify the impact of the higher mortality rate on financial and actuarial products designed for both survival contingencies (e.g., annuities) and death contingencies (e.g., risk products).

2. Data and actuarial mortality models

In this research, we employ data from two sources. On the one hand, the general mortality population data is used from the registry of the HMD database (Human Mortality Database, 2023), which provides comprehensive mortality information from the National Office of Statistics. In this study, we use data from twelve countries (Australia, Canada, Denmark, France, Greece, Germany, Italy, Japan, Spain, Sweden, the United Kingdom and the United States) covering the period from 1990 to 2019. On the other hand, to study the economic implications, we use an economic database from an actual insurance company (see the supplementary material in Lledó and Pavía (2022)). This dataset outlines anonymized data pertaining to the policies in force within a life-risk insurance portfolio held by a Spanish insurance company, specifically focusing on a year-term life insurance.

In mortality methods, the central death rate is calculated as follows: $d_{x,t}$ represents the number of deaths in a population at age x during period t and $E^c_{x,t}$ is the central exposure to risk for individuals aged x during period t; both are obtained from HMD. These two outcomes are used to calculate the central death rates at age x and period t: $m_{x,t} = d_{x,t} / E_{x,t}$.

The analysis carried out in this research employs three distinct models: the Lee-Carter model (Lee and Carter, 1992), the Bi-Factorial Lee-Carter model (Renshaw and Haberman, 2003), and the Plat model

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(Plat, 2009). We have decided to use these models due to their forecasting ability and the fact that they are well established in the literature (Atance et al., 2020; Kessy et al., 2022). A brief overview of these three models used for fitting and forecasting central death rates is provided in Table 1.

The model parameters, whose descriptions can be found in their respective literature, are estimated using *StMoMO* R package (Villegas et al., 2018) through the utilization of a Generalized Linear Model in the fitting process.

3. Empirical results

3.1. Mortality projection

To examine mortality trends, Fig. 1 displays logarithmically scaled central death rates for ages 55, 60, 65, and 70 years in the population of France over a 40-year span from 1990 to 2019. The figure includes both observed mortality data and mortality forecasts generated by the LC, LC2, and PLAT models. These projections are based on data gathered from 1990 to 2009, representing the calibration period for the models, and are used to predict the period from 2010 to 2019 (shaded region).

Fig. 1 illustrates a notable mortality trend. Until 2010, central death rates are seen to steadily decrease. However, after 2010, a pronounced slowdown is observed, almost to the point of stagnation, particularly for ages 65 and 70. This slowdown is slightly more pronounced for women. It seems that commonly used models such as LC and LC2 tend to underestimate mortality; this is noticeable across (almost) all countries, as shown in Figures S1 to S11 in the supplementary material. This underestimation carries significant economic implications for various financial products and highlights the need for a thorough assessment.

The increase in mortality among the studied countries during the period 2010–2020 is mainly due to the increase in certain health issues which can lead to death. For example, Ho and Hendi (2018) assess the decline in life expectancy in the period 2015–2016 among 18 high-income countries and identify respiratory diseases, circulatory diseases, Alzheimer's disease, nervous system diseases, and mental disorders, as well as drug overdoses in men, as key drivers of these declines. Furthermore, Acosta et al. (2020) study the excess of mortality in the 2010–2020 periods in the USA and Canada. They attribute this phenomenon to behavioural causes of death, namely drug abuse, alcohol abuse, HIV/AIDS, hepatitis C, COPD, and suicide.

3.2. Impact on risk products

To assess how a decline in mortality improvements affects an insurance product, we select 4695 policies (of insured aged between 60 and 69 years) from a total of 76,102 policies within the insurance portfolio. This study employs a year-term life insurance, ${}_1A_x$, where beneficiaries receive a capital sum (C) upon the insured's death. To calculate the expected pure insurance premium (P), we use the formula: $P = C{\cdot}{}_1A_x = C{\cdot}q^i_{x,t}{\cdot}(1+i)^{-1}$, with $q^i_{x,t}$ representing the probability of a person aged x not reaching $x+1$ in scenario/model i, obtained from the relation $m_{x,t} \leftrightarrow q_{x,t}$; $q_{x,t} = \frac{m_{x,t}}{1+0.5{\cdot}m_{x,t}}$. For fair comparison of expected claims and income, expenses and taxes are not considered.

Table 2 displays the expected premium values for selected policies, using the observed mortality rates, and the forecasted values provided by the model projections (LC, LC2, and PLAT) for the population of France alongside the differences in relative terms. The premiums are categorized by gender and cover three projected years: 2010, 2015, and 2019. Similar to prior studies (e.g., Lledó et al., 2017), we use general mortality data for pricing insurance products covering the insured population. This approach, which does not impact the outcomes, simplifies cross-country comparisons by not relying on country-specific life tables established by regulatory authorities. It is important to note that the *basis risk* that may arise due to the unique characteristics of the insured population compared to the general population has not been taken into account.

Table 2 illustrates significant economic findings. Across the periods a noticeable decline is seen in the total expected premiums due to decreased central death rates. However, the expected pure premium obtained using all models exhibit a more pronounced reduction in mortality compared to the actual values (Fig. 1). This points to a growing latent economic loss over the years as mortality surpasses model expectations. For instance, in 2015 for males, a projected loss of 383 thousand euros is seen between actual premiums and the value estimated with the LC model. All three models yield significantly different results from actual values, with the PLAT model showing a slight improvement over LC and LC2. Table S1 in the supplementary material presents similar relative values for all other countries, with a few minor exceptions, in line with the results obtained for France.

Table 1
Description of the model structures employed to fit the central death rates.

Model	Structure
Lee-Carter (LC)	$\log m_{x,t} = a_x + b_x k_t$
Bi-Factorial Lee-Carter (LC2)	$\log m_{x,t} = a_x + b^{(1)}_x k^{(1)}_t + b^{(2)}_x k^{(2)}_t$
Plat (PLAT)	$\log m_{x,t} = a_x + k^{(1)}_t + (x-\bar{x})k^{(2)}_t + (x-\bar{x})^+ k^{(3)}_t + \gamma_{t-x}$

3.3. Impact on saving products

In the field of finance and insurance, annuities aim to ensure a consistent and dependable income stream, catering to individual or family financial requirements. These income sources are accessible through public pension systems and insurance industry savings products. An elevated central death rate, as depicted in Fig. 1, signals potential and quantifiable *cost savings* for such financial products.

To assess annuities comprehensively, central death rates from the real mortality data and using the mortality rates predicted by the models (LC, LC2, and PLAT) for 2010, 2015, and 2019 are used. Table 3 outlines the relative difference in the expected actuarial present value of a €12,000-per-year annuity (up to age 100), VA_x, for both genders, between real data and models. This analysis takes into account a 3% interest rate, an age of 65, and the year 2015.

Table 3 shows predominantly positive relative disparities across the analysed models and countries. These disparities stem from the lower mortality indicated by the three models (see Fig. 1). Consequently, the expected actuarial present values, calculated from the expected mortality projections of the models using fitting data from 2010, significantly exceed the expected values using the real mortality data in period 2015, resulting in substantial 'savings' for those marketing these financial products. These implicit savings gain significance in the context of annuities, representing a notable gap between expected beneficiary payouts and expected actual payments. In line with these findings, Tables S2 and S3 provide detailed data for 2015 and 2019, encompassing multiple countries and covering four reference ages (55, 60, 65, and 70), and both genders.

4. Conclusions

This study shows the deep economic implications arising from changes in mortality, particularly in the context of financial and actuarial products. Our analysis covers twelve countries (Australia, Canada, Denmark France, Greece, Germany, Italy, Japan, Spain, Sweden, the United Kingdom, and the United States), spanning the years 1990 to 2019, and employs various models such as LC, LC2, and PLAT to assess mortality dynamics. One key observation is the substantial reduction in mortality until 2010, followed by a marked slowdown thereafter, especially among individuals close to retirement age (see Fig. 1). Notably, our analysis reveals that the commonly used models tend to underestimate mortality, leading to significant discrepancies between

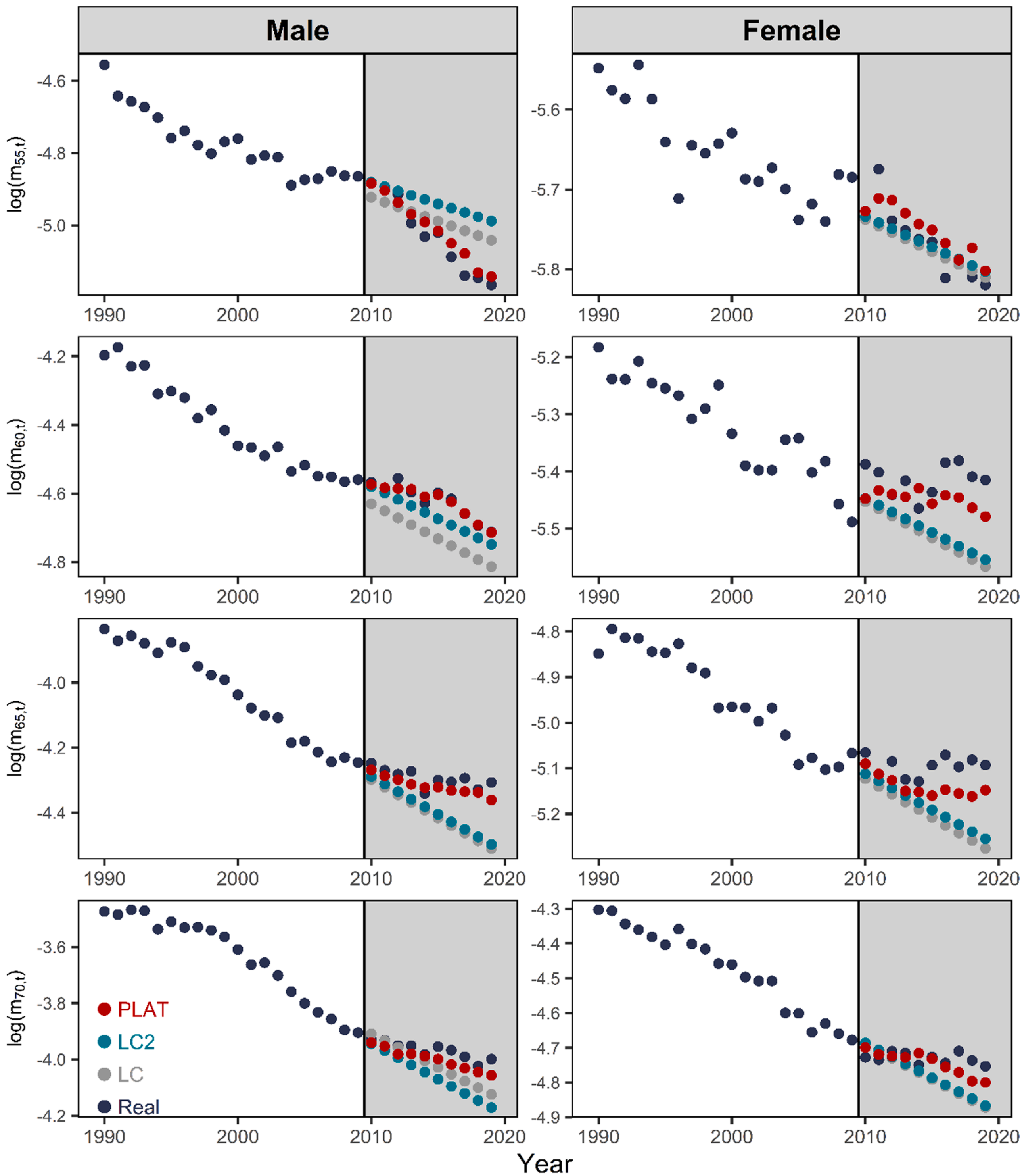

Fig. 1. Logarithmic central death rate in France (1990–2019). Blue represents observed data, while light blue, grey, and red signify logarithmic rate projections using LC, LC2, and PLAT models for 2010–2019. Projections rely on 1990–2009 data. Panels vary by age (55/60/65/70) and gender (men/women).
Note: separate scales are used for each panel to maintain data precision.

actual and projected values.

These discrepancies translate into implicit "extra" cost in risk products in the insurance sector, but a "saving" for annuity market where expected payouts to beneficiaries differ significantly from expected actual payments. Apart from a few exceptions, these results can be extrapolated to all the analysed countries. Ultimately, our study highlights the importance of adapting financial and actuarial strategies to account for evolving mortality trends.

These changes in mortality trends could have an impact on insurance and financial strategies. On the one hand, with the rising cost in risk-based insurance, insurers need to reconsider their pricing strategies to deal with higher mortality rates than previously anticipated. On the other hand, the noticeable savings in annuity payments provide valuable insights for both individuals and financial institutions, revealing opportunities to improve the management of financial risks during evolving longevity dynamics.

Table 2
Expected total pure premiums (in thousands of euros) for 4695 policies in the insurance portfolio, using the mortality probabilities of the population of France as actual data and three models (LC, LC2, and PLAT) for 2010, 2015, and 2019, across both genders. Also shown are the relative differences between the models and actual values. In this study, a 3% interest rate, i, is considered.

Type	Value	Male 2010	2015	2019	Female 2010	2015	2019
Real	€	3197.24	3086.46	2943.81	553.94	542.00	555.92
LC	€	3035.01	2703.44	2464.25	539.17	499.07	469.19
	%	(5.07)	(12.41)	(16.29)	(2.67)	(7.92)	(15.6)
LC2	€	3118.31	2791.20	2554.29	543.75	505.67	477.19
	%	(2.47)	(9.57)	(13.23)	(1.84)	(6.7)	(14.16)
PLAT	€	3156.18	3033.19	2867.38	544.78	530.91	521.20
	%	(1.28)	(1.73)	(2.6)	(1.65)	(2.05)	(6.25)

Table 3
Relative discrepancies between the actual value r and each of the models i, expressed as $\frac{{}^{i}VA_x - {}^{r}VA_x}{{}^{R}VA_x}$, pertain to the expected actuarial present value of a €12,000 annuity, computed at a 3% interest rate for a 65-year-old. The mortality models incorporate actual data up to the year in 2015. Note that the life tables used are static and do not incorporate any mortality improvement effects, aligning with the observations in Fig. 1.

Country	Male LC	LC2	PLAT	Female LC	LC2	PLAT
Australia	0.44	0.52	1.87	1.24	1.31	1.88
Canada	(0.31)	(0.06)	1.97	0.04	0.11	1.30
Germany	1.86	2.05	2.75	1.88	1.93	3.00
Spain	0.31	0.66	(0.26)	0.99	1.08	1.91
France	(0.04)	0.68	1.07	0.89	0.91	1.15
Greece	1.33	1.41	1.15	1.38	1.38	3.23
Italy	0.88	0.94	1.39	1.84	1.90	2.63
Japan	0.52	0.66	0.65	2.14	2.26	3.95
United Kingdom	2.11	2.27	3.46	1.70	1.88	2.46
United States	1.27	1.97	5.01	0.14	0.56	1.98
Denmark	2.20	1.98	0.09	3.40	3.12	1.22
Sweden	0.31	0.40	2.12	0.70	0.74	1.86

It is worth noting that the LC model and its extensions make projections based on the trend observed in the fitting period. Consequently, if there is a declining trend during the fitting period, the model will project future mortality rates following this trend. Indeed, this is the reason why the projections are not able to capture this anomalous mortality behavior in our manuscript. One approach to address this limitation is to incorporate expert opinions that consider demographic, epidemiological and other relevant knowledge into the projections. The Lee-Carter model and its extensions can be used to produce different scenarios, allowing assumptions to be made about the future value of mortality based on a broader understanding. Additionally, it is essential to highlight that the actuarial regulations (e.g., in the annual calculation of the mortality and longevity shock in the Solvency Capital Requirement, SCR of Solvency II framework) underscores the importance of yearly updating mortality projections to avoid potential losses and effectively manage risks.

Declaration of Competing Interest

The authors declare no competing interests.

Data availability

All the data used are openly accessible. On one hand, access to the HMD database is available through the following link <www.mortality.org>. Prior registration is necessary for downloading datasets. On the other hand, the insurance portfolio data can be obtained freely through two options: (i) in the supplementary material in the work developed by Lledó and Pavía (2022), accessible at <https://links.uv.es/MB40YDA>, or (ii) in the OPENICPSR repository, which is free with prior registration, with DOI reference: https://doi.org/10.3886/E178881V1.

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Supplementary materials

Supplementary material associated with this article can be found, in the online version, at doi:10.1016/j.econlet.2023.111424.

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