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Financial consequences of temperature changes on mortality: International evidence[1]

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Abstract

Changes in mortality rates have a significant impact on financial and pension planning. The pricing of financial, pension and insurance products that are contingent upon survival or death is based on the accurate forecasting of mortality rates. Knowledge of future mortality change is therefore very important from a financial point of view as a significant proportion of the financial markets are driven by pension funds.

Mortality can also be associated with weather conditions with a higher number of deaths in winter months compared to the summer. Many countries proactively act to avoid as many of the negative effects as possible of those patterns and temperature related events. For example, in the United Kingdom, well known government policies, such as winter fuel allowances, are designed to reduce the mortality effects of cold winters. Thus, a fundamental question in the study of mortality rates and temperature changes is how those changes could impact on mortality rates across the World.

In our research, we implement a new factor related to temperature and show this produces a better fitting and forecasting model. We also show how changes in our environment could impact on future mortality rates and, as a consequence, the prices of linked insurance and financial products. This research provides international evidence from Australia, Austria, France, Italy, Japan and United Kingdom.

Keywords: Mortality; Climate changes (temperature); international evidence; forecasting; linked insurance products; pricing

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I. INTRODUCTION

In the field of actuarial science modelling mortality rates and in particular the accurate forecasting of mortality rates has become a topic of great interest to academics, actuaries and financial professionals. Life insurers, pension funds and annuity providers are especially aware of their exposure to the risk of mortality changes and the need for better models for risk management.

Modelling mortality using time series to extrapolate the time trend based on historic mortality experience began in the early 1990's. These kinds of models make an assumption that past trends identified in the data will continue into the future. They do not make any allowance for structural changes in those trends and the consequences that might have for mortality however, they are good attempts for modelling mortality.

In 1992, Ronald Lee and Lawrence Carter's mortality model [15] was the first attempt to explain longevity data in a stochastic fashion by fitting the past mortality data and modelling the time trend as a stochastic process. Since then, to improve the performance of the Lee-Carter model, several extensions to the original version have been proposed including Booth et al. (2002) [2], Brouhns et al. (2002) [3], Renshaw and Haberman (2006) [20], Plat (2009) [19], Cairns et al. (2006) [4], (2011) [5], O'Hare and Li (2012) [17], French and O'Hare (2013) [9], (2014) [10] and many others.

The climate is a key ingredient in the earth's complex system that sustains human life and well-being. Extreme weather events such as droughts, hurricanes and heatwaves generate the risk of weather-related death in a population (Deschênes and Moretti, 2009 [8]). This risk increases progressively once temperatures rise above specific threshold levels, and similarly the risk of cold related death increases once temperatures drop below cold thresholds (Hajat et al., 2013 [13]). Both the heat and cold thresholds and the strength of the relationships varies greatly between countries and regions due to differing climatic, demographic, traditions and socioeconomic profiles as well as sensitivity of populations to temperature.

Studies in various parts of the world have shown different values at which changes in heat and cold related mortality begin. These depend on the acclimatization of the population in question to local changes of climate (Analitis et al. 2008 [1], Dell et al. 2014 [7], McMichael et al. 2008 [17], Gosling et al. 2009 [11] [12], Vardoulakis et al. 2014 [23], Staddon et al. (2014) [21]). The increases in death rates that have been observed occur principally in the elderly. According to the studies published since 2008 the impacts of future temperatures on

mortality, have mainly been conducted in Europe and North America (Gosling et al., 2009 [11]).

In 2014 World Meteorological Organization published the report "The Atlas of Mortality and Economic Losses from Weather, Climate and Water Extremes" (2014 [25]) which sought to raise awareness of these challenges on the World. Information included in the Atlas confirm and emphasise the significant contribution that weather related deaths make to overall mortality (see Figure 1.).

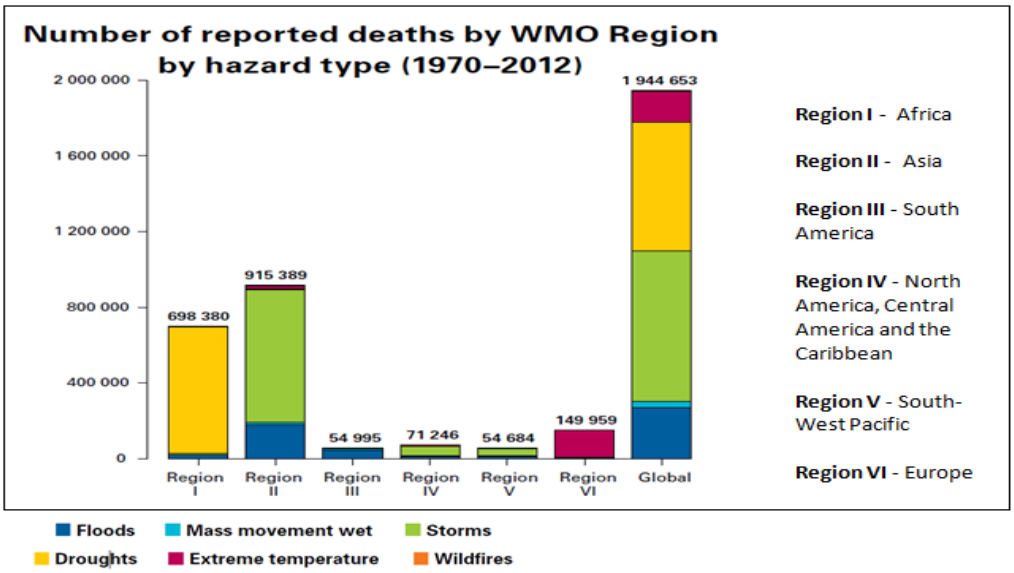

Figure 1. Number of Reported Deaths by WMO Region by Hazard Type[2].

Our study of mortality rates and associated ambient temperature changes is motivated by the desire to show how those anomalies could impact on mortality rates across the World. Based on our results for the three main parties of the United Kingdom (Seklecka et al. [22]), we show that the proposed model performs well in fitting to the data from a range of countries.

Mortality data used in this study was downloaded from *The Human Mortality Database* (www.mortality.org) and annual anomalies of the temperatures from *Berkeley Earth (www.berkeleyearth.org)*.

[2]Source: World Meteorological Organisation, The Atlas of Mortality and Economic Losses from Weather, Climate and Water Extremes 1970-2012.

II. TEMPERATURE CHANGES

Many lines of scientific evidence show the Earth's temperature is changing (IPCC 2014 [6], Huntingford et al. 2013 [14], Orlowsky 2012 [18]). According to the summary provided by the Intergovernmental Panel on Climate Change (IPCC)[3], the mean global surface temperature has increased by 1.5°C over the past 250 years. In particular, for Austria the mean surface temperature has increased by 2.58 °C in the last century, around 2.46 °C in Italy, around 1.67 ° in the United Kingdom, around 1.41°C in France, around 0.96 °C in Japan and around 0.58°C in Australia. The temperature changes are noticeable for all countries, and more there is a division into two groups in the countries we consider European countries and Japan and Australia. There are also differences we could notice in the period of time considered in this study (years from 1974 to 2006). Similarly, we observe differences between European countries (see Figure 3., 4., 5. and 7.) and non-European (see Figure 2. and 6.) in this period of time.

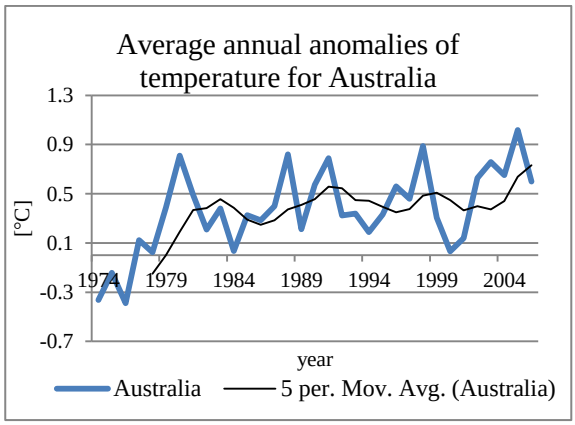

Figure 2. Average annual anomalies of temperature for Australia for the period of time between 1974 and 2006.

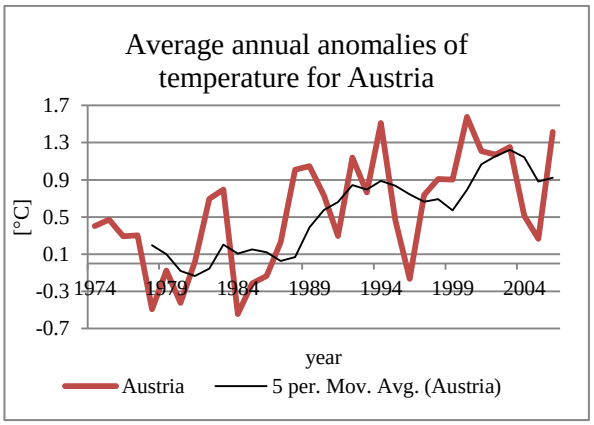

Figure 3. Average annual anomalies of temperature for Austria for the period of time between 1974 and 2006.

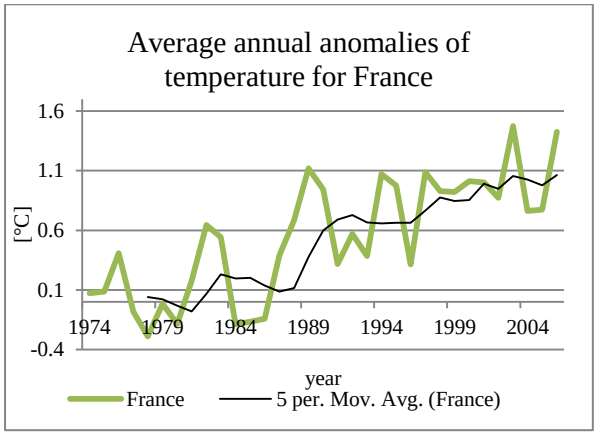

Figure 4. Average annual anomalies of temperature for France for the period of time between 1974 and 2006.

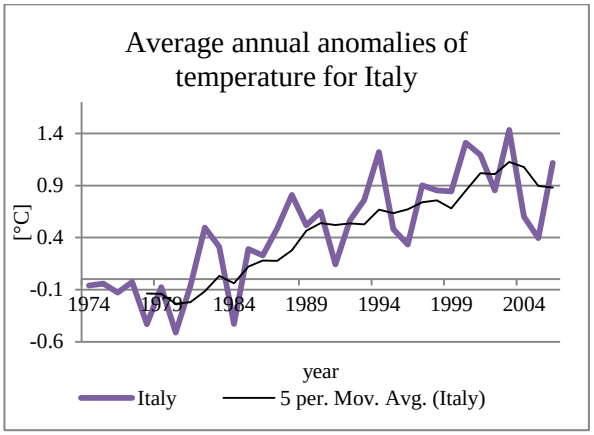

Figure 5. Average annual anomalies of temperature for Italy for the period of time between 1974 and 2006.

[3] Source: Intergovernmental Panel on Climate Change

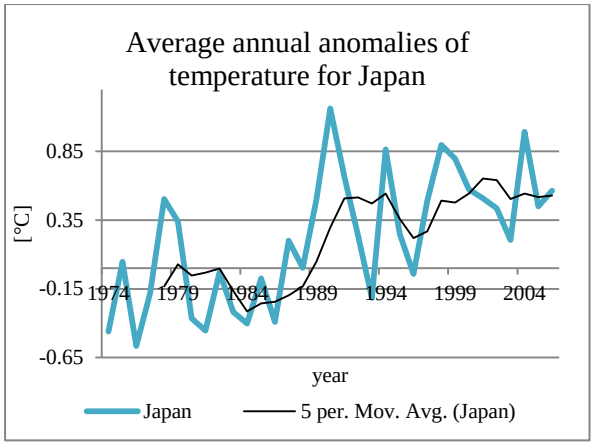

Figure 6. Average annual anomalies of temperature for Japan for the period of time between 1974 and 2006.

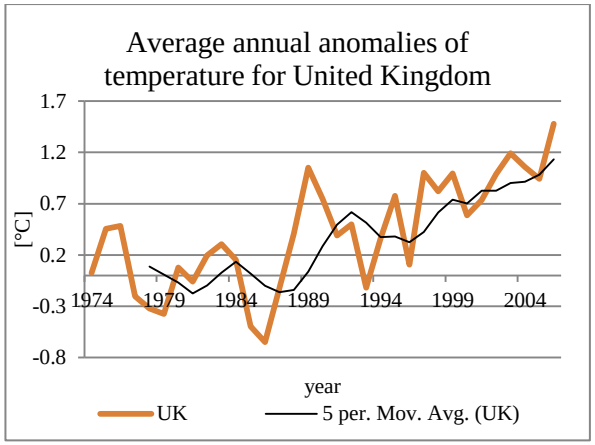

Figure 7. Average annual anomalies of temperature for United Kingdom for the period of time between 1974 and 2006.

III. THE MORTALITY MODELS

The most famous and widely used mortality model in recent decades is the model proposed by Lee and Carter in 1992. The model postulated by Lee and Carter (1992) [15] is given by:

$$\ln(m_{xt}) = b_x^1 + b_x^2 k_t^1 + \varepsilon_{xt},$$

where:

- m_{xt} is the central mortality rate, calculated as the ratio between the number of people aged x who died in a year t, and the exposure to risk, calculated as the average population aged x in year t,
- b_x^1 makes sure that the basic shape of the mortality curve over ages is in line with historical observation,
- k_t^1 factor represents changes in mortality between ages reflecting the historical observation that improvement rates can differ for different age classes independent of time average age specific,
- b_x^2 pattern of deviations from the age of profile as the k_t^1 varies (explains how rapidly/slowly mortality rates decline in response to k_t^1),
- ε_{xt} is the error term at age x and time t, usually defined as independent and identically distributed random variables following a normal (Poisson) distribution.

This model has outperformed other mortality models due to its simplicity and least prediction of errors. However, recent studies have revealed other new models extended from the Lee Carter Model.

In 2009 Plat [19] developed a four factor model which maintained the goods and left out some of the weaker features of the previous extensions of the Lee Carter model as:

$$\ln(m_{xt}) = b_x^1 + k_t^2 + (\bar{x} - x)\, k_t^3 + (\bar{\mathrm{x}} - \mathrm{x})^+ k_t^4 + \gamma_{t-x}^3 + \varepsilon_{xt},$$

where $(\bar{\mathrm{x}} - \mathrm{x})^+ = max(\bar{\mathrm{x}} - \mathrm{x}, 0)$ and $\bar{x}$ is the average of the ages considered.

Many papers propose that mortality in advanced ages is influenced by the mortality experiences at the younger age range. This implies that experience at the younger ages is important to consider when modelling the mortality experience of a population. In 2012 O'Hare and Li proposed adaptation of Plat model as:

$$\ln(m_{xt}) = b_x^1 + k_t^2 + (\bar{x} - x)\, k_t^3 + ((\bar{\mathrm{x}} - \mathrm{x})^+ + [(\bar{\mathrm{x}} - \mathrm{x})^+]^2) k_t^4 + \gamma_{t-x}^3 + \varepsilon_{xt}$$

Following O'Hare and Li (2012) [17] approach, who capture the non-linear features of mortality at younger ages, (see also Seklecka et al. (2015) [22]) added a new factor related to fluctuation of temperature in the non-linear approach for elderly ages. The proposed model of the central mortality rate m_{xt} is as follows:

$$\ln(m_{xt}) = b_x^1 + k_t^2 + (\bar{x} - x)\, k_t^3 + (\bar{\mathrm{x}} - \mathrm{x})^+ k_t^4 + ([a - x]^+)^2 k_t^5 + c_x([x - a]^+)^2 k_t^6 + \gamma_{t-x}^3 + \varepsilon_{xt}.$$

In comparison to the previous models, there appeared an additional time independent factor c_x for ages after a (a differs between the countries). This factor is the pattern of deviations from the age profile as the k_t^6 varies in response to the time changes of the temperature. The additional factor is appearing as a consequence of Pearson's correlation coefficient between temperatures and mortality rates.

IV. RESULTS FOR DIFFERENT COUNTRIES

Many studies show that the number of factors driving changes in the mortality rates is similar across different countries. Therefore, we consequently expanded the previous investigation for the United Kingdom, Australia, Austria, France, Italy and Japan. Similar to the previous studies, the dataset was divided by sex and age range 20 – 85 and the hypothesis were verified by Pearson's correlation coefficient.

The results of the Pearson correlation coefficient confirm that the elderly ages (both for females and males) are especially exposed to temperature changes (see Figure 8. and 9.).

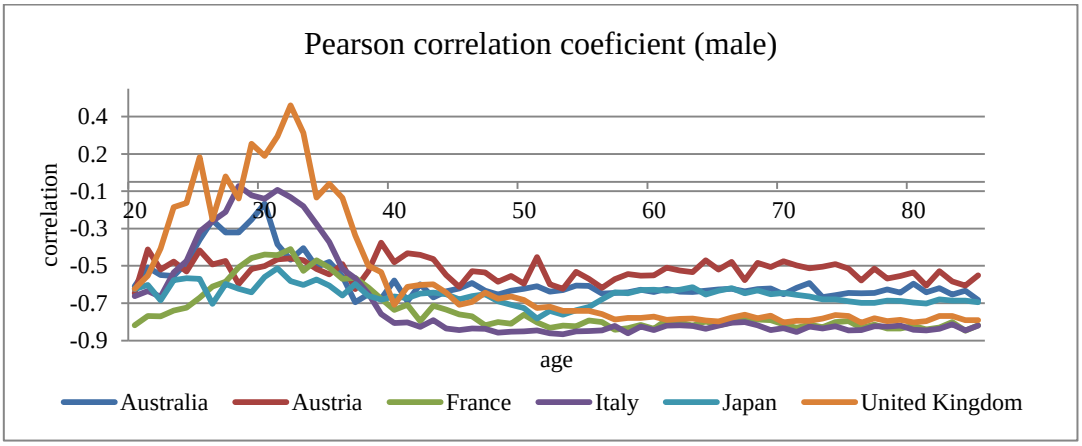

Figure 8. Pearson correlation coefficient for male between mean annual temperatures anomalies and mortality rates (temperature data and mortality rates from 1974 to 2006) calculated for single age.

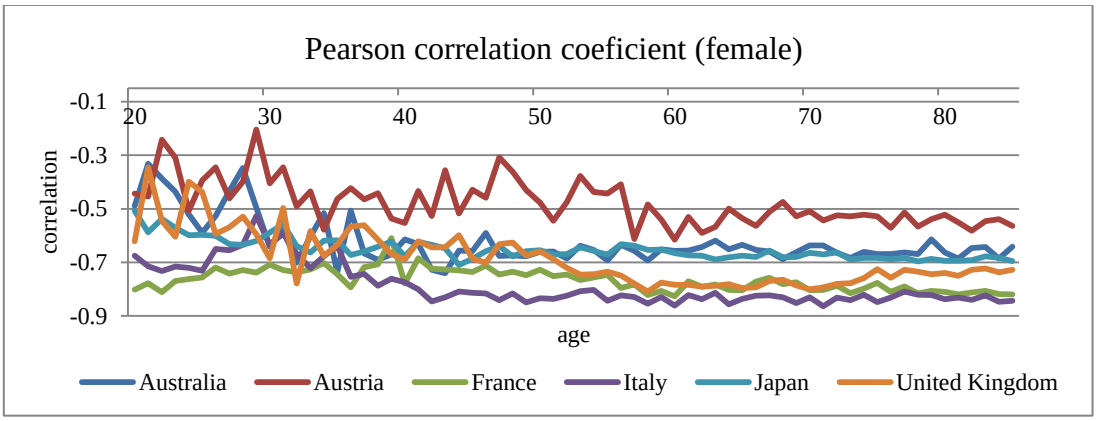

Figure 9. Pearson correlation coefficient for male between mean annual temperatures anomalies and mortality rates (temperature data and mortality rates from 1974 to 2006) calculated for single age.

To compare the fit quality of the models we follow O'Hare and Li (2012 [17]) and use the Mean Absolute Percentage Error (MAPE) measure and the Bayesian Information Criterion (BIC) measure defined as:

$$\text{MAPE} = \frac{1}{NM}\sum_{x,t}\frac{\left|\left|\widehat{m_{x,t}} - m_{x,t}\right|\right|}{m_{x,t}},$$

where we have N (N=33) time dimensions and M (M=66) age dimensions, and

$$\text{BIC} = L(\varphi) - \frac{1}{2}Kln(P),$$

where $L(\varphi)$is the log-likelihood of the estimated parameter φ, P is the number of observations and K is the number of parameters being estimated.

TABLE 1. The MAPE for the model fit to ages 20-85 (male).

	Lee Carter [15]	Plat [19]	O'Hare and Li [17]	Proposed new model
Australia	5.70%	6.02%	6.34%	**4.68**%
Austria	6.04%	5.52%	5.51%	**5.49**%
France	5.30%	3.20%	3.21%	**2.88**%
Italy	6.00%	4.14%	4.48%	**3.82**%
Japan	4.04%	3.17%	3.13%	**2.39**%
United Kingdom	4.09%	3.64%	4.07%	**2.67**%

TABLE 2. The MAPE for the model fit to ages 20-85 (female).

	Lee Carter [10]	Plat [19]	O'Hare and Li [17]	Proposed new model
Australia	6.39%	6.23%	6.25%	**5.68**%
Austria	8.20%	7.83%	7.89%	**7.67**%
France	4.65%	3.57%	3.46%	**3.24**%
Italy	4.97%	3.84%	3.92%	**3.77**%
Japan	4.15%	2.69%	2.87%	**2.69**%
United Kingdom	4.47%	3.25%	3.36%	**2.99**%

TABLE 3. The BIC for the model fit to ages 20-85 (male).

	Lee Carter [10]	Plat [19]	O'Hare and Li [17]	Proposed new model
Australia	-11591	-11640	-11877	**-11148**
Austria	-10430	**-10190**	-10228	-10238
France	-18582	-13867	-13904	**-13471**
Italy	-19960	-14554	-15006	**-14031**
Japan	-20128	-15941	-16336	**-14301**
United Kingdom	-16118	-13552	-14122	**-12719**

TABLE 4. The BIC for the model fit to ages 20-85 (female).

	Lee Carter [10]	Plat [19]	O'Hare and Li [17]	Proposed new model
Australia	-10241	-10273	-10295	**-10230**
Austria	-9509	**-9482**	-9526	-9563
France	-13483	-12030	-11973	**-11774**
Italy	-14085	-12066	-12115	**-11910**
Japan	-15379	-12693	-12994	**-12720**
United Kingdom	-15164	-12159	-12266	**-11904**

From the results in the tables above is evident that the new model is better fitting for all countries under consideration in this study. However, dependent on country and sex we observe different improvement (see Table 5.).

TABLE 5. Improvement of the MAPE in comparison to the best of considered models.

	male	female
United Kingdom	**26.62**%	**8.07**%
Japan	**23.65**%	0.07%
Australia	**17.86**%	**8.78**%
France	10.04%	**6.57**%
Italy	7.89%	2.00%
Austria	0.47%	1.95%

As we can see there is a significant improvement for males from United Kingdom, Japan and Australia (for France and Italy we have also noticed good results). The improvement for female is not so impressive as for males, however it is still notable for United Kingdom, Australia and France.

V. Financial consequences.

Modern risk-management practice requires companies to manage mortality risk as effectively as possible as part of a wider framework of enterprise risk management. Thus, it is essential that they are correct and represent reality as well as it is possible. It is well known that mortality rates are the basis for many financial products (Wills and Sherris, 2008[24], Seklecka et al., 2015 [22]). As a consequence of the new temperature related factor in our

proposed model, mortality rates are shown to differ and those differences affect the pricing of the financial and pension products.

As an example we used n - years annuities, on which the payments of £1000 are made at the end of each year by n years and the actuarial present value is given by

$$\ddot{a}_{\overline{x:n|}} = \sum_{k=0}^{n-1} v^k \, {}_kp_x$$

where $v = \frac{1}{1+i}$, and i is an interest rate (in our example $i = 3\%$) and ${}_kp_x$ is the probability that the x years old person survives to age $x + k$.

For almost all countries under consideration in this study the temperature related factor works for the ages above 50, for that reason we consider 10, 15, 20, 25 and 30 year annuities for 50 years old males and females. In most cases we achieve prices closer than for other models in comparison with life tables (see Figure 10-19. Of course, the results are much better for countries with better improvement. Nevertheless, in most cases results are good.

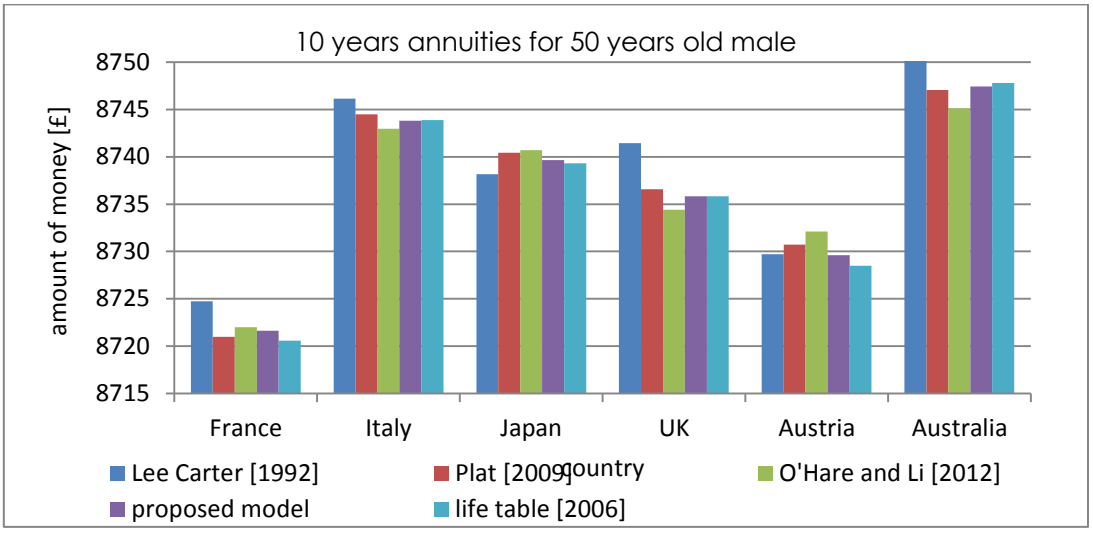

Figure 10. Comparison of 10-years annuity for various models and life table for 50 years old male from different countries.

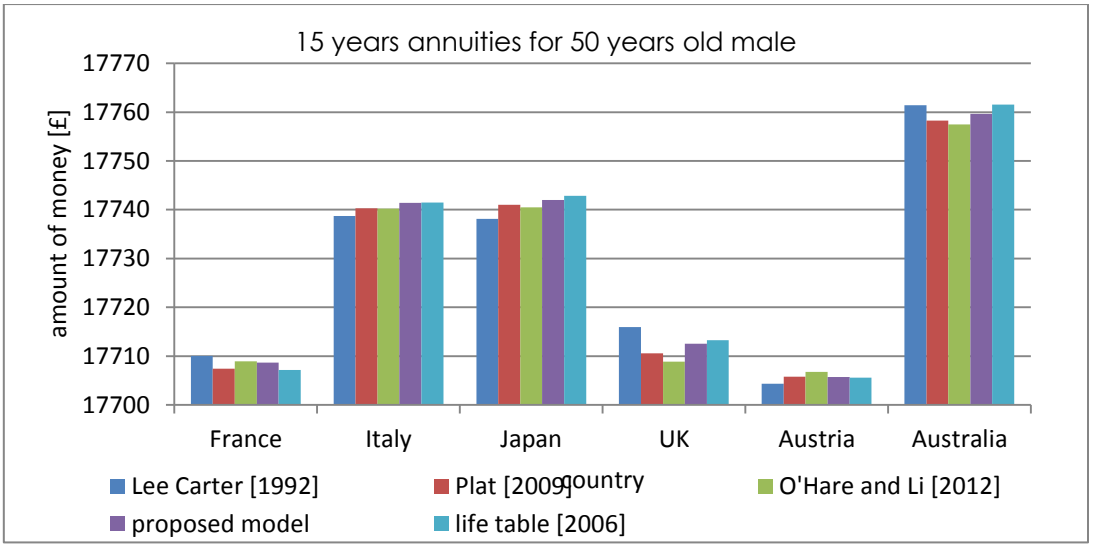

Figure 11. Comparison of 15-years annuity for various models and life table for 50 years old male from different countries.

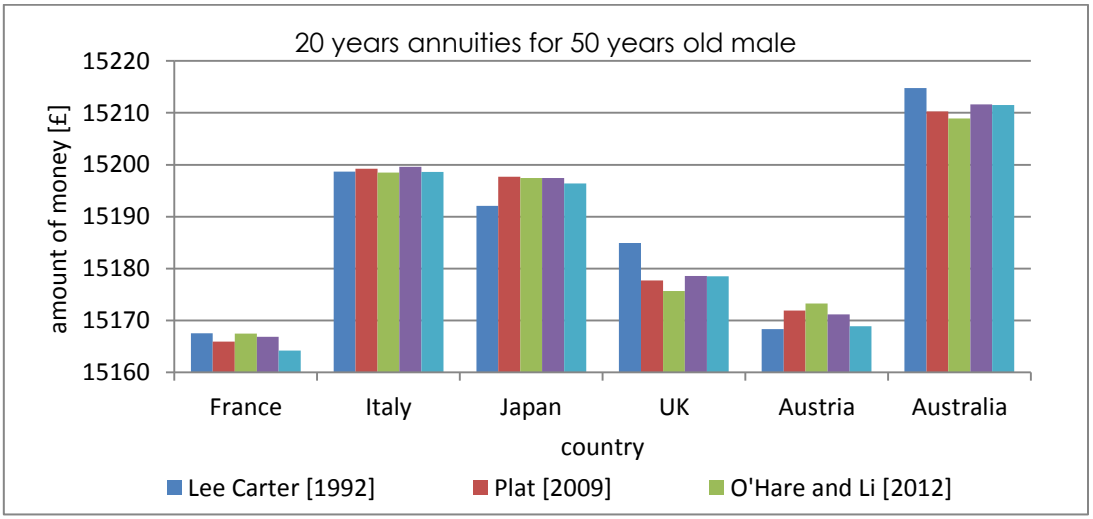

Figure 12. Comparison of 20-years annuity for various models and life table for 50 years old male from different countries.

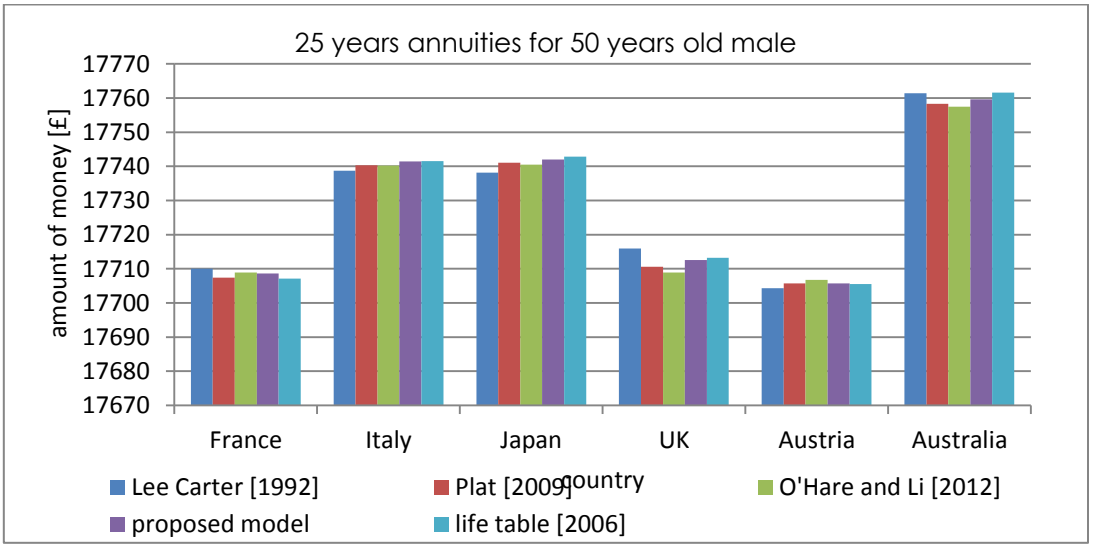

Figure 13. Comparison of 25-years annuity for various models and life table for 50 years old male from different countries.

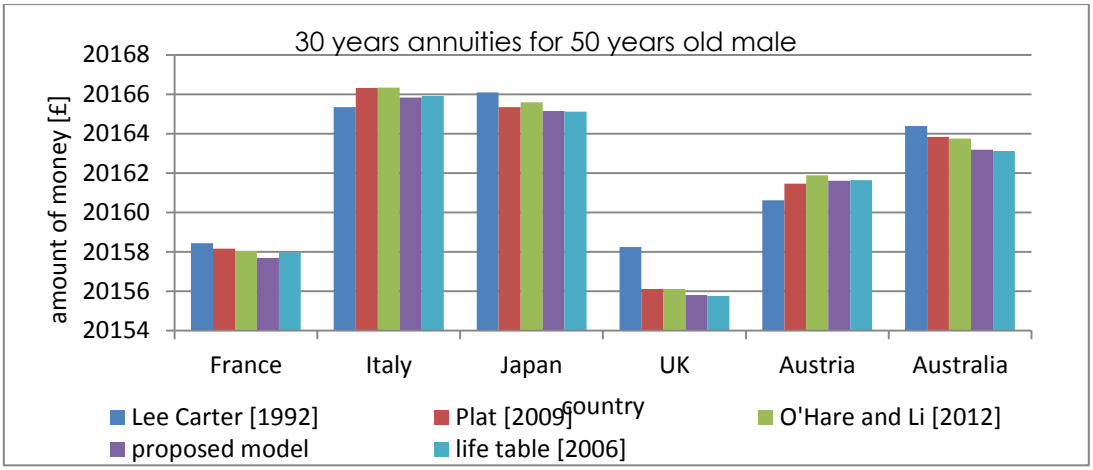

Figure 14. Comparison of 30-years annuity for various models and life table for 50 years old male from different countries.

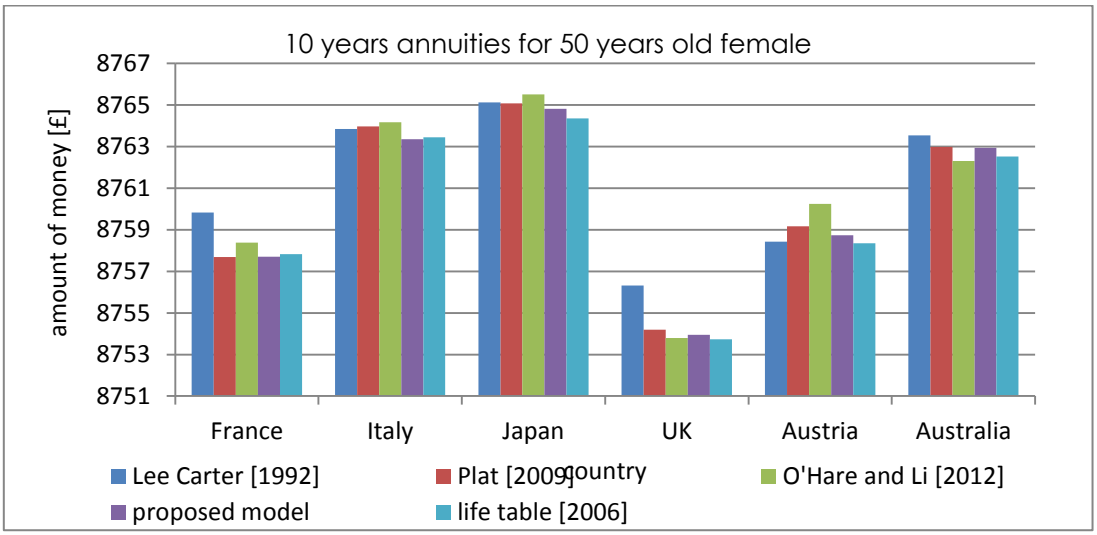

Figure 15. Comparison of 10-years annuity for various models and life table for 50 years old female from different countries.

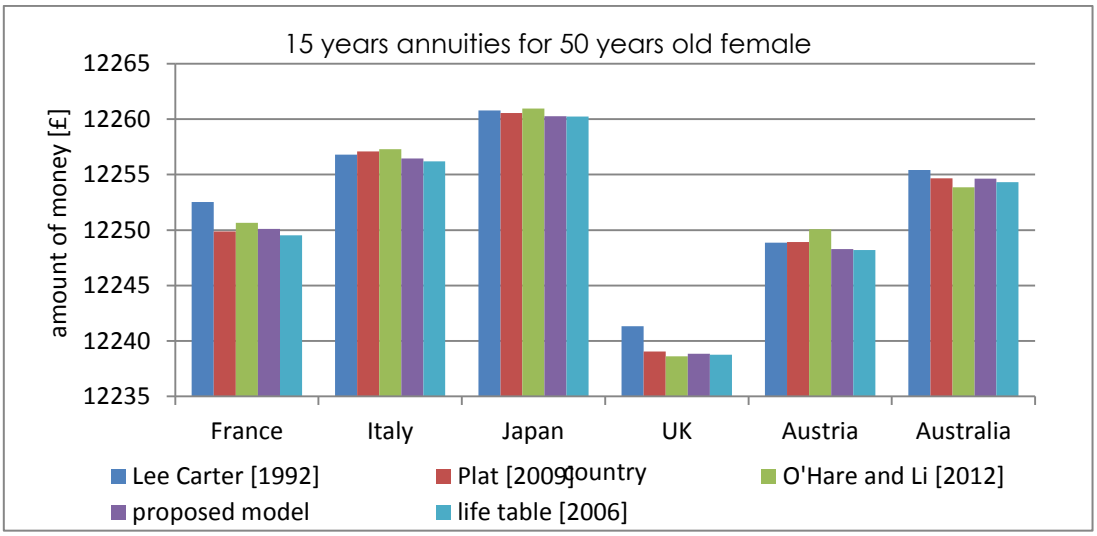

Figure 16. Comparison of 15-years annuity for various models and life table for 50 years old female from different countries.

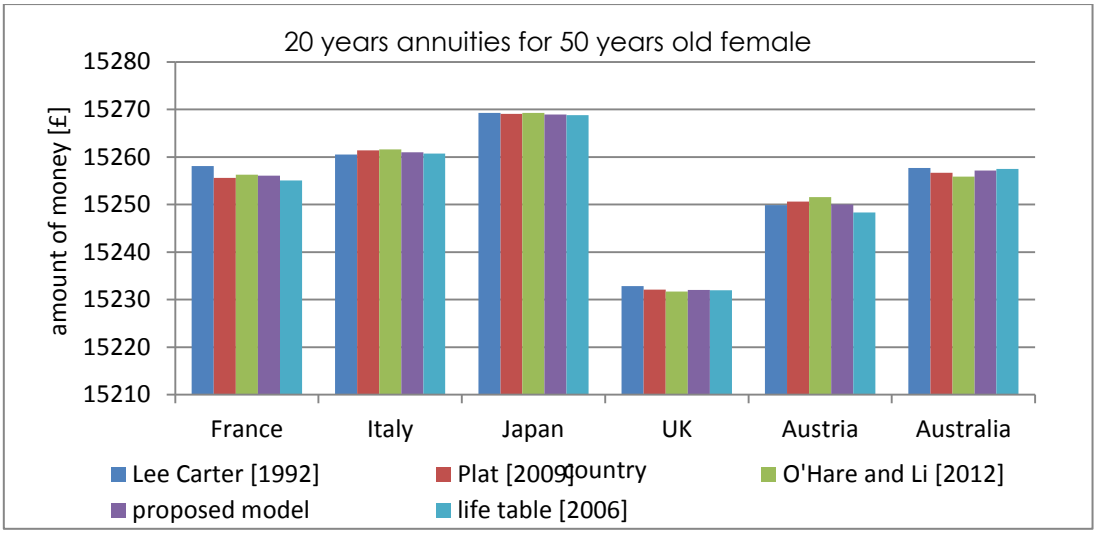

Figure 17. Comparison of 20-years annuity for various models and life table for 50 years old female from different countries.

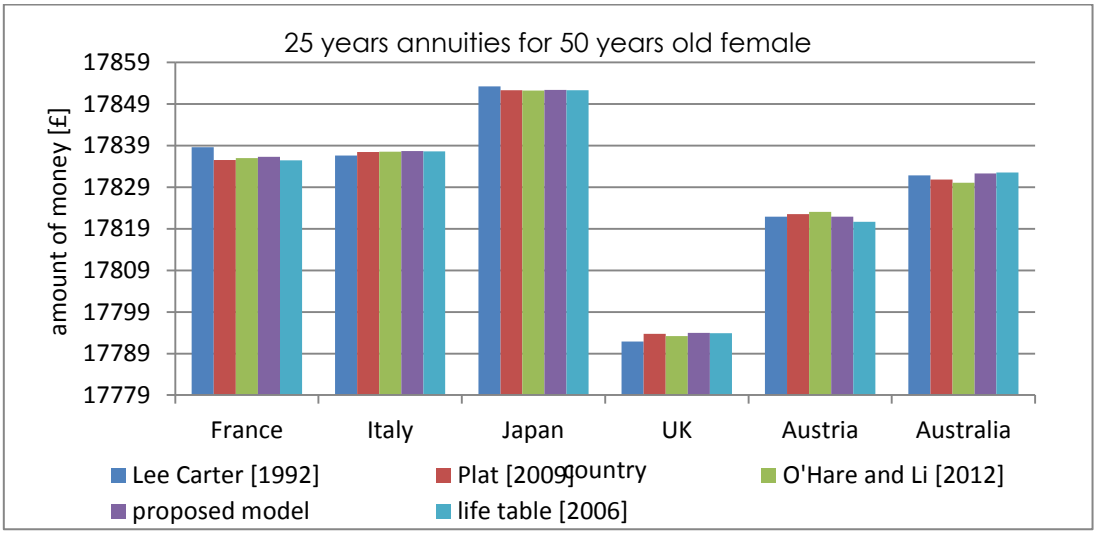

Figure 18. Comparison of 25-years annuity for various models and life table for 50 years old female from different countries.

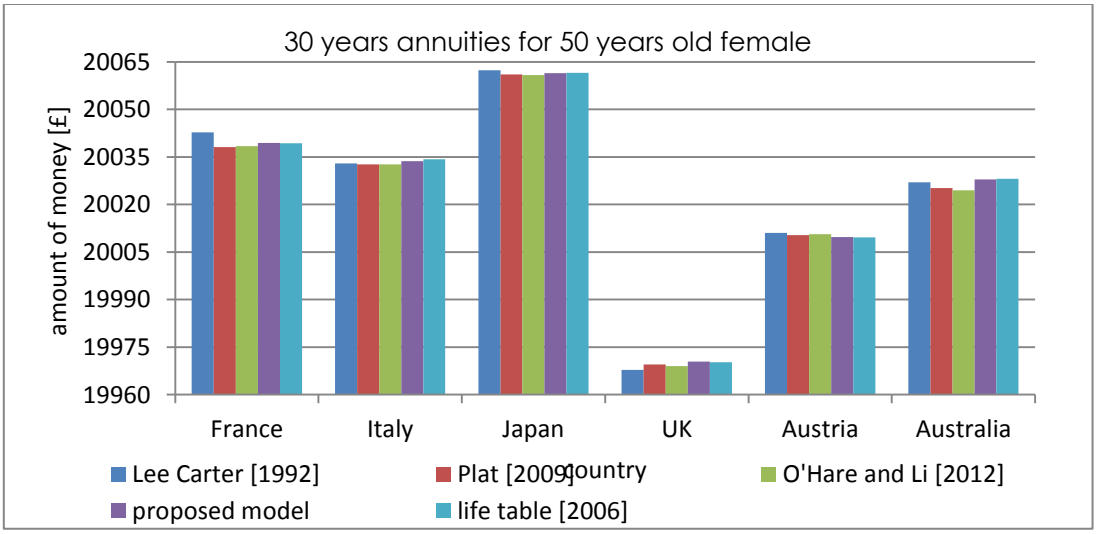

Figure 19. Comparison of 30-years annuity for various models and life table for 50 years old female from different countries.

VI. Conclusion

This paper is an international investigation of goodness of fit of a mortality model with in built temperature related factor which was used for the first time by Seklecka et al. [22] for the seasonal study of mortality for England, Scotland and Northern Ireland. This study was focused on the data from six countries (United Kingdom, Australia, Austria, France, Italy and Japan) and all the calculations were done for males and females.

The model considered in this paper provides a very good fit to almost all the countries under consideration (for ages 20-85 from 1974-2006), however, we notice remarkably better fitting for males than for females. Mortality rates resulting from the new model better approximate data from life tables, and as consequence affect the pricing of the annuities.

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