Mortality forecasting via multi-task neural networks

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Luca De Mori, Steven Haberman, Pietro Millossovich, Rui Zhu

Bayes Business School
City, University of London

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Current Section

Introduction

Research's aim: forecasting simultaneously the mortality rates of populations that are to some degree related in order to provide coherent forecasts.

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Approach previously studied:

- Feed-forward single-task neural networks proposed by Richman and Wüthrich (2021).
- They generally perform well but have poor forecasting performances for populations that show different mortality trends with respect to the rest of the populations in the pool.

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We want to implement an alternative deep-learning approach that avoids or mitigates the problem previously mentioned:

- Multi-task neural networks allow leveraging helpful information contained in multiple related tasks to help improve the generalization performance of all the tasks.

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- Multi-task neural networks allow leveraging helpful information contained in multiple related tasks to help improve the generalization performance of all the tasks.
- The structure of these multi-task neural networks also reflects past mortality trends through the grouping of the populations considered into clusters.

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Current Section

Methodology - multi task NN

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- 10 country-specific hidden layers with 32 neurons and Tanh activation function.

Methodology - multi task NN

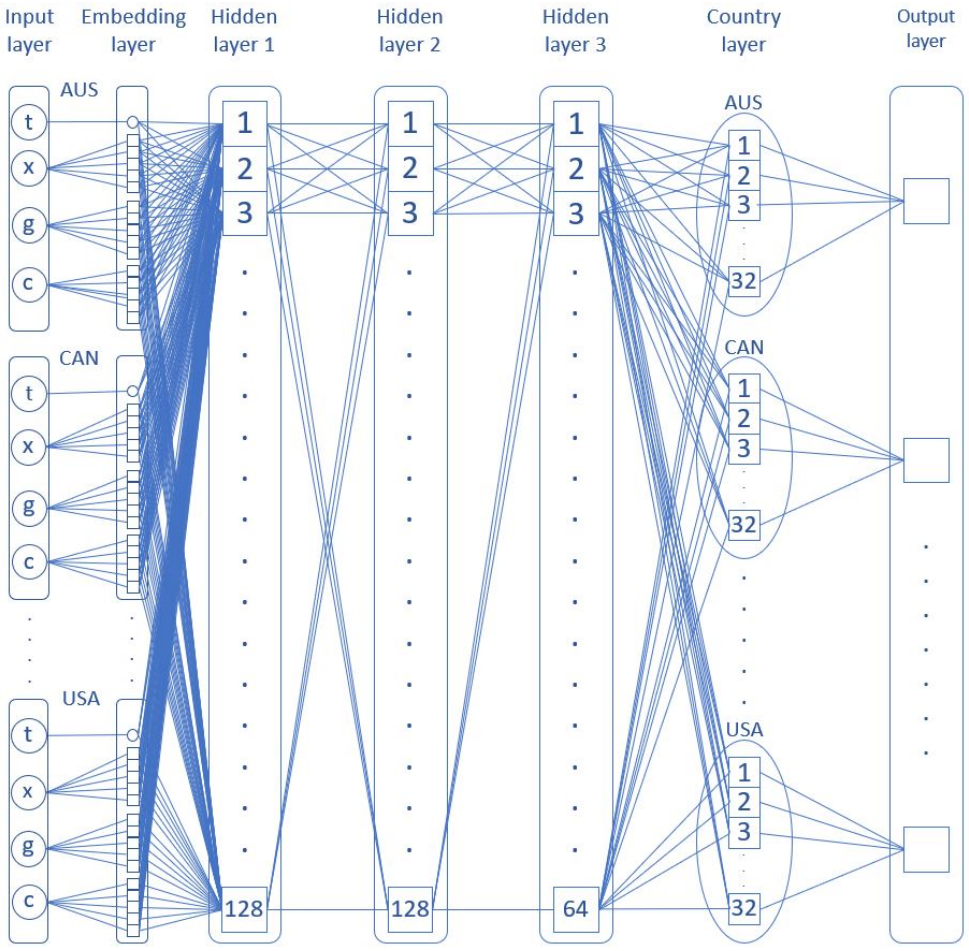

Figure 1: MT1 structure.

Methodology - single task NN

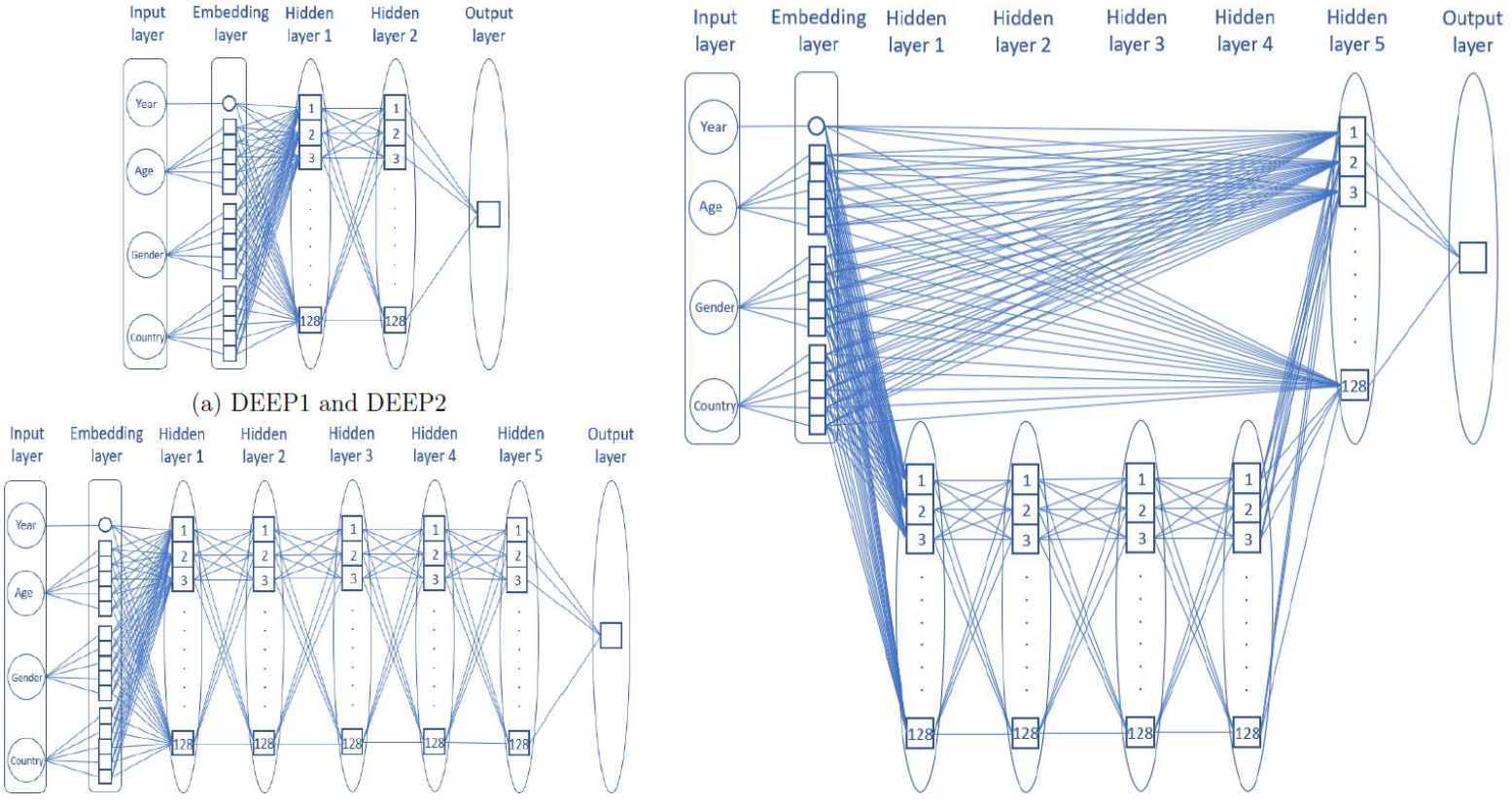

Figure 2: Example of single-task neural networks proposed by Richman and Wüthrich (2021).

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- Clustering by country in the third shared hidden layer.
- Clustering of the 10 countries using k-means technique based on M and F life expectancy (standard deviation) changes in the training period.
- The 10 country-specific hidden layers are the same as MT1 and the activation function is Tanh for all the layers.

Methodology - multi task NN

MT1		MT2		MT3	
Country	**Cluster**	**Country**	**Cluster**	**Country**	**Cluster**
Australia	1	Australia	1	England & Wales	1
Canada		Canada		France	
England & Wales		England & Wales		Italy	
France		France		Spain	
Italy		Italy		Sweden	
Japan		Netherlands		Japan	2
Netherlands		Spain		Australia	3
Spain		Sweden		Canada	
Sweden		USA		Netherlands	
USA		Japan	2	USA	

MT4		MT5	
Country	**Cluster**	**Country**	**Cluster**
France	1	France	1
England & Wales		England & Wales	
Italy		Italy	
Netherlands		Netherlands	
Australia	2	Canada	2
Canada		Japan	
Japan		Sweden	
Spain		USA	
Sweden		Australia	3
USA		Spain	

Figure 3: Clustering results.

Methodology - multi task NN

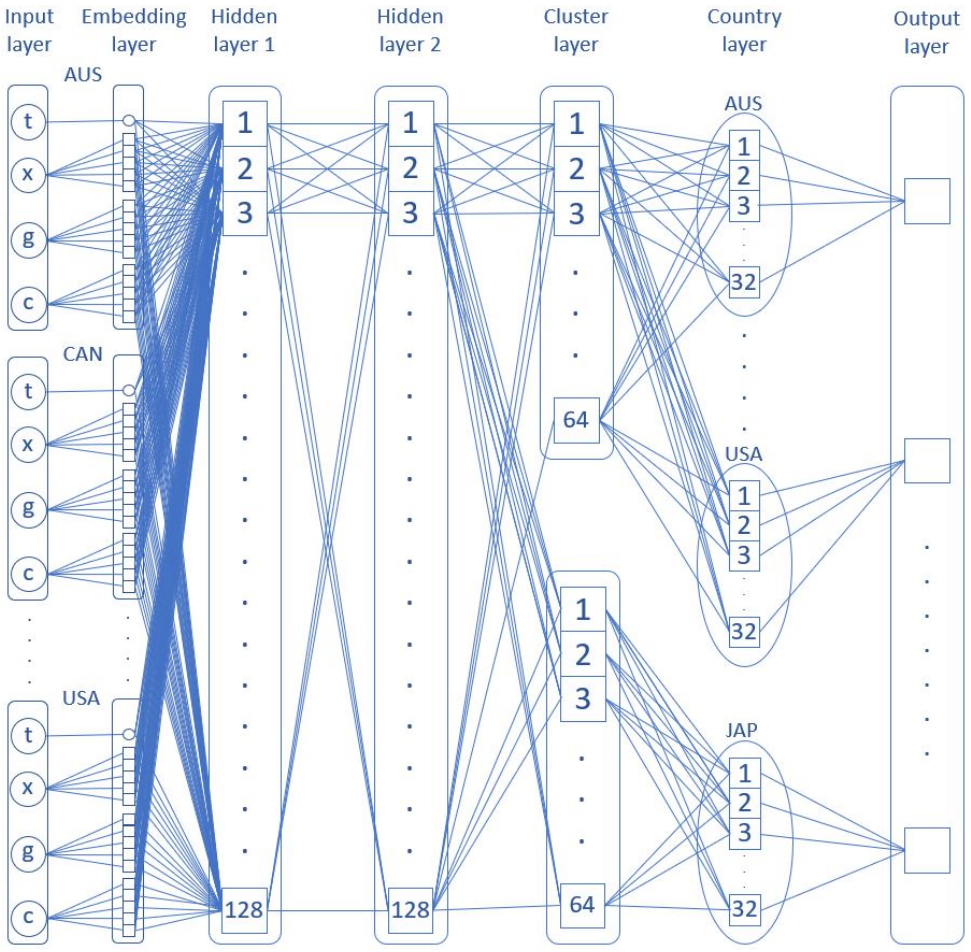

Figure 4: MT2 structure.

Methodology - multi task NN

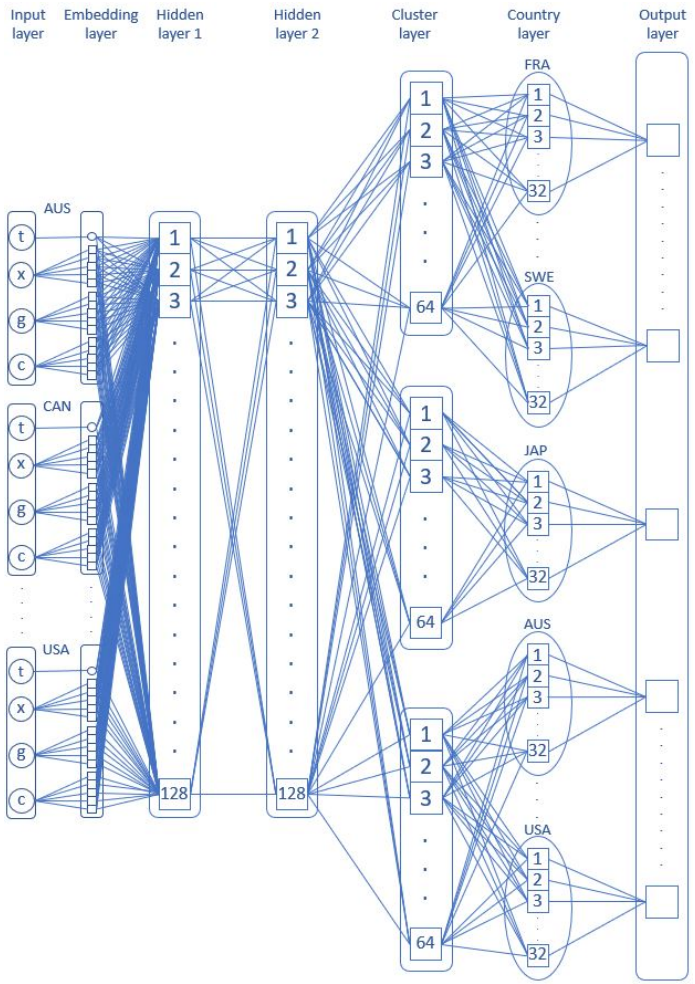

Figure 5: MT3 structure.

Current Section

Results

Dataset considered:

- 10 countries: Australia, Canada, England&Wales, France, Italy, Japan, Netherlands, Spain, Sweden, USA.

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- Training (test) periods: from 1950-1979 (1980-1994) to 1975-2004 (2005-2019).

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- 10 countries: Australia, Canada, England&Wales, France, Italy, Japan, Netherlands, Spain, Sweden, USA.
- Male and female populations.
- Age interval: 55-89.
- Training (test) periods: from 1950-1979 (1980-1994) to 1975-2004 (2005-2019).

Training hyperparameters:

- Loss function = MSE, #epochs = 200, Optimizer = Adam.

Results

Metrics considered:

- Truncated life expectancy

$$\mathring{e}_{55:\overline{35}|,t} = \sum_{j=1}^{35} {}_{j-1}p_{55,t}\left(1 - \frac{1}{2}q_{55+j-1,t}\right)$$

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- Truncated standard deviation

$$sd_{55:\overline{35}|,t} = \sqrt{\sum_{x=0}^{34} {}_{x|1}q_{55,t}\ (x - \mathring{e}_{55:\overline{35}|,t})^2 + {}_{35}p_{55,t}(35 - \mathring{e}_{55:\overline{35}|,t})^2}$$

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Benchmarks:

- Feed-forward single-task neural networks proposed by Richman and Wüthrich (2021).

Results

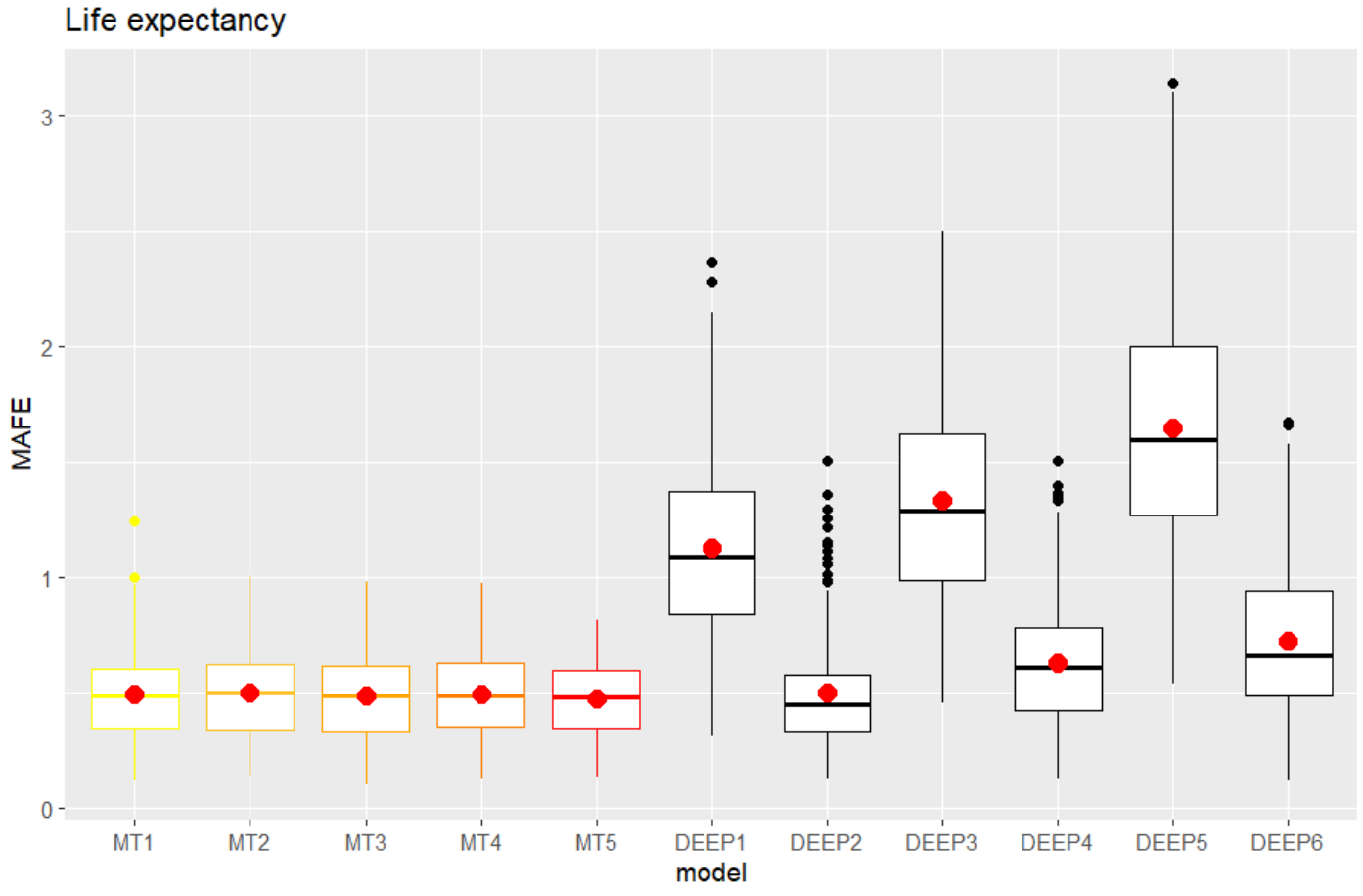

Figure 6: Summary of the life expectancy MAFEs by neural network.

Results

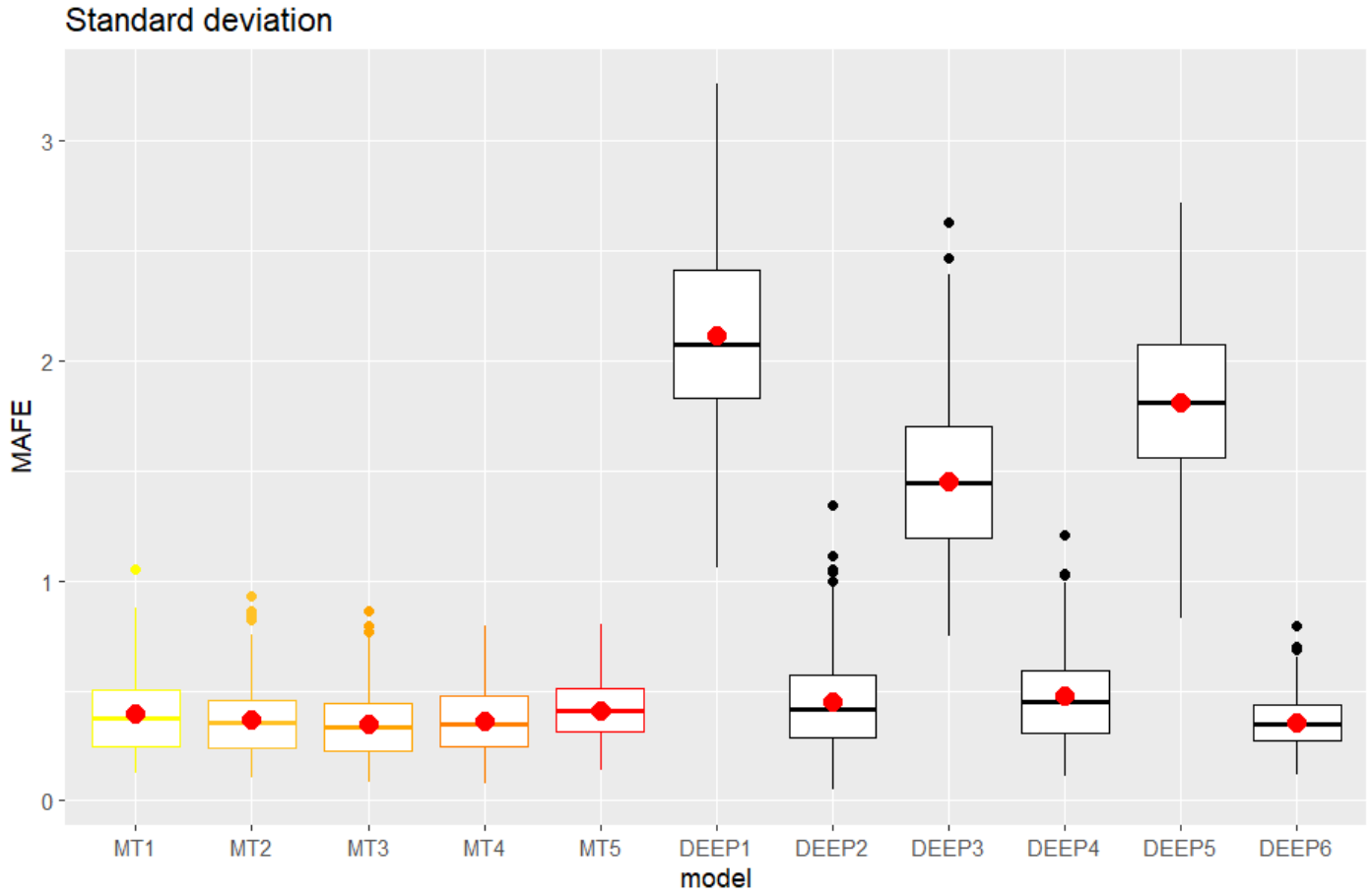

Figure 7: Summary of the standard deviation MAFEs by neural network.

Results

	MT1	MT2	MT3	MT4	MT5	DEEP1	DEEP2	DEEP3	DEEP4	DEEP5	DEEP6
AUS	5	6	5	6	3	5	1	9	7	11	9
CAN	4	4	5	5	4	9	1	10	7	11	7
ENG&WL	5	4	4	5	3	8	1	9	6	11	9
FRA	3	4	4	4	4	9	7	10	6	10	9
ITA	4	6	4	6	3	9	1	10	6	11	7
JPN	4	4	3	3	3	9	6	10	7	11	8
NLD	4	4	5	4	6	9	4	10	5	11	2
ESP	4	5	3	3	3	9	6	10	6	11	8
SWE	3	3	5	4	5	9	4	10	8	11	6
USA	3	4	4	4	5	9	8	10	7	11	3

Figure 8: Median ranking by country (life expectancy).

Results

	MT1	MT2	MT3	MT4	MT5	DEEP1	DEEP2	DEEP3	DEEP4	DEEP5	DEEP6
AUS	3	3	3	4	5	11	3	9	7	10	8
CAN	4	3	2	5	4	11	5	9	7	10	6
ENG&WL	3	3	2	4	4	11	6	9	7	10	6
FRA	5	4	4	4	6	11	6	9	5	10	1
ITA	5	4	3	5	5	11	5	9	5	10	5
JPN	5	6	5	5	6	11	5	9	3	10	1
NLD	5	4	3	4	5	11	4	9	7	10	3
ESP	5	4	4	5	6	11	5	9	3	10	2
SWE	5	4	3	5	5	11	5	9	7	10	3
USA	4	3	3	4	5	11	8	9	7	10	4

Figure 9: Median ranking by country (standard deviation).

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Conclusions

Main findings:

- Overall, the proposed multi-task neural networks outperform the benchmark NNs in terms of average MAFE for both life expectancy and standard deviation.

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- Multi-task neural networks also perform notably better in countries with unusual mortality trends such as Japan and the US.

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Next steps:

- Analyse how a wider range of countries impacts the forecasting performances.

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- Analyse how a wider range of countries impacts the forecasting performances.
- Use a different input (e.g. gender) as multi-task variable.
- Cluster with a different machine learning technique rather than k-means.

Current Section

References

[1] Michael Crawshaw.
Multi-task learning with deep neural networks: A survey.
arXiv preprint arXiv:2009.09796, 2020.

[2] Abhijit Ghatak.
Deep learning with R.
Springer, 2019.

[3] Ronald Richman and Mario V Wüthrich.
A neural network extension of the lee–carter model to multiple populations.
Annals of Actuarial Science, 15(2):346–366, 2021.

[4] Yu Zhang and Qiang Yang.
A survey on multi-task learning.
IEEE Transactions on Knowledge and Data Engineering, 2021.

Thank you for your attention.