Multi-population mortality modeling with economic trends: A hybrid neural network approach

Qiqi Wang[1,2], Katja Hanewald[2,3], and Xiaojun Wang[1]

[1] *Renmin University of China, School of Statistics*

[2] *Australian Research Council Centre of Excellence in Population Ageing Research (CEPAR)*

[3] *UNSW Sydney, School of Risk & Actuarial Studies*

Introduction

Background:

- Human longevity continues to increase
- Mortality improvements in different populations are correlated
- Life insurers: 1. mortality risk hedge 2. more accurate mortality prediction for small populations
- Predict the mortality for multiple populations and find the potential relationships

We propose a **new hybrid neural network approach** for estimating and predicting the **mortality rates of multiple populations**

- Includes **economic conditions** into mortality prediction (e.g., Hanewald, 2011)
- Combines **convolutional neural network (CNN) layers** and a **long short-term memory (LSTM) structure**

Multi-Population Mortality Modeling

Li and Lee model (Li and Lee, 2005)

$$\log(m(x, t, i)) = a(x, i) + B(x)K(t) + b(x, i)k(t, i) + \varepsilon(x, t, i), \qquad 0 \le t \le T.$$

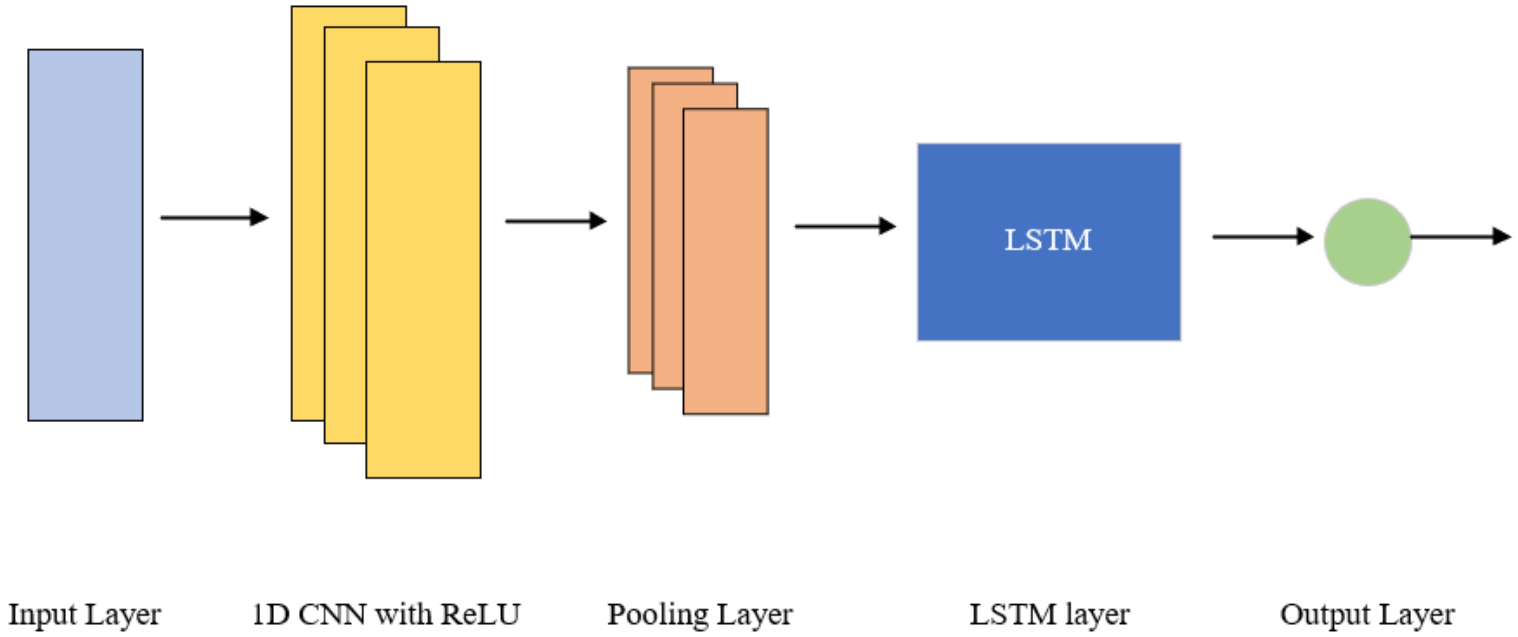
GDP-LL model (Boonen and Li, 2015)

$$\log m_{i,x,t} = a_{i,x} + \sum_{j=1}^{J} B_{j,x} K_{j,t} + \sum_{\ell=1}^{L} \gamma_{\ell,x} g_{\ell,t} + b_{i,x} k_{i,t} + \varepsilon_{i,x,t}$$

Our proposed model:

1. Uses a hybrid neural network structure – CNN + LSTM
2. Finds linear and non-linear relationships between mortality and GDP
3. Predicts gross domestic product (GDP) per capita and mortality rates simultaneously for multiple populations

Our proposed model



Convolutional layer
produces new feature values by convolution operation between the raw input data

Pooling layer
produces a lower dimension matrix

LSTM
learns long-term dependencies

Correlations

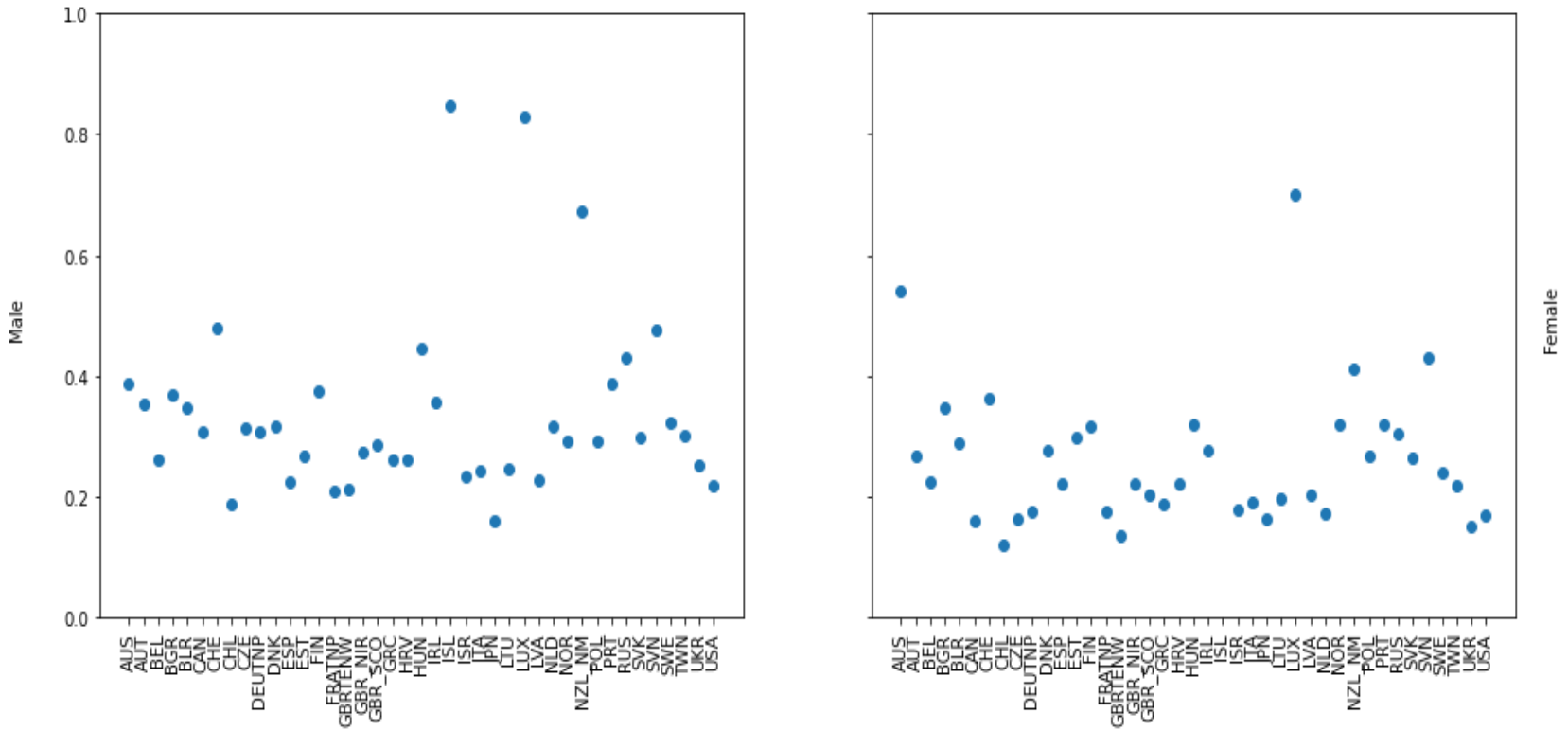
Data: Human Mortality Database (HMD) for the years 1971 to 2018
Real GDP per capita data are obtained from the World Bank

	GPD growth: average over years				Life Expectancy			Correlation between mortality and GPD per capita			
Country	1971-1980	1981-1990	1991-2000	1971-2000	1971	2000	Δ2000-1971	Age 30 Male	Age 30 Female	Age 60 Male	Age 60 Female
LVA			5.24	5.24	70.16	70.31	0.15	-0.73	-0.51	-0.79	-0.66
IRL	4.75	3.65	7.03	5.15	71.13	76.54	5.41	-0.47	-0.67	-0.95	-0.94
ISR	5.32	3.79	6.12	5.07	71.72	78.95	7.23	-0.20	-0.07	-0.70	-0.71
EST			4.99	4.99	69.91	70.42	0.51	-0.61	-0.41	-0.86	-0.76
...											
SVN			1.85	1.85	68.83	75.41	6.58	-0.68	-0.50	-0.92	-0.81
CHE	1.30	2.23	1.22	1.58	73.13	79.68	6.55	-0.77	-0.78	-0.95	0.90
BGR		2.55	-2.08	0.24	70.87	71.66	0.79	-0.65	-0.50	-0.36	-0.82
BLR			-0.87	-0.87	70.09	68.91	-1.18	-0.59	-0.45	-0.26	-0.68
RUS		-3.00	-3.62	-3.56	68.38	65.48	-2.89	0.02	0.30	-0.44	-0.64

Note: Countries are ordered by GDP growth average between 1971 and 2000

MSE for Mortality rates predictions

Data: Human Mortality Database (HMD) for the years 1971 to 2018
Real GDP per capita data are obtained from the World Bank

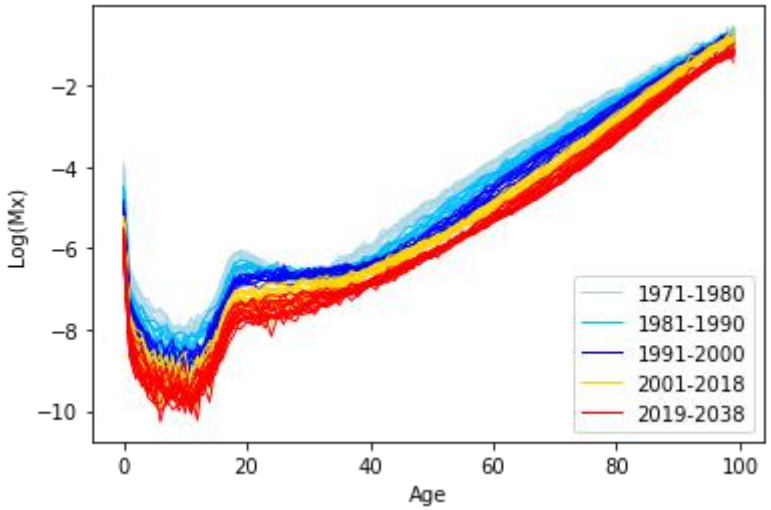


MSE for Countries

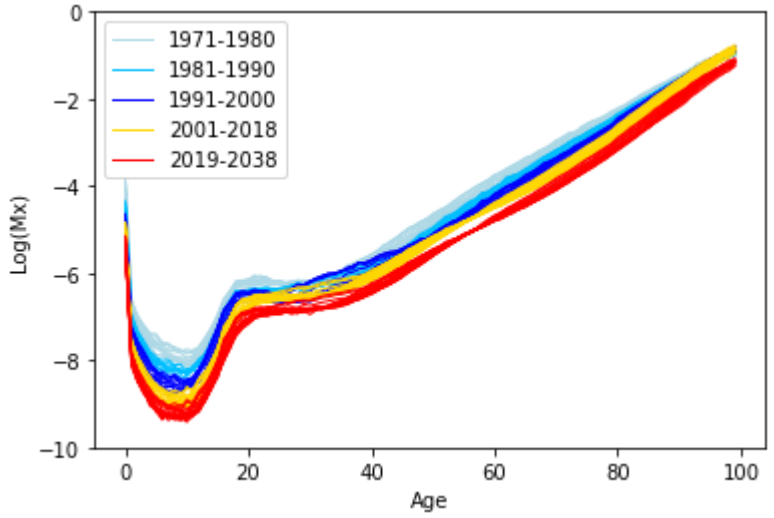
Mortality rates estimation and prediction

Data: Human Mortality Database (HMD) for the years 1971 to 2018
Real GDP per capita data are obtained from the World Bank

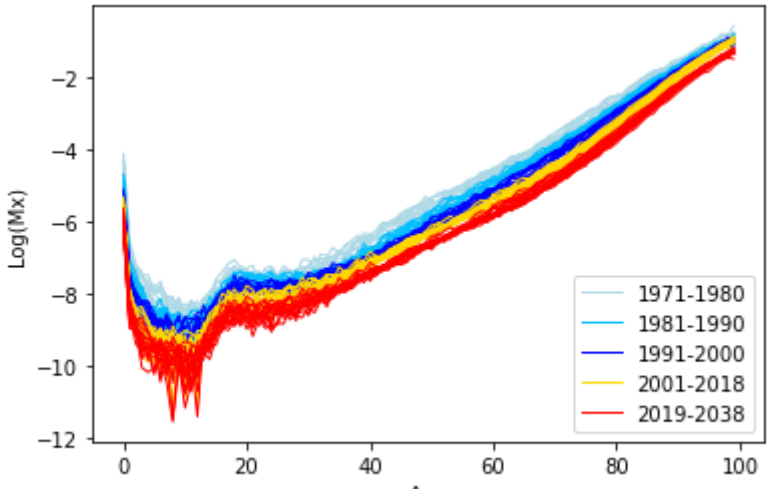
AUS Male



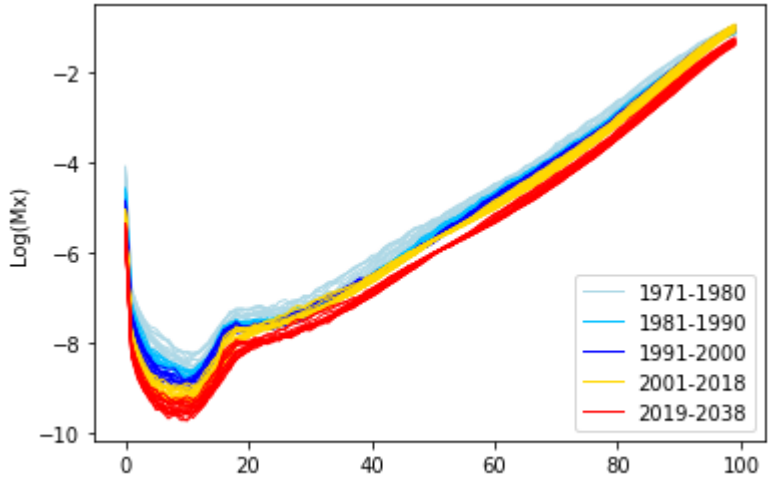
USA Male



AUS Female



USA Female



Conclusion

We propose **a hybrid neural network model for multi-population mortality prediction**

- Uses a hybrid neural network structure – CNN + LSTM
- Make better prediction of mortality by finding linear and non-linear relationships between mortality and GDP
- Predicts gross domestic product (GDP) per capita and mortality rates simultaneously for multiple populations

References

Boonen, T. J., & Li, H. (2017). Modeling and forecasting mortality with economic growth: A multipopulation approach. *Demography*, 54(5), 1921-1946.

Li, N., & Lee, R. (2005). Coherent mortality forecasts for a group of populations: An extension of the Lee-Carter method. *Demography*, 42(3), 575-594.

Hanewald, K. (2011). Explaining mortality dynamics: The role of macroeconomic fluctuations and cause of death trends. *North American Actuarial Journal*, 15(2), 290-314.

Thank you!

Contact:

Qiqi Wang: wangqiqi_ruc@outlook.com

Katja Hanewald: k.hanewald@unsw.edu.au