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# Financial consequences of temperature changes on mortality: International evidence

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# CONTENTS

# AIM OF THE PROJECT

**The main aims** of the project are:

- to consider the impact of temperature on mortality rates for countries from different parts of the World which have various climate experience
- to construct a model of mortality rates that explicitly allows for temperature changes
- to assess the impact on theoretical product pricing of allowing for temperature changes (we consider here an endowment assurance policy )

# MOTIVATION OF THE PROJECT

- ✓ Very good results of the Seklecka et al. (2015) model for seasonal data from the United Kingdom
- ✓ Many lines of scientific evidence show the Earth's temperature is changing
- ✓ Positive and negative anomalies are observed over the World

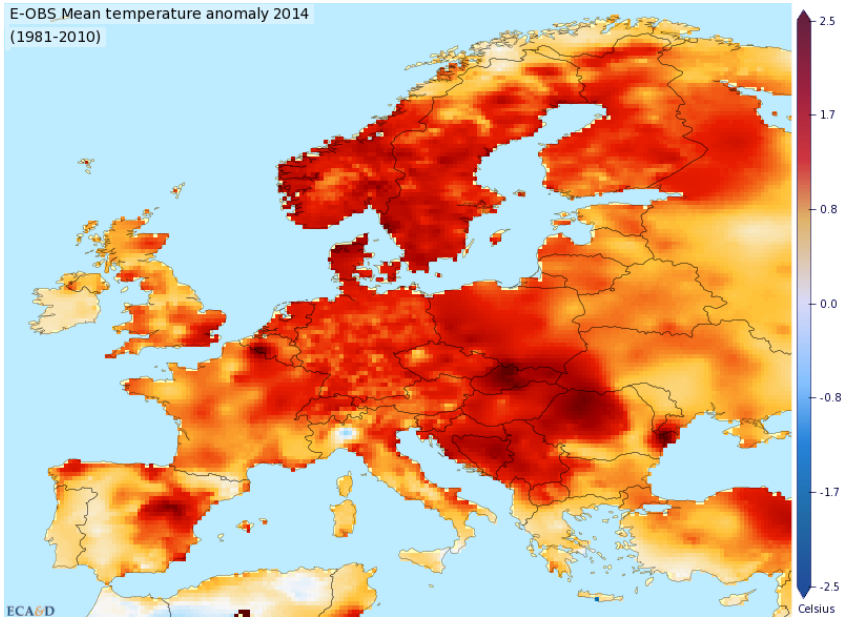



**Figure 1.** Map of anomalous annual temperature for 2014, with respect to the 1981-2010 climatology.

# MOTIVATION OF THE PROJECT

- ✓ The mean global surface temperature has increased by 1.5°C over the past 250 years
- ✓ According to the studies published since 2008 the impacts of future temperatures on mortality, have mainly been conducted in Europe and North America (Gosling, 2009)

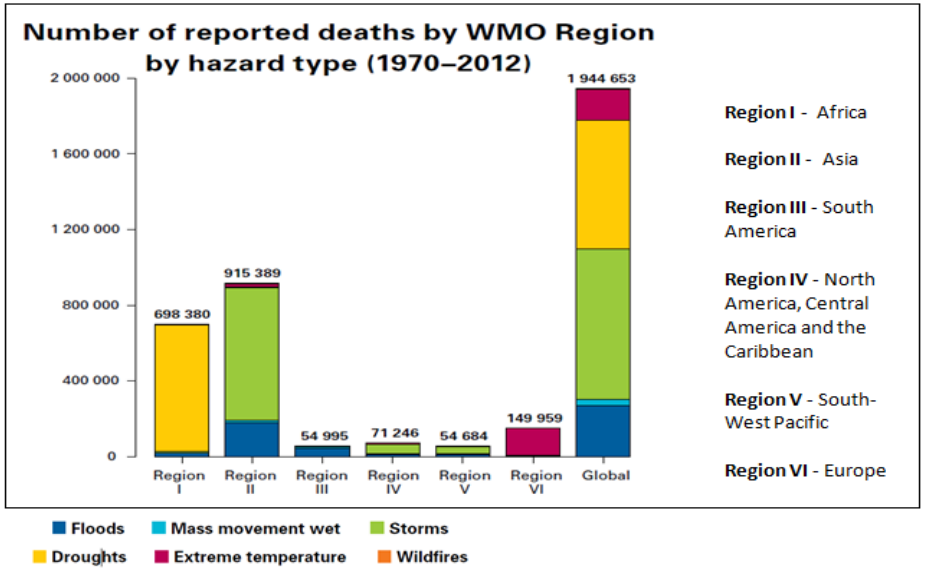
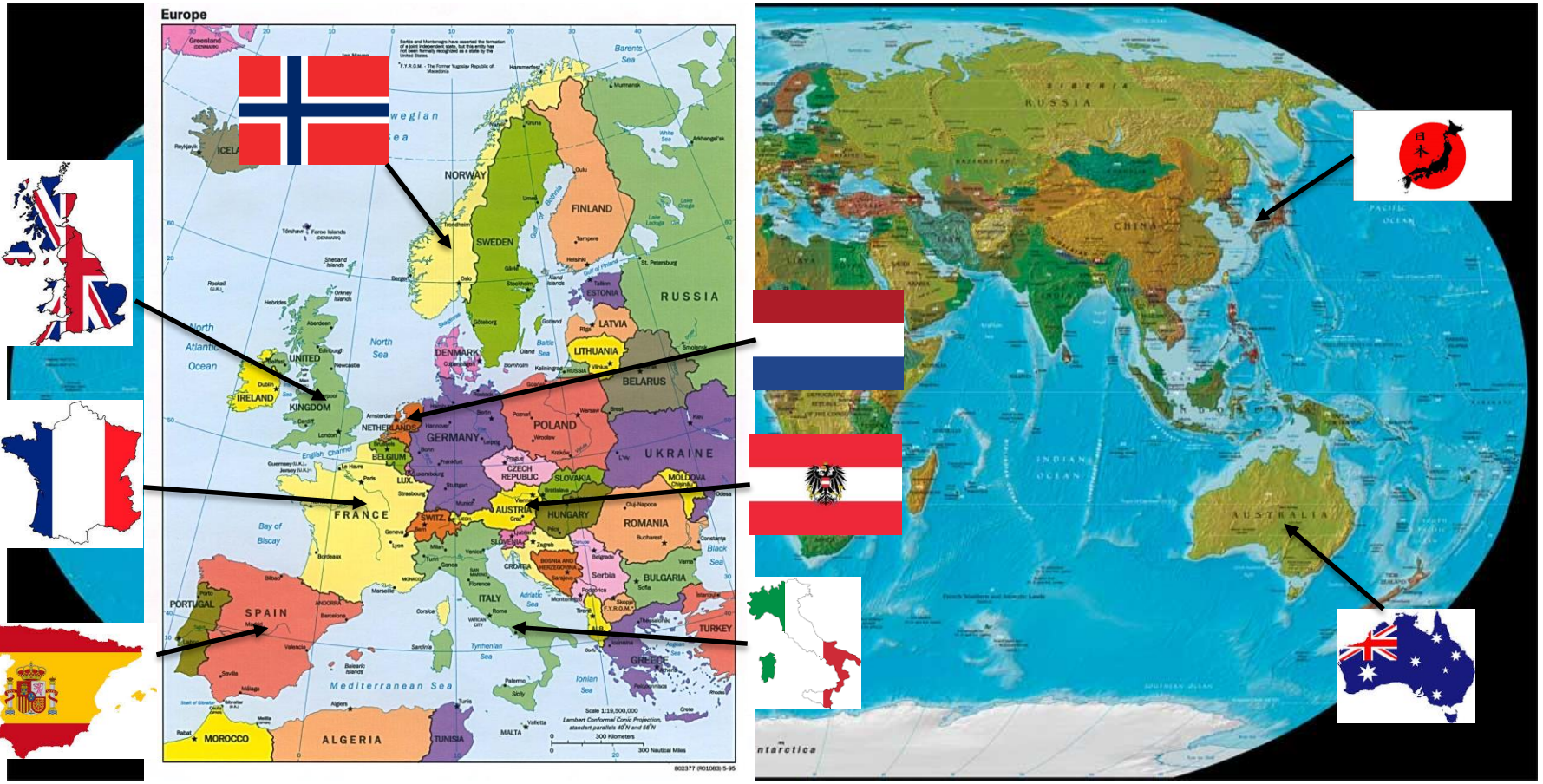



**Figure 2.** Number of Reported Deaths by WMO Region by Hazard Type. Source: Intergovernmental Panel on Climate Change.

# MOTIVATION OF THE PROJECT

## Which countries of the World?



# MOTIVATION OF THE PROJECT

Annual avererage temperature anomalies for those countries

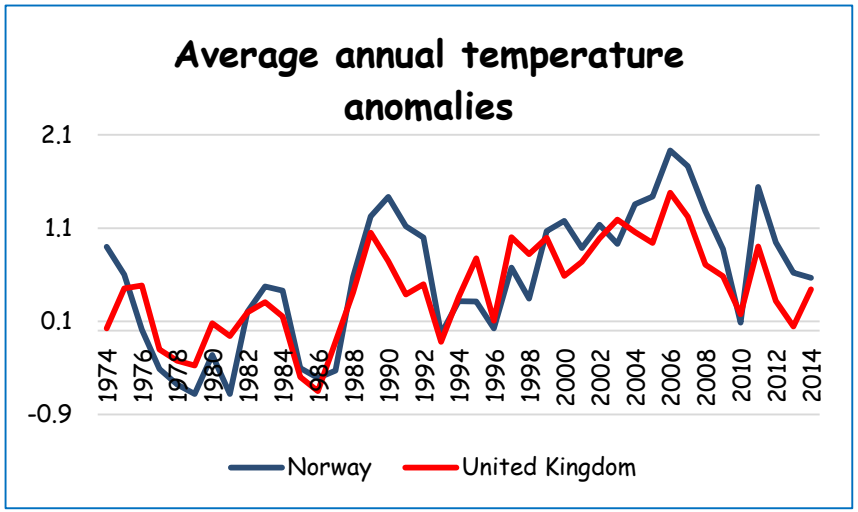



**Figure 4.** Average annual temperature anomalies for Norway and United Kingdom.

Data source: Berkeley Earth

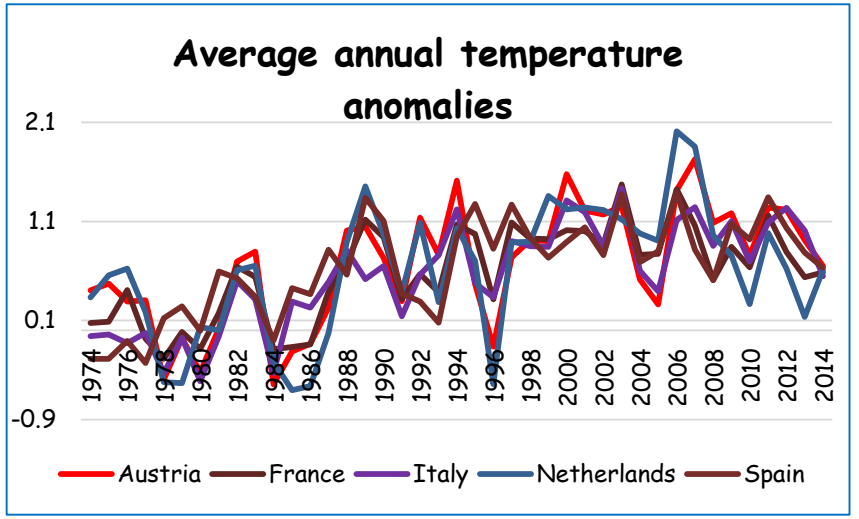



**Figure 3.** Average annual temperature anomalies for five European countries.

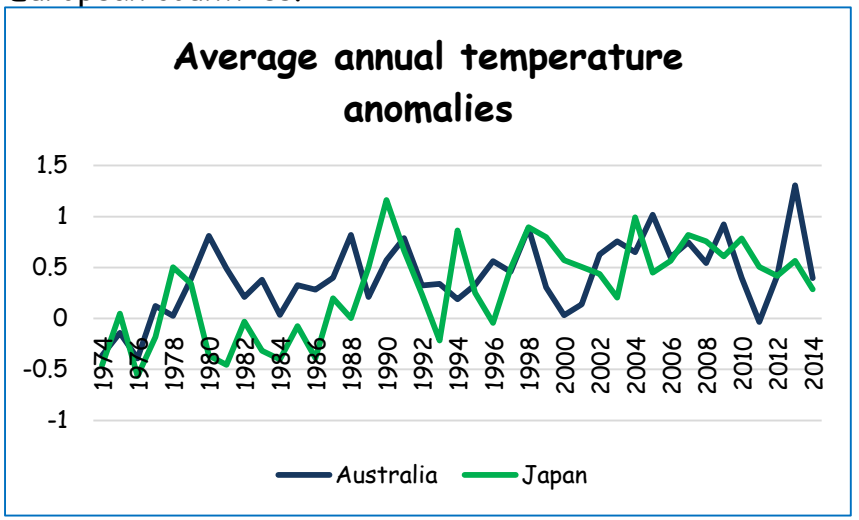



**Figure 5.** Average annual temperature anomalies for Australia and Japan.

# PEARSON'S CORRELATION COEFFICIENT

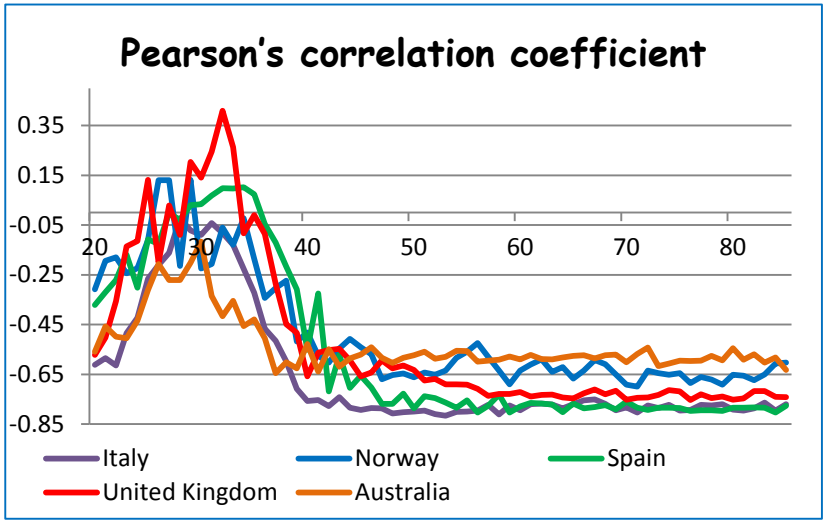



**Figure 6.** Pearson's correlation coefficient for males from Australia, Italy, Norway, Spain and the United Kingdom (data from 1974 to 2006).

Data source:

- Human Mortality Database
- Berkeley Earth

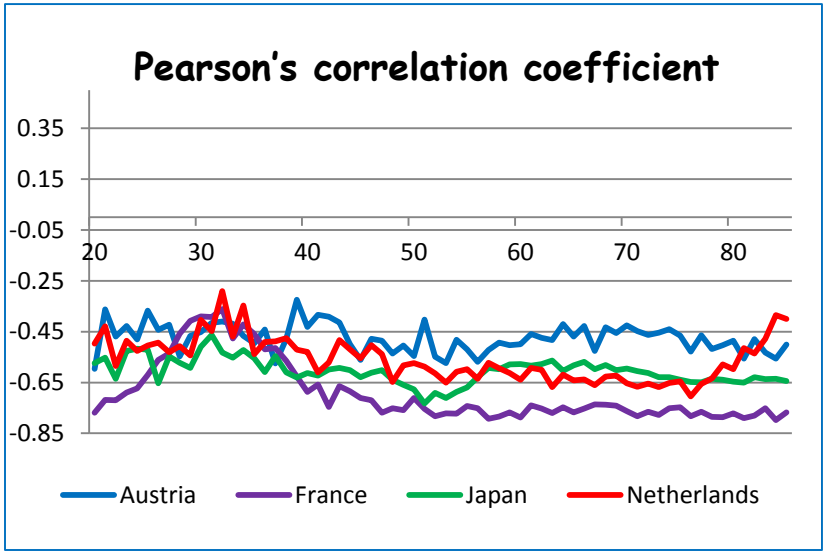



**Figure 7.** Pearson's correlation coefficient for males from Austria, France, Japan, Netherlands (data from 1974 to 2006).

# MODELLING MORTALITY

Time series modelling of mortality rates started at the beginning of 1990s :

- ✓ **Lee and Carter model** (1992) - The first stochastic model
- ✓ **Renshaw and Haberman** (2003) - Cohort effect additions
- ✓ **Plat** (2009) - Age-period and cohort additions combined
- ✓ **O'Hare and Li** (2012) – The nonlinear profile of mortality at lower ages
- ✓ **Seklecka et al.** (2015) – additional temperature-related factor

# MODELLING MORTALITY

**Lee and Carter model** (1992) - The first stochastic model

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

Where:

- $m_{xt}$ is the central mortality rate, calculated as the ratio between the number of people aged $x$ who died in the year $t$ , $D_{xt}$, and the exposure to risk, calculated as the average population aged $x$ in the year $t$, $E_{xt}$
- $b_x^1$ and $b_x^2$ are age effects
- $k_t^1$ is a random period effect
- $\varepsilon_{xt}$ is the error term at age $x$ and time

# MODELLING MORTALITY

**Renshaw and Haberman** (2003) - Cohort effect additions

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

where $\gamma_{t-x}^3$ models the cohort effect

**Plat** (2009) - Age-period and cohort additions combined

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

where, $\boldsymbol{k_t^3}$ - models period effect, $\boldsymbol{k_t^4}$ - models the effects specific to the lower age only, $(\bar{\boldsymbol{x}} - \boldsymbol{x})^+ = \max(\bar{x} - x, 0)$, and $\bar{x}$ is the average of the ages considered

**O'Hare and Li** (2012) – The nonlinear profile of mortality at lower ages

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

where, $\boldsymbol{k_t^4}$ is the adjusted coefficient designed to capture some of the non-linear effects observed at the lower ages, the "quadratic lower age effect"

# MODELLING MORTALITY

**Seklecka, Pantelous and O'Hare (**2015) model:

Additional temperature related factor to capture seasonal trend for elderly ages

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

where

- $\boldsymbol{c_x}$ - additional time independent factor for ages after $\boldsymbol{a}$ ($\boldsymbol{a}$ could differ between the countries, but in most cases $\boldsymbol{a} = \bar{x}$ ), appearing as a consequence of Pearson's correlation coefficient between temperatures and mortality rates
- $\boldsymbol{k_t^5}$ - this factor is the pattern of deviations from the age profile as the varies in response to the time changes of the temperature

# METHODOLOGY OF THE FITITNG

- Estimating parameters by maximizing the log-likelihood function, given by:

$$L(\varphi; D, E) = \sum_{xt} \{D_{xt} ln[E_{xt} m_{xt}(\varphi)] - E_{xt} m_{xt}(\varphi) - ln(D_{xt}!)\}$$

- R –code of the software package "Lifemetrics" (this package gives opportunity to make a good comparison between the proposed model and existing models)
- Fit suitable ARIMA-processes

# QUALITY OF THE FITTING

✓ Mean Absolute Percentage Error (MAPE) measure

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

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

✓ Bayesian Information Criterion (BIC) measure

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

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

# COMPARISON OF THE FITTING RESULTS

**TABLE 1**. The MAPE for the model fit for males, ages 20-85+.

| | Lee Carter | Plat | O'Hare and Li | Seklecka et al. |
|---|---|---|---|---|
| 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%** |
| Netherlands | 5.02% | 4.65% | 4.75% | **4.44%** |
| Norway | 7.38% | 6.98% | 7.22% | **6.80%** |
| Spain | 7.51% | 4.96% | 4.94% | **4.38%** |
| UK | 4.09% | 3.64% | 4.07% | **2.66%** |

Very good MAPE results
for all countries
and BIC for most of them


**TABLE 2**. The BIC for the model fit for males, ages 20-85+.

| | Lee Carter | Plat | O'Hare and Li | Seklecka et al. |
|---|---|---|---|---|
| Australia | -11591 | -11640 | -11877 | **-11148** |
| Austria | -10430 | **-10190** | -10228 | -10234 |
| France | -18582 | -13867 | -13904 | **-13471** |
| Italy | -19960 | -14554 | -15006 | **-14031** |
| Japan | -20128 | -15941 | -16336 | **-14301** |
| Netherlands | -10795 | **-10506** | -10543 | -10543 |
| Norway | **-8909** | -8980 | -9012 | -9012 |
| Spain | -19436 | -14174 | -14067 | **-14067** |
| UK | -16118 | -13552 | -14122 | **-12719** |

# LET'S CHECK EFFECTS ON PRICING

We consider an endowment assurance policy i.e. a life insurance contract designed to pay a lump sum (here equal to £1000) on death or after a specific term (on its "maturity"$= n$) if the policyholder is still alive and the actuarial present value is given by


$$A_{\overline{x:n}|} = \sum_{k=0}^{n-1} v^{n+1}\ {}_kp_x q_{x+k} + v^n\ {}_np_x.$$

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

$$ {}_kp_x = 1 - \frac{m_x}{1 + (1 - a_x)m_x}$$

where $a_x$ is the average number of years lived within the age interval $[x, x + 1)$ for people dying at that age

# EFFECT ON THE PRICING OF THE ENDOWMENT

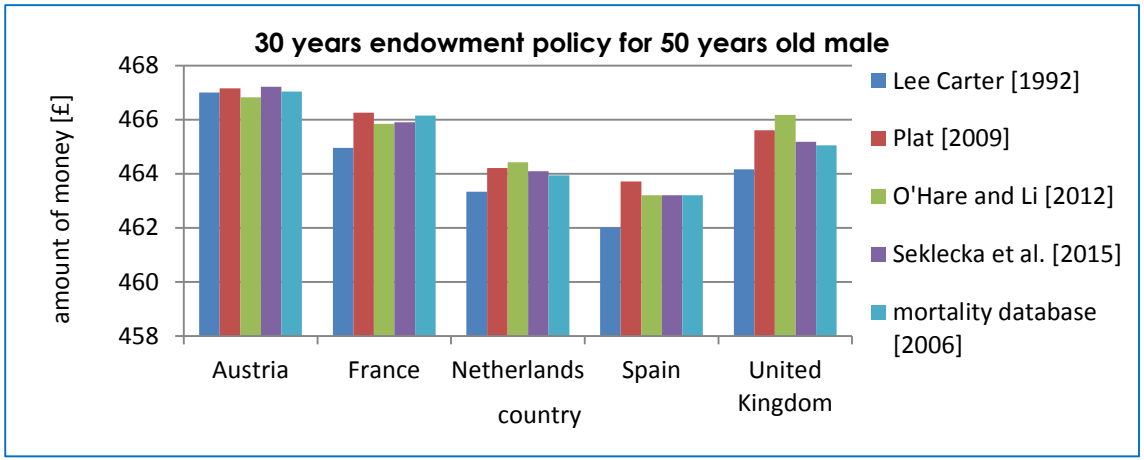



**Figure 8.** Comparison of 30-year endowment policy for various models for 50 years old male from Austria, France, Netherlands, Spain and the United Kingdom.

Present value of the endowment assurance policy calculated according to the mortality rates from proposed model is closer to the real one for most countries

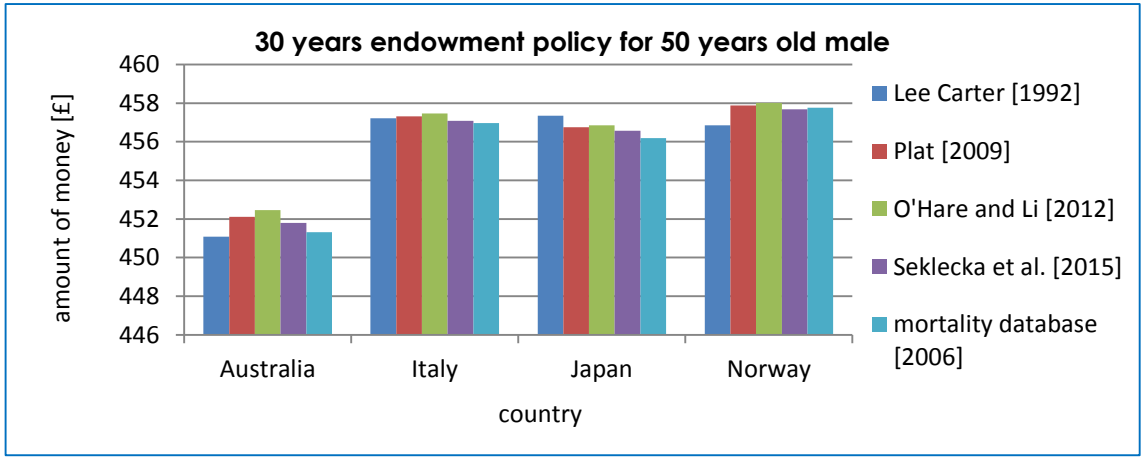



**Figure 9.** Comparison of 30-year endowment policy for various models for 50 years old male from Australia, Italy, Japan and Norway.

# FORECASTING

At the end Seklecka et al. (2015) model was used to forecast mortality rates.

Stochastic parameters were forecasted by using the **forecast.Arima** function from R package.

# QUALITY OF FORECASTING RESULTS

**TABLE 3**. The MAPE for forecasting results for males, ages 20-85+.

| | Lee Carter | Plat | O'Hare and Li | Seklecka et al. |
|---|---|---|---|---|
| Australia | 13.35% | 13.14% | 11.47% | **6.73%** |
| Austria | 8.60% | 10.01% | 9.74% | **8.56%** |
| France | 11.56% | **4.20%** | 5.80% | 6.53% |
| Italy | 15.10% | **5.21%** | 5.42% | 5.51% |
| Japan | 6.01% | **4.35%** | 4.70% | **4.35%** |
| Netherlands | 11.20% | 6.96% | 7.30% | **6.75%** |
| Norway | 13.04% | 10.71% | 12.09% | **10.60%** |
| Spain | 30.79% | **7.56%** | 8.11% | 9.10% |
| United Kingdom | 10.47% | 13.20% | 12.26% | **4.85%** |

To make this comparison we forecasted stochastic parameters for other models using the same methodology like for the Seklecka et al. model

# FORECASTING RESULTS

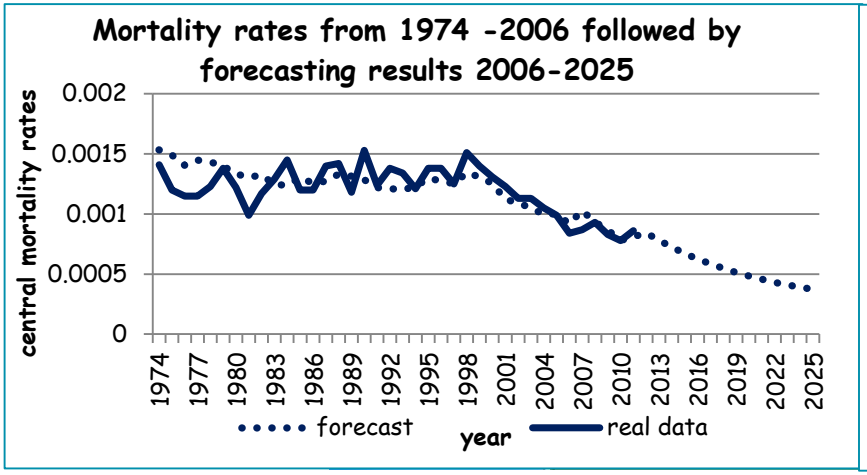



**Figure 10.** Mortality rates for 30 years old male from **Australia** from 1974–2006 followed by forecasting results 2007–2025.

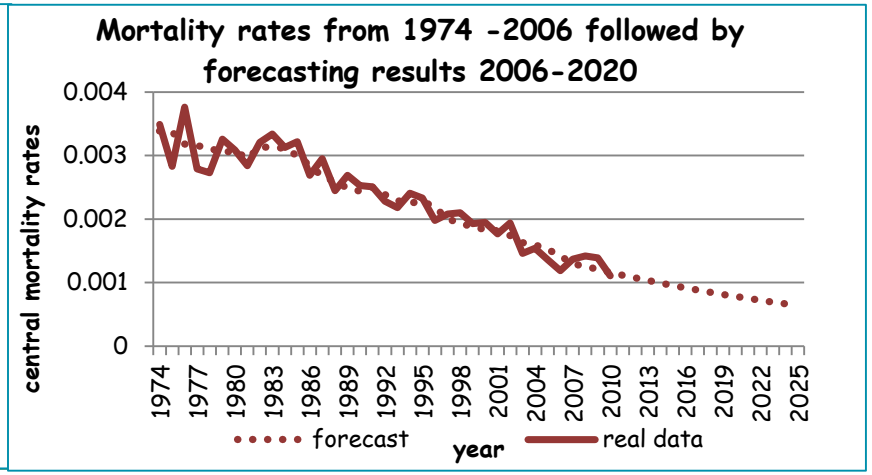



**Figure 11.** Mortality rates for 40 years old male from **Austria** from 1974–2006 followed by forecasting results 2007–2025.

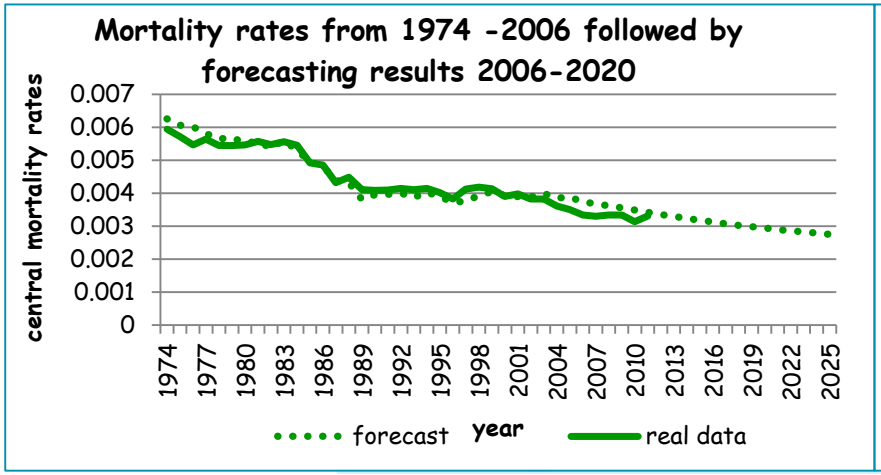



**Figure 12.** Mortality rates for 50 years old male from **Japan** from 1974–2006 followed by forecasting results 2007–2025.

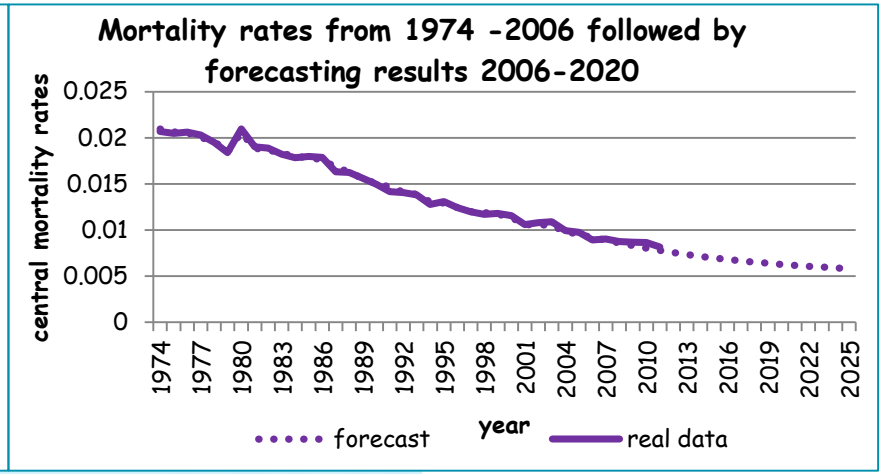



**Figure 13.** Mortality rates for 60 years old male from **the United Kingdom** from 1974–2006 followed by forecasting results 2007–2025.

# FORECASTING RESULTS… more countries

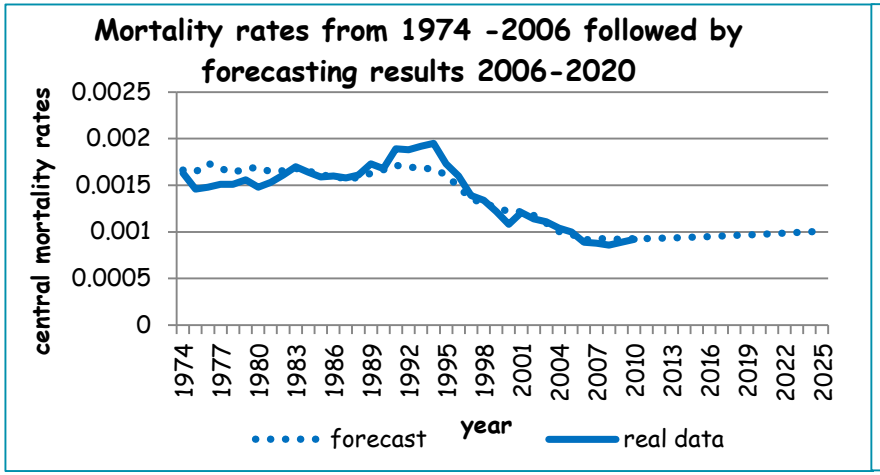



**Figure 14.** Mortality rates for 30 years old male from **France** from 1974–2006 followed by forecasting results 2007–2025.

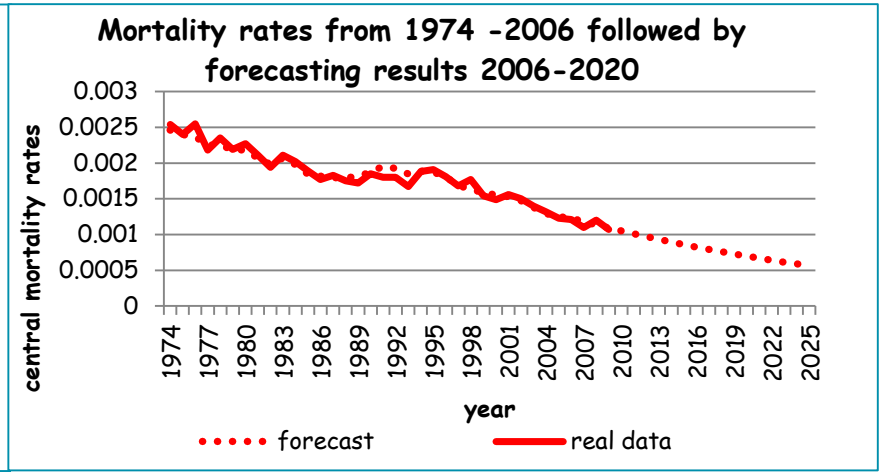



**Figure 15.** Mortality rates for 40 years old male from **Italy** from 1974–2006 followed by forecasting results 2007–2025.

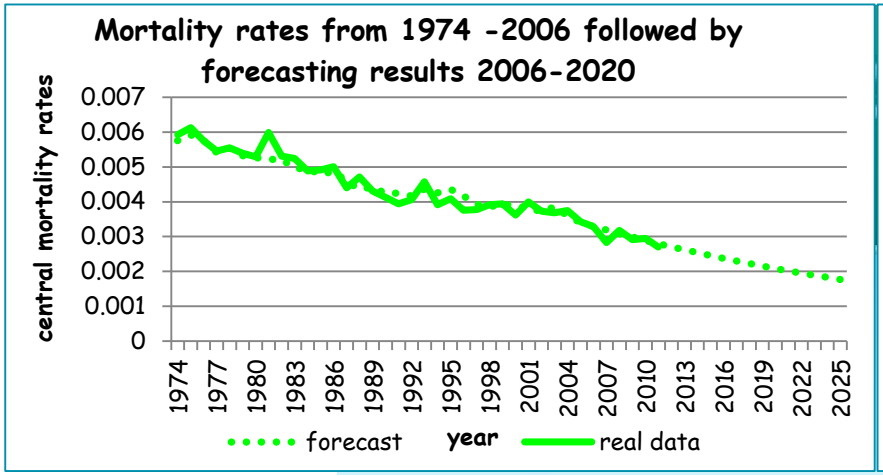



**Figure 16.** Mortality rates for 50 years old male from **Netherlands** from 1974–2006 followed by forecasting results 2007–2025.

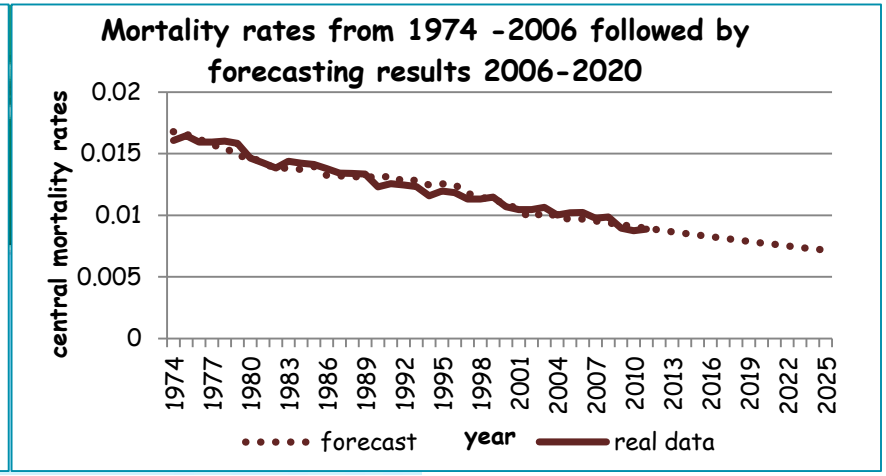



**Figure 17.** Mortality rates for 60 years old male from **Spain** from 1974–2006 followed by forecasting results 2007–2025.

# CONCLUSIONS

- We can observe the correlation between annual average temperature annomaly and mortality rates
- For all countires correlation is much stronger for eldery ages
- New mortality model with additonal temperature related factors gives a better performance to the real data (improved MAPE and BIC) and good forecasting for most of the countries
- In terms of pricing the endowment policy values, the proposed model is more accurate in comparison to the observed real data

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# THANK YOU
for your
# ATTENTION!

# ANY QUESTIONS?