SAS (2) - Climate Finance

Mortality Modelling using Temperature Metrics

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DRP Context

Climate Metrics

- Initially for portfolio management
- Pivoted to mortality modelling
- Focus now on Lee-Carter model with temperature data

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Climate Metrics

Captures the status of the climate or the impact on the climate. i.e.

Carbon Footprint	ESG Score
Temperature	Natural Disaster Index

Motivation?

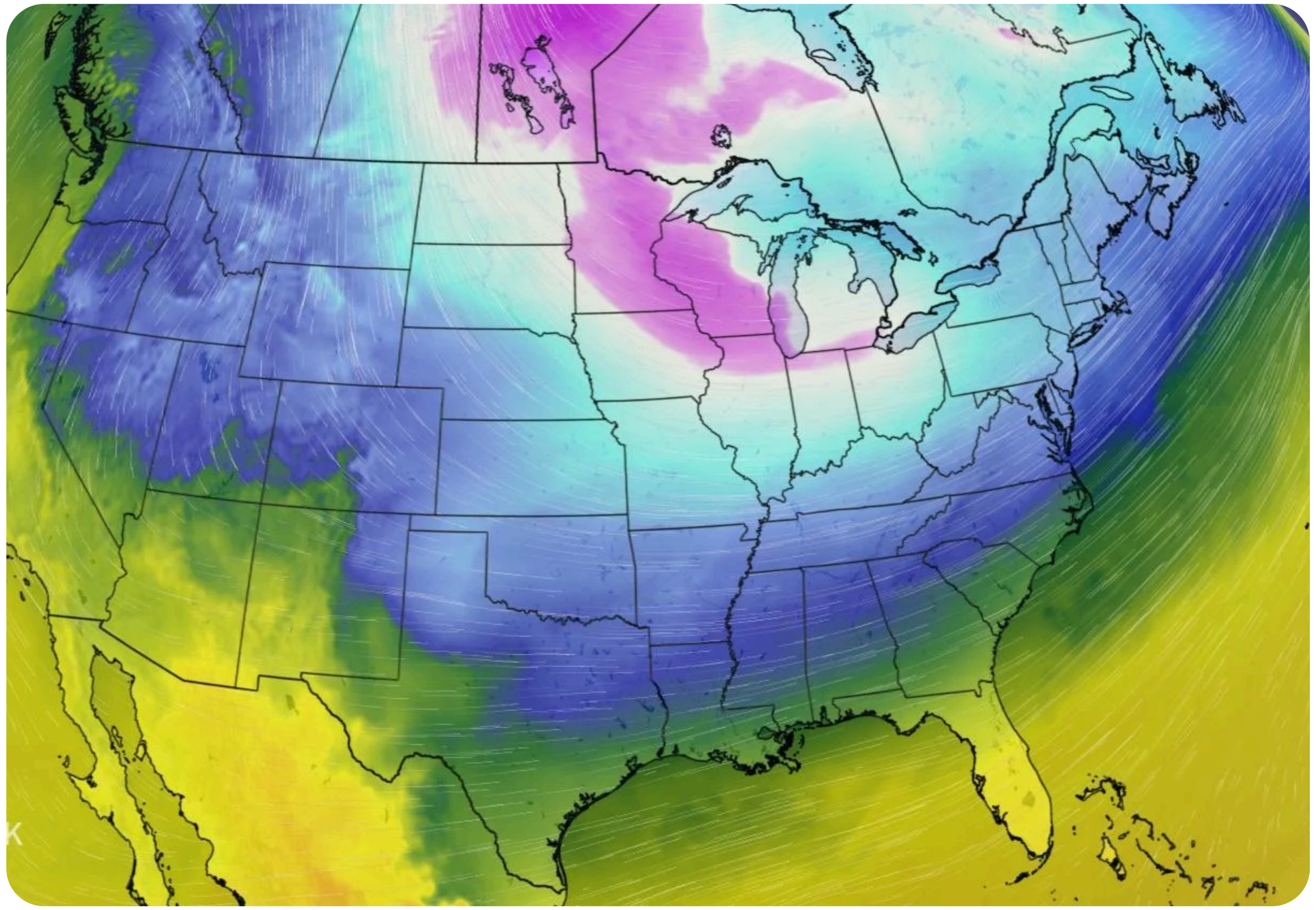
Pricing Liabilities

(Life, P&C, Mortgages, etc)

Core Questions

- **Does temperature affect mortality in Ontario?**
- **How can we model it?**
- **Is it better than traditional methods?**

Aim of our project



- **Evaluate** the performance of the classic Lee-Carter mortality model using Ontario data (1991–2023) for males and females.
- **Extend** the model by incorporating mean annual temperature derived from daily climate records.
- **Compare** baseline and climate-adjusted models using forecast accuracy metrics (RMSE, MAPE).
- **Analyze** whether temperature trends explain additional variation in mortality rates.
- **Validate** model assumptions through residual analysis.

Data Sources

Deaths

Yearly Deaths from 1991-2023 for age bins from 20-89

Types:

- Male
- Female

Exposure

Yearly Exposure from 1991-2023 for age bins from 20-89

Types:

- Male
- Female

Temperature

Mean Annual Temperature for Toronto from 1991-2023

	1991	1992	1993	1994
22	1061978	1051986	1041399	1030001
27	1272329	1230926	1182339	1136797
32	1301807	1310907	1322893	1331842
37	1174389	1204928	1239438	1264078
42	1069653	1074605	1089326	1116243
47	844293	900503	946112	987468
52	675039	698991	730094	760293
57	616719	613492	616800	628825
62	579778	587841	592319	594584
67	498506	502964	510437	515979
72	364432	381693	396877	412194
77	255667	259131	260594	261541
82	142053	147879	153830	160060
87	62040	63705	65832	68117

Year	Average Temperature
1991	8.940109589
1992	7.036448087
1993	7.261534247
1994	7.405068493
1995	7.878383562
1996	7.180081967
1997	7.586821918
1998	10.18816438
1999	9.493369863

What is Lee-Carter Model

- A statistical model used in demography and actuarial science to project mortality rates over time.
- Separates mortality patterns into **age effects** and **time effects**.

$$\ln m_{x,t} = a_x + b_x k_t$$

- $m_{x,t}$: Mortality rate at age x, year t
- a_x: Average mortality pattern by age
- b_x: Sensitivity of each age group to overall mortality changes
- k_t: Overall mortality trend index (captures changes over time)

- Widely adopted by actuaries and statisticians for forecasting because it's simple, interpretable, and performs well with long-term historical data.
- Forms the basis for many national life tables and insurance pricing models.

Model Framework

We extend the Lee–Carter mortality model from:

$$\ln m_{x,t} = a_x + b_x k_t$$

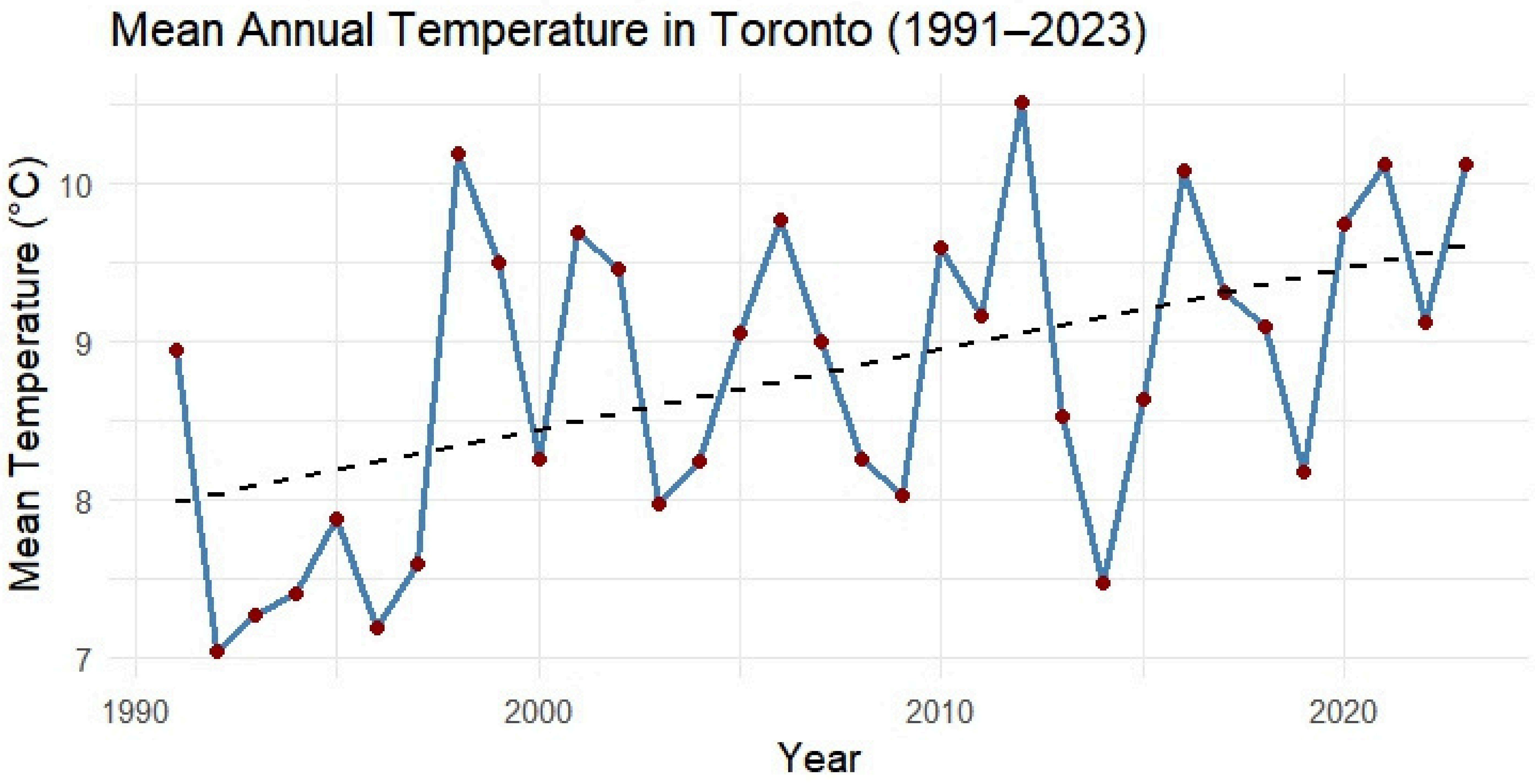
To:

$$\ln m_{x,t} = a_x + b_x k_t + c_x T_t$$

Where:

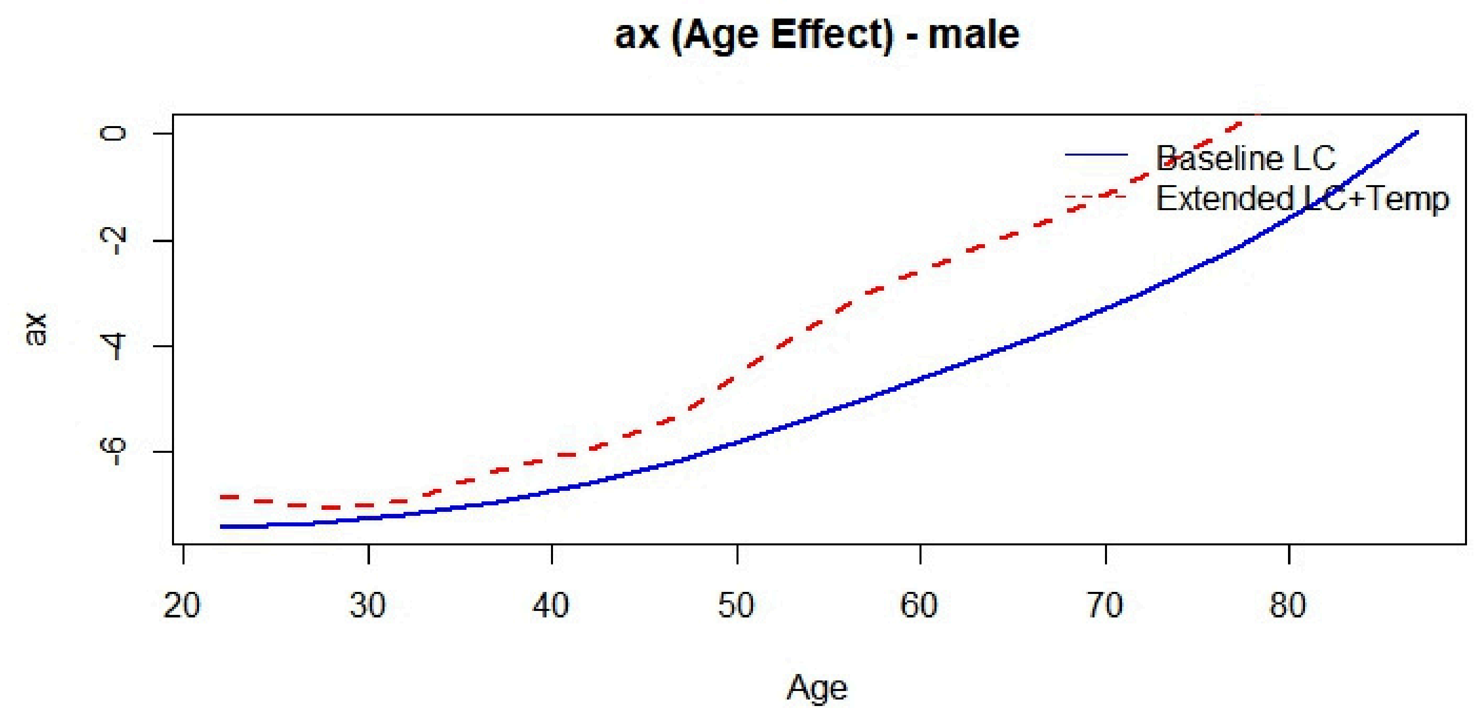
- $m_{x,t}$: mortality rate at age x in year t
- a_x: age-specific average log mortality
- b_x: sensitivity of mortality to the time-varying index k_t
- k_t: time-varying mortality index
- c_x: sensitivity of mortality to **mean annual temperature** T_t

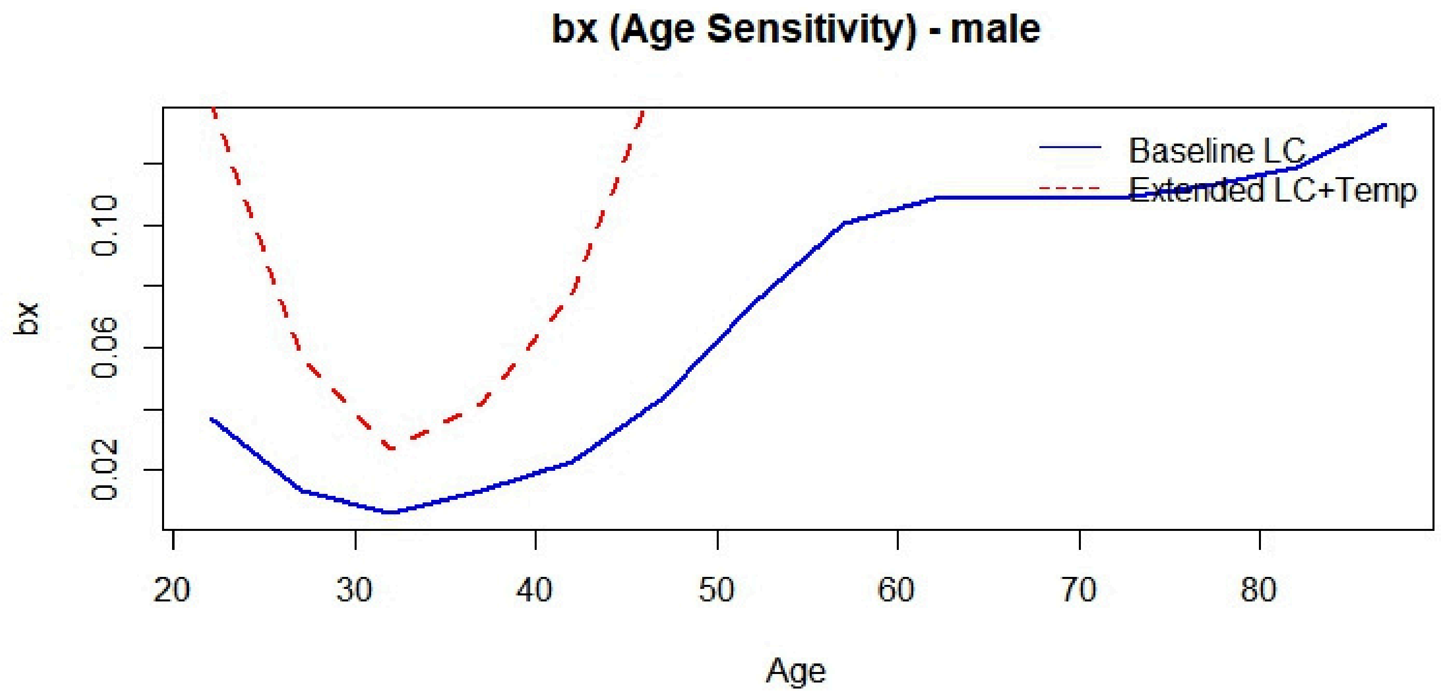
Mean Annual Temperature Trend

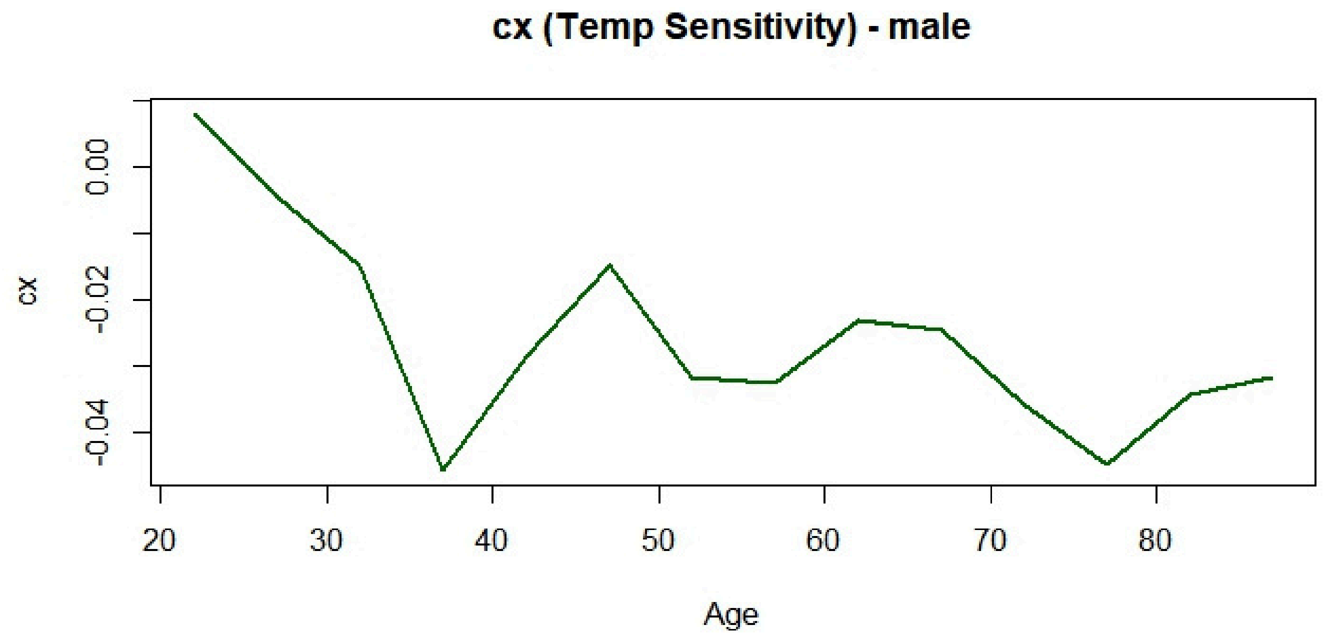


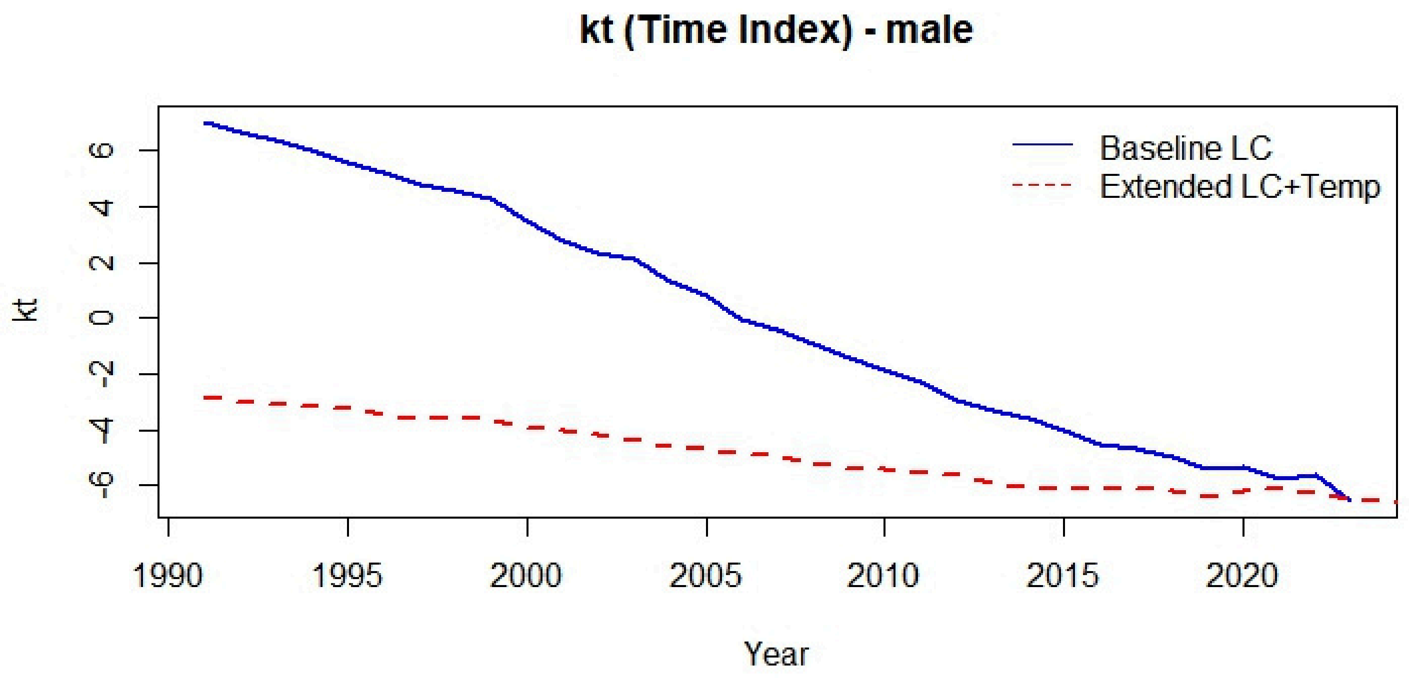
ONTARIO MORTALITY RESULTS

Baseline vs Climate Model

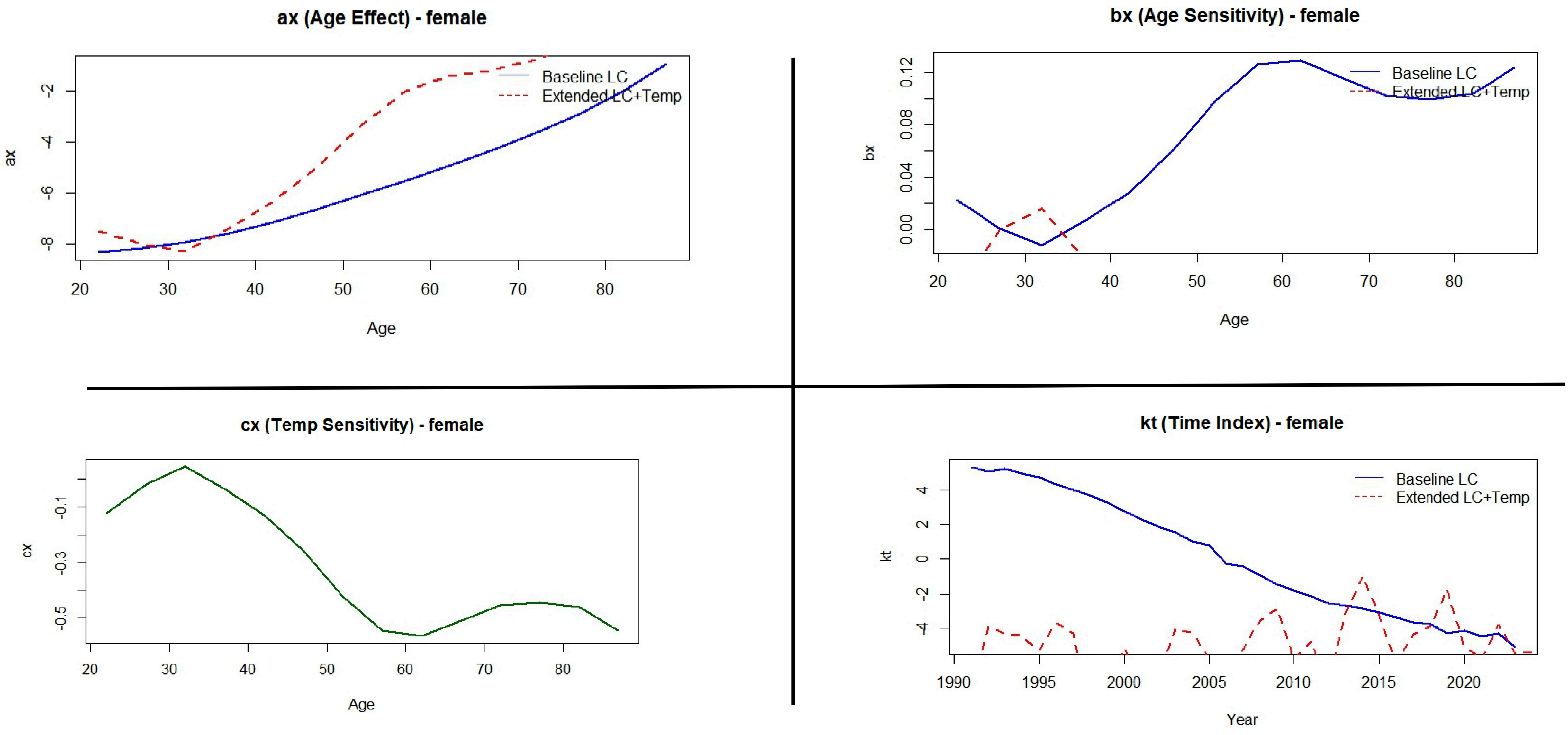








Baseline vs Climate Model



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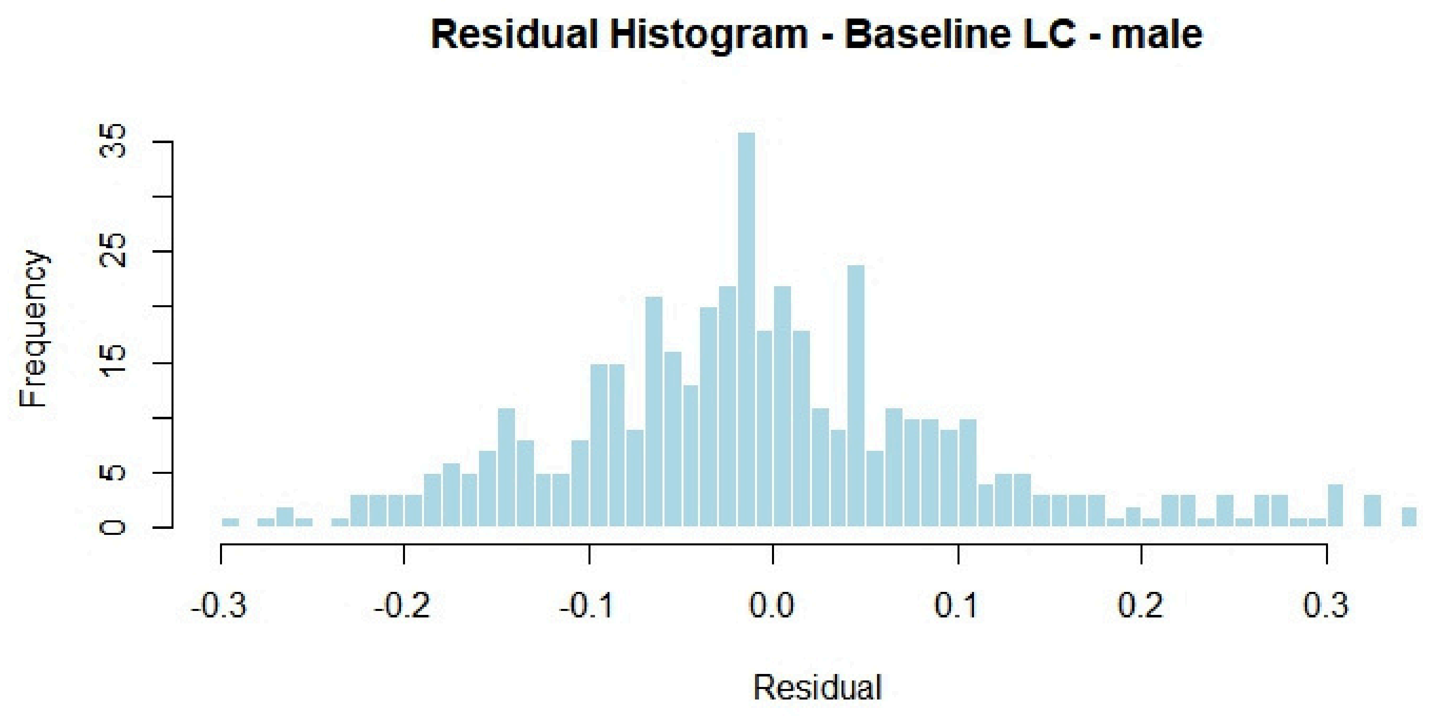
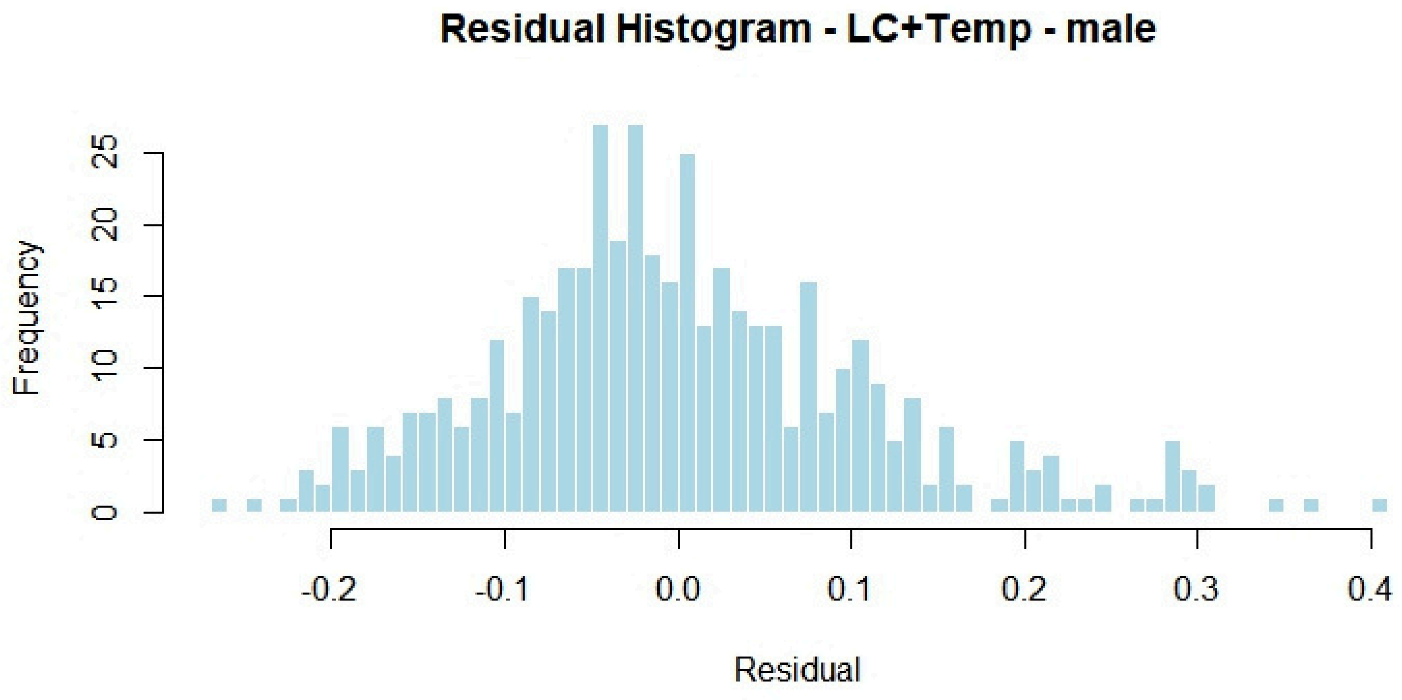
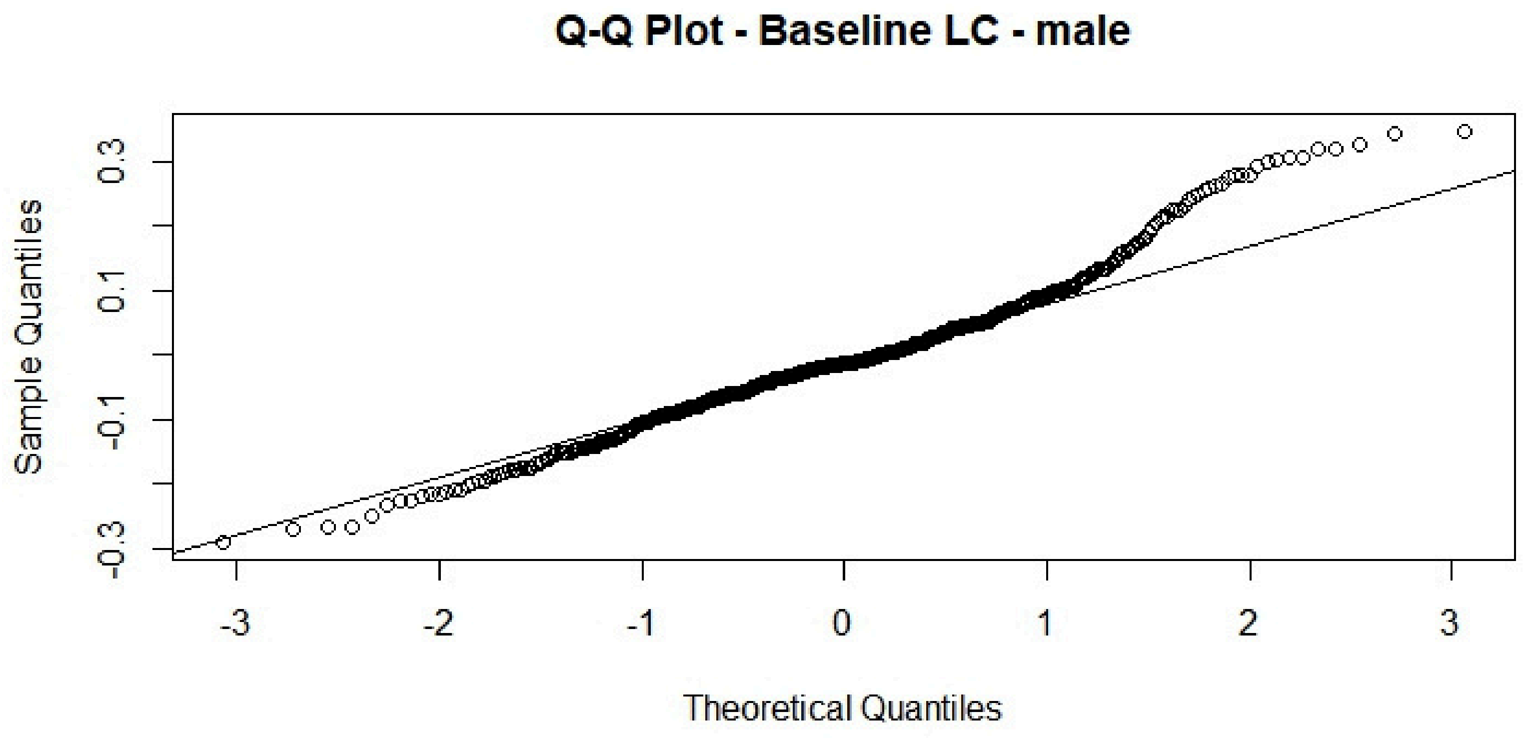
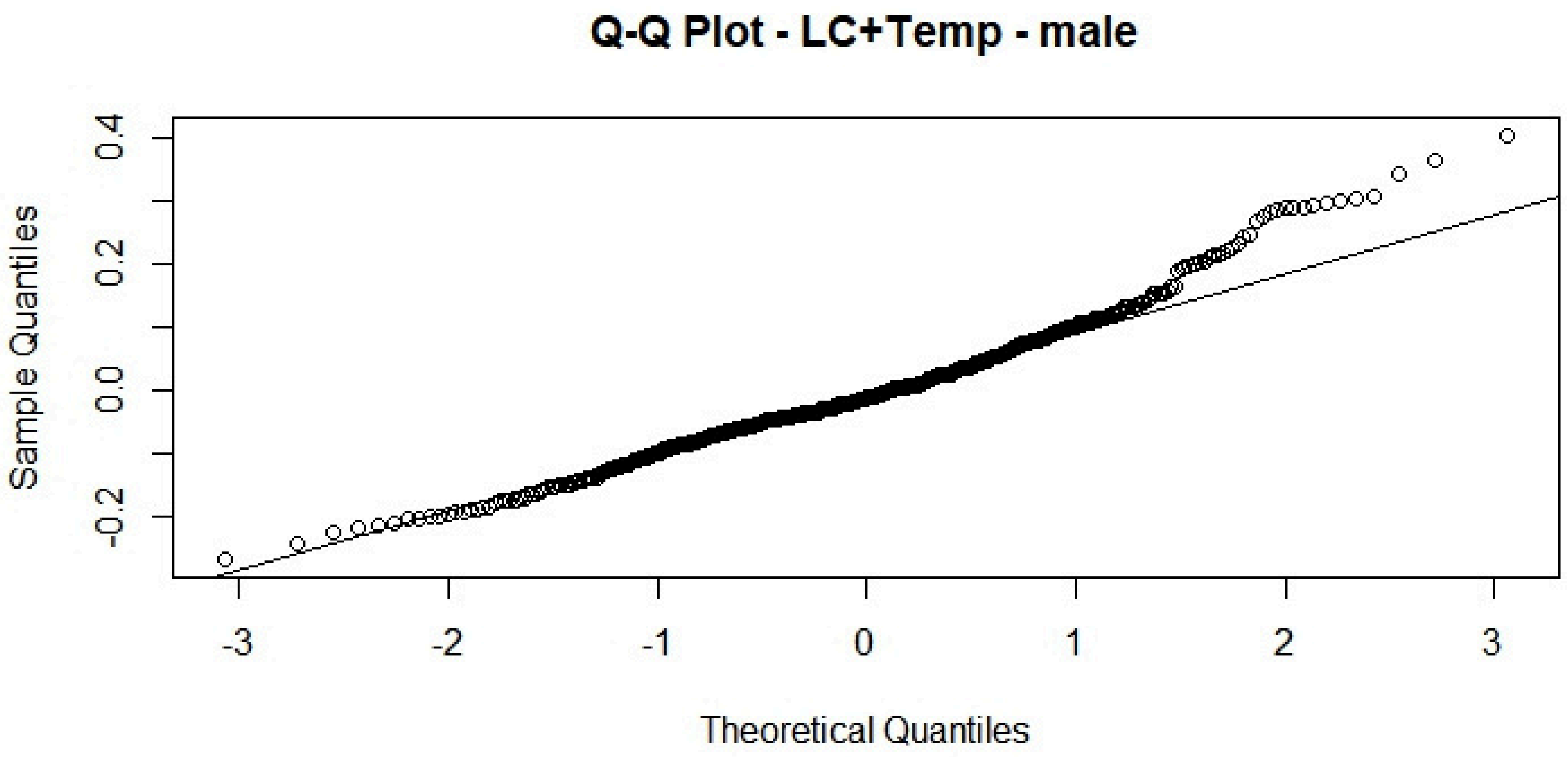
Residual Analysis

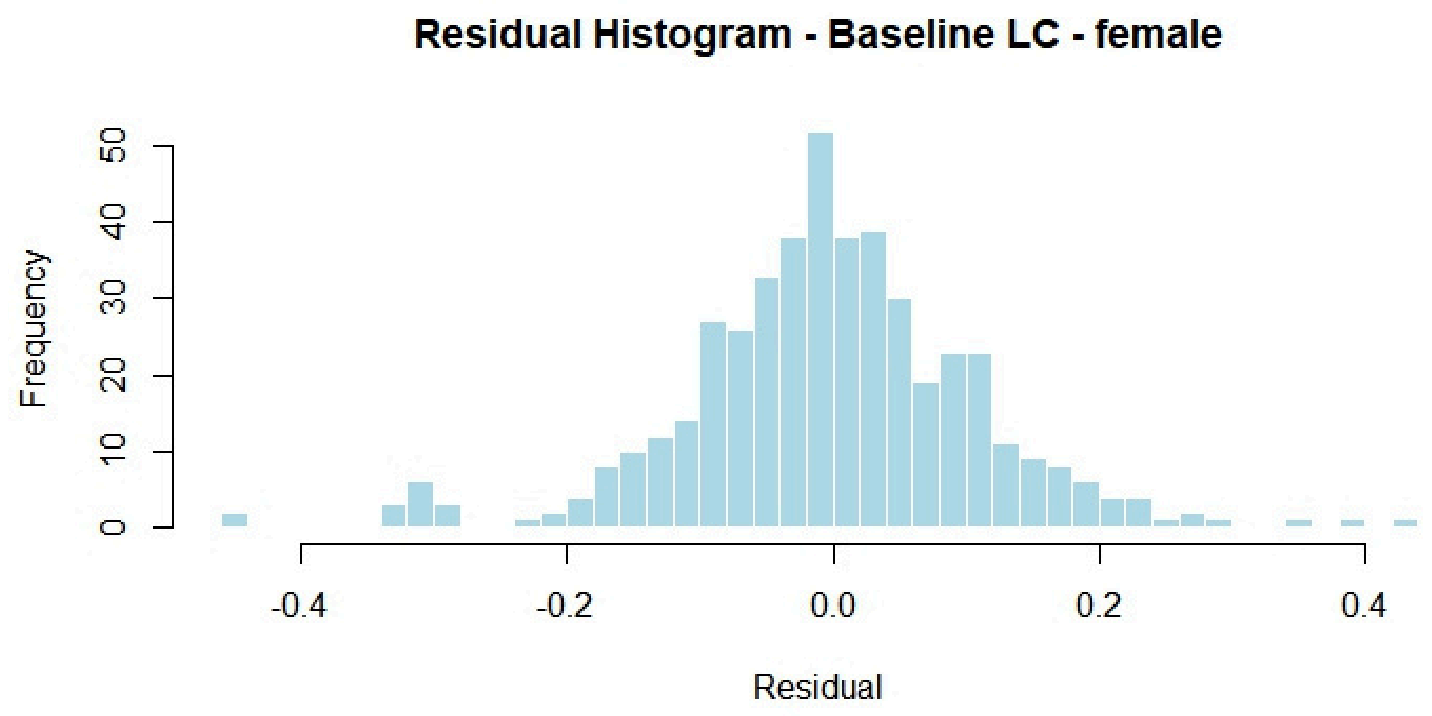


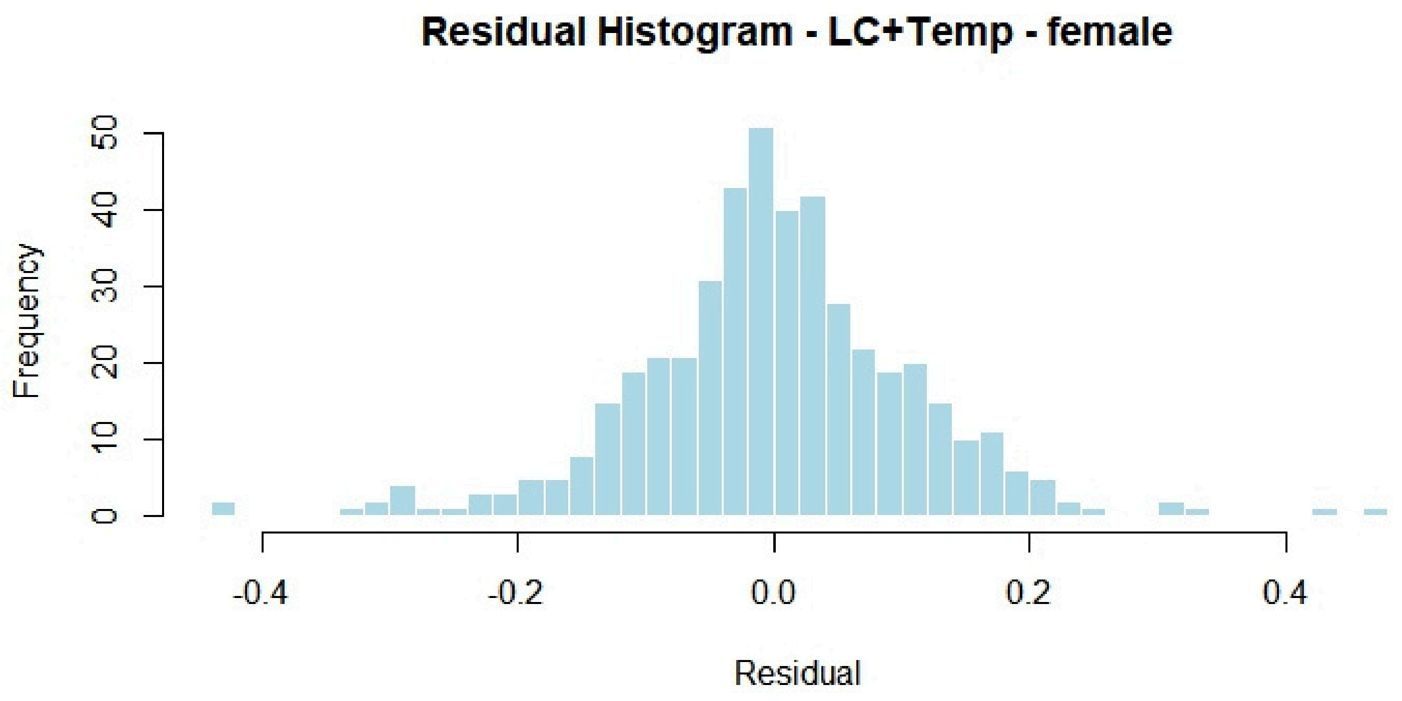


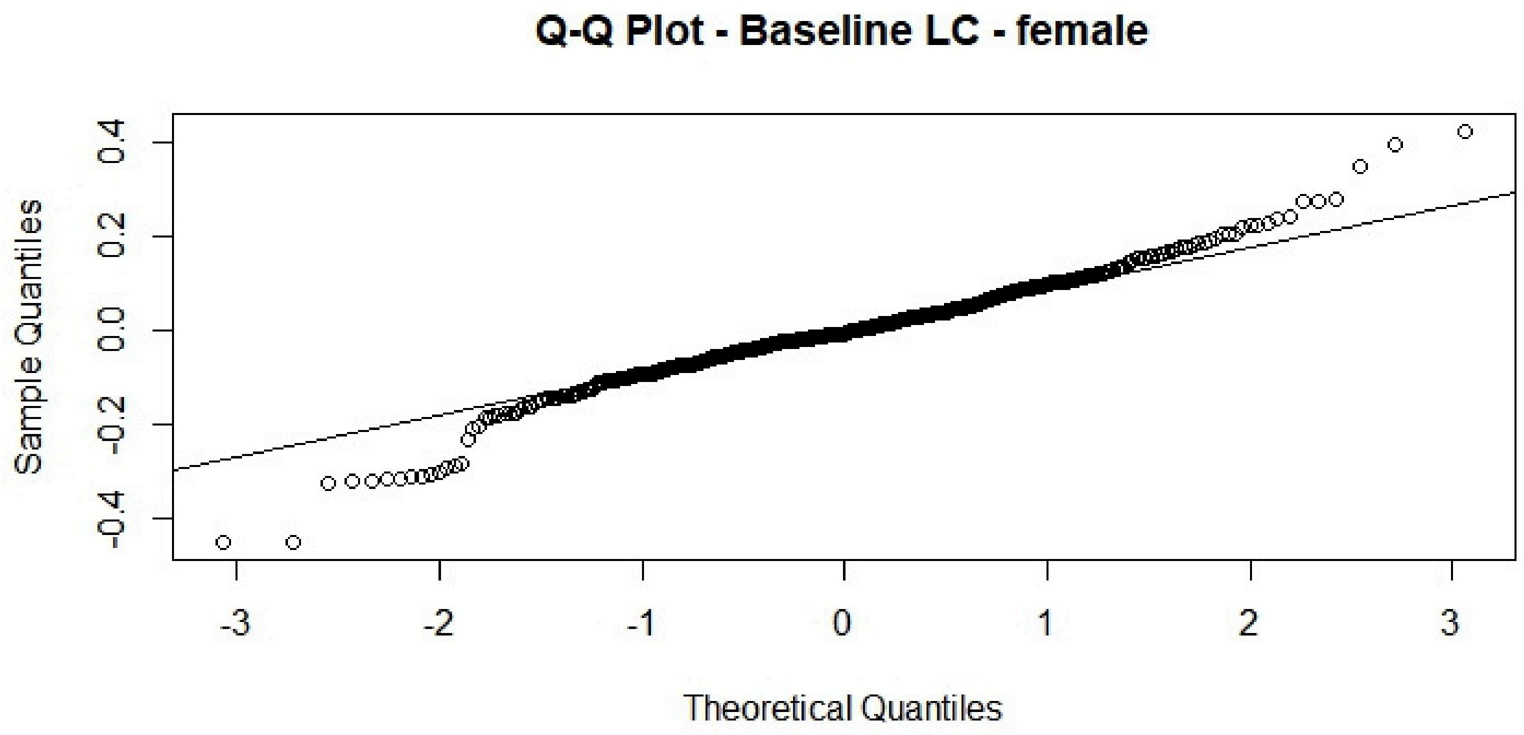


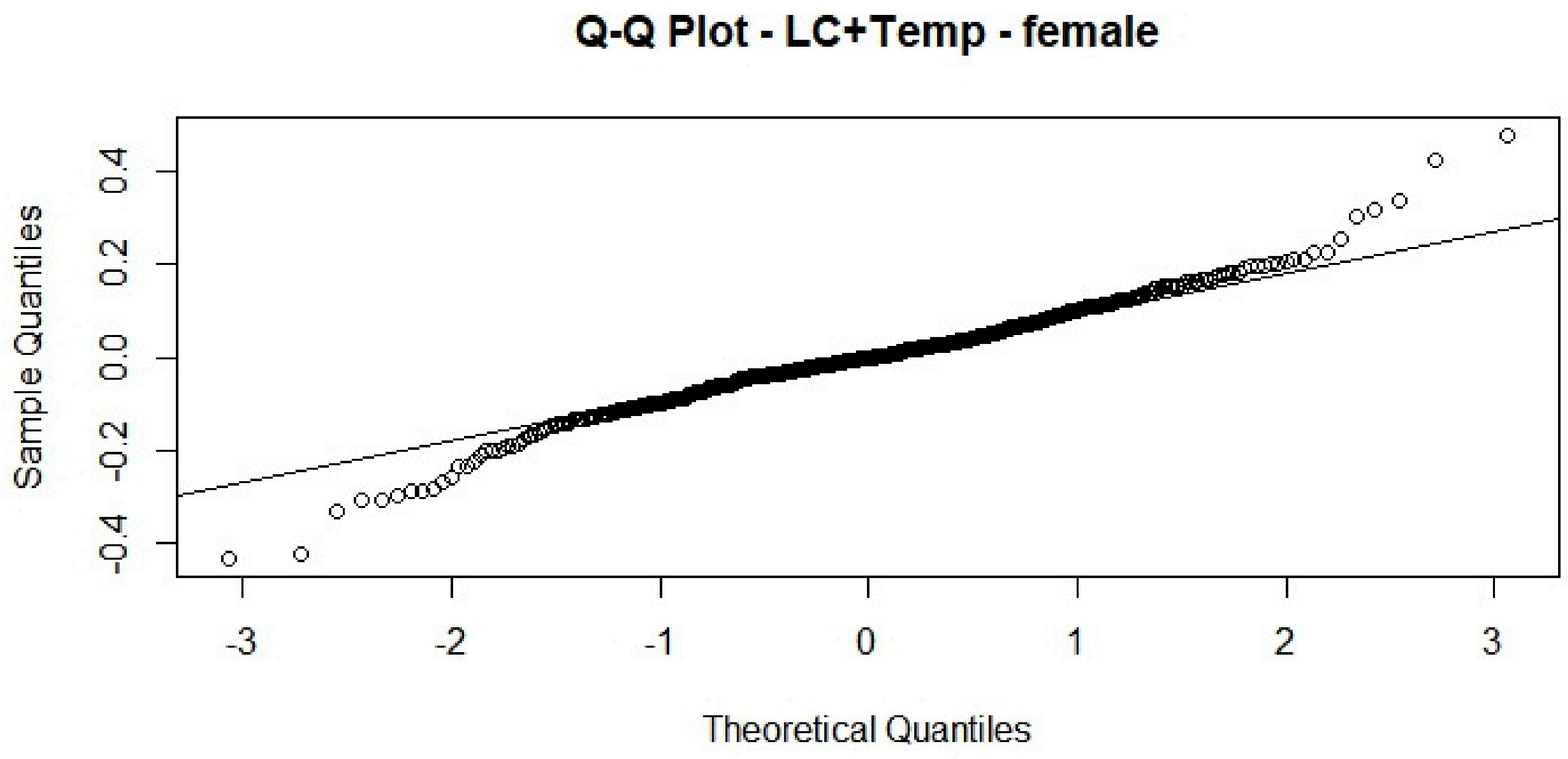


Residual Analysis









Fit Error Metrics

Male

Baseline	Climate
RMSE: **11.37%**	RMSE: **10.94%**
MAPE: **8.53%**	MAPE: **8.29%**

Female

Baseline	Climate
RMSE: **11.16%**	RMSE: **10.92%**
MAPE: **8.24%**	MAPE: **8.04%**

Key Insights

1. Consistent Improvement
2. Modest but real gains
3. Slight gender differences
4. Overall model quality

TAKEAWAYS

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The Apparent Paradox

What we know:

- **cx**: Shows warmer temperatures are generally protective
- **Temperature trend**: Ontario has been warming from 1991-2023
- **kt**: The extended model shows less mortality improvement than the baseline model

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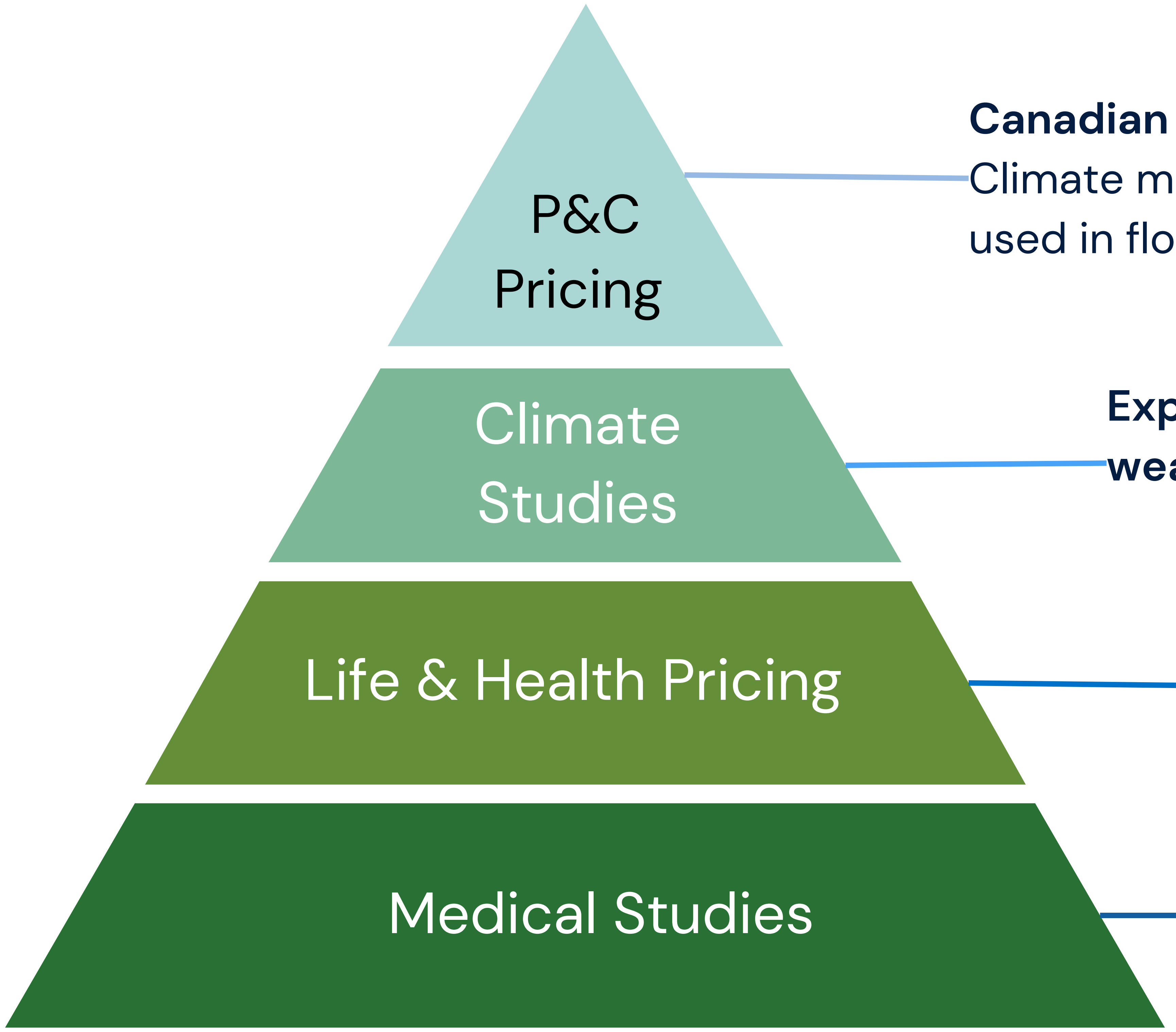
If warming temperatures are protective AND Ontario is warming, why isn't there MORE mortality improvement in the extended model?

CLIMATE METRIC APPLICATIONS



Canadian Flood Insurance Plan
Climate metrics like precipitation used in flood exposure

Exposures to natural disaster, pollution, or weather

Colder Climate – Higher Premium?
Potentially significant risk measures in morbidity and mortality

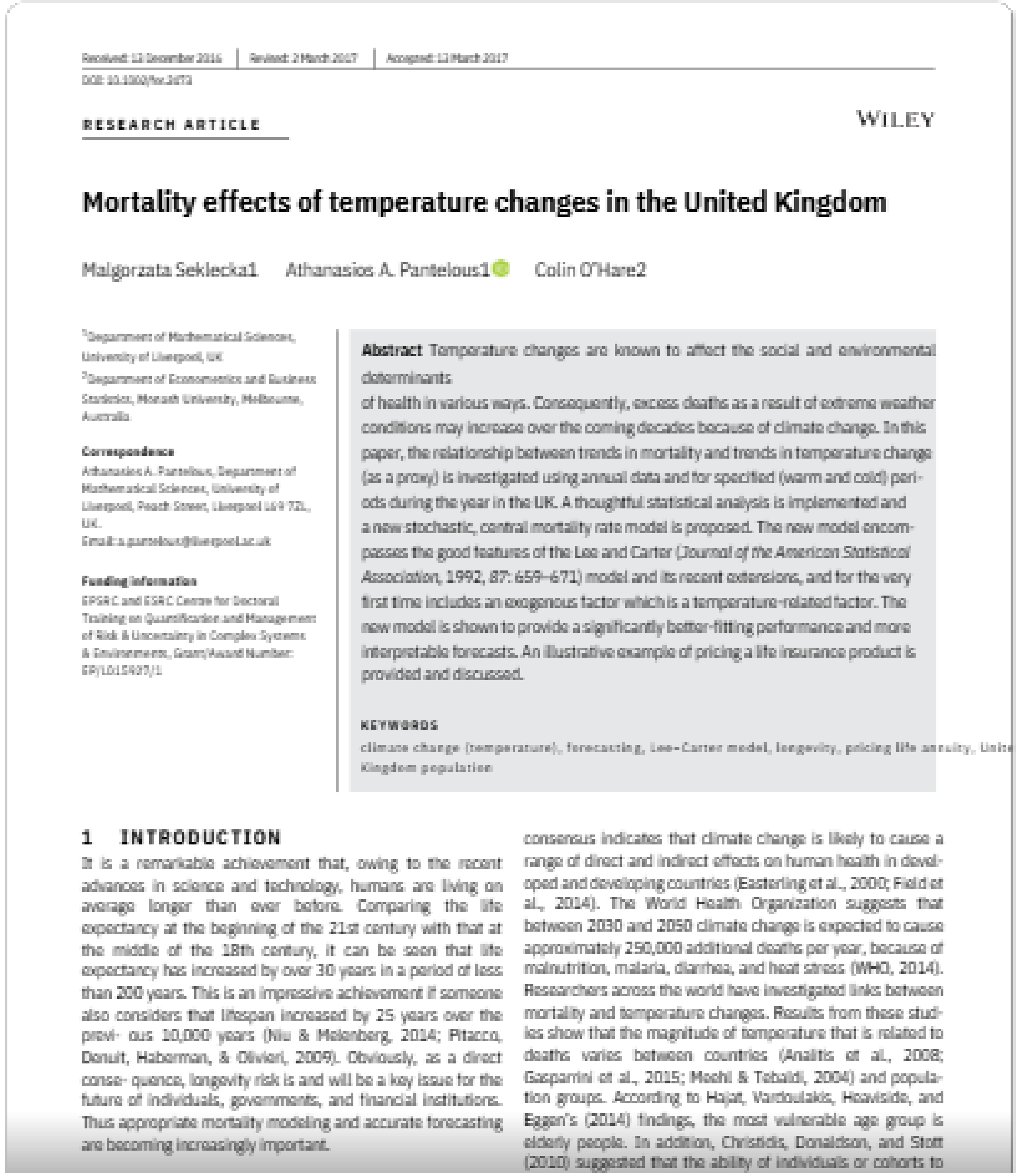
Long-term effects of lifestyles or medications

FURTHER READINGS

SEKLECKA, PANTELOUS, AND O'HARE (2017)

Mortality effects of temperature changes in the United Kingdom

- Extended LC Model with temperature metric
- Performed better out-of-sample forecasts than base LC (Improves BIC by over 8%)
- Most significant effects found in elderly populations



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RESEARCH ARTICLE

WILEY

Mortality effects of temperature changes in the United Kingdom

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Abstract Temperature changes are known to affect the social and environmental determinants of health in various ways. Consequently, excess deaths as a result of extreme weather conditions may increase over the coming decades because of climate change. In this paper, the relationship between trends in mortality and trends in temperature change (as a proxy) is investigated using annual data and for specified (warm and cold) periods during the year in the UK. A thoughtful statistical analysis is implemented and a new stochastic, central mortality rate model is proposed. The new model encompasses the good features of the Lee and Carter (*Journal of the American Statistical Association*, 1992, *87*: 659–671) model and its recent extensions, and for the very first time includes an exogenous factor which is a temperature-related factor. The new model is shown to provide a significantly better-fitting performance and more interpretable forecasts. An illustrative example of pricing a life insurance product is provided and discussed.

KEYWORDS
climate change (temperature), forecasting, Lee–Carter model, longevity, pricing life annuity, United Kingdom population

1 INTRODUCTION

It is a remarkable achievement that, owing to the recent advances in science and technology, humans are living on average longer than ever before. Comparing the life expectancy at the beginning of the 21st century with that at the middle of the 18th century, it can be seen that life expectancy has increased by over 30 years in a period of less than 200 years. This is an impressive achievement if someone also considers that lifespan increased by 25 years over the previ- ous 10,000 years (Niu & Melenberg, 2014; Pitacco, Denuit, Haberman, & Olivieri, 2009). Obviously, as a direct conse- quence, longevity risk is and will be a key issue for the future of individuals, governments, and financial institutions. Thus appropriate mortality modeling and accurate forecasting are becoming increasingly important.

consensus indicates that climate change is likely to cause a range of direct and indirect effects on human health in developed and developing countries (Easterling et al., 2000; Field et al., 2014). The World Health Organization suggests that between 2030 and 2050 climate change is expected to cause approximately 250,000 additional deaths per year, because of malnutrition, malaria, diarrhea, and heat stress (WHO, 2014). Researchers across the world have investigated links between mortality and temperature changes. Results from these studies show that the magnitude of temperature that is related to deaths varies between countries (Analitis et al., 2008; Gasparrini et al., 2015; Meehl & Tebaldi, 2004) and population groups. According to Hajat, Vardoulakis, Heaviside, and Eggen's (2014) findings, the most vulnerable age group is elderly people. In addition, Christidis, Donaldson, and Stott (2010) suggested that the ability of individuals or cohorts to

FURTHER READINGS

Effect of Climate Metrics on Insurance Pricing

Academic Papers - Climate Metrics in Insurance Pricing

ESG

Carannante, A., D'Amato, V., & Staffa, M. S. (2024). How ESG corporate reputation affects sustainability premiums in the insurance industry. *Frontiers in Applied Mathematics and Statistics, 10.* https://www.frontiersin.org/journals/applied-mathematics-and-statistics/articles/10.3389/fams.2024.1474565/fullfrontiersin

Bailey, M., & Wittenberg, D. (2025). Why Insurers Price Carbon Low: An Analysis of Financed Emissions and Investment Decisions. *SSRN Working Paper.* *(No direct link found; usually available at SSRN.com)*

Flores, R. M., Lee, S., & Fischer, A. (2023). The role of insurance status in the association between temperature and MI hospitalizations. *Environmental Health*, 22(3), 101-112. https://pmc.ncbi.nlm.nih.gov/articles/PMC10403039/ and https://pubmed.ncbi.nlm.nih.gov/37545806/pmc.ncbi.nlm.nih+1

Natural Disaster Risk Index

Keys, B. J., & Mulder, T. (2024). Disaster Risk and Rising Home Insurance Premiums. *NBER Working Paper No. 32579.* https://www.nber.org/papers/w32579 and summary: https://www.nber.org/digest/202410/disaster-risk-and-rising-home-insurance-premiums nber+1

Montero, E. (2024). Natural disasters, stock price volatility in the property insurance sector. *Journal of Insurance and Risk Management*, 19(2), 132-153. *(No direct link found)*

Q, Z., Wang, H., & Yang, S. (2022). Exposure to Abnormally Hot Temperature and the Demand for Commercial Health Insurance. *Frontiers in Public Health*, 10, 842665. https://www.frontiersin.org/journals/public-health/articles/10.3389/fpubh.2022.842665/full and https://pubmed.ncbi.nlm.nih.gov/35145944/pubmed.ncbi.nlm.nih+1

- ESG
- Carbon Footprint
- Temperature
- Natural Disaster Index

Conclusion

Replicated UK Mortality study with Ontario population

Extension of Lee-Carter with Temperature

Thanks!

ANY QUESTIONS?