COS 513 – Spring 2025 – Final Project Proposal

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Abstract

This proposal outlines our project to develop accurate and interpretable yield curve models for robust interest rate risk assessment for insurance companies. We aim to address the limitations of current regulatory models by providing a more granular, data-driven alternative.

1 Introduction

This project focuses on developing yield curve models that are both accurate and interpretable, thereby enhancing interest rate risk assessment. The proposed methods aim to overcome the limitations of current regulatory models by incorporating advanced Bayesian techniques and non-parametric estimation.

2 Dataset Description

We will use historical daily yield curve data for JPY spanning from January 1, 2008, to December 31, 2024. Each observation includes yields across multiple maturities (e.g., 1–10 years, 15-year, 20-year, 25-year, 30-year, 40-year) provided by the Ministry of Finance, Japan.

The summary statistics are presented in Table 1.

Table 1: Historical Statistics

	Count	Mean	Std	Min	Median	Max
1	4160	0.02	0.21	-0.37	0.00	0.80
2	4160	0.05	0.23	-0.37	0.01	1.01
3	4160	0.08	0.27	-0.37	0.03	1.23
4	4160	0.14	0.31	-0.38	0.08	1.41
5	4160	0.19	0.34	-0.39	0.14	1.53
6	4160	0.24	0.37	-0.41	0.18	1.60
7	4160	0.31	0.41	-0.42	0.26	1.65
8	4160	0.39	0.45	-0.39	0.35	1.68
9	4160	0.48	0.49	-0.35	0.42	1.81
10	4160	0.56	0.52	-0.30	0.48	1.87
15	4160	0.92	0.62	-0.15	0.90	2.23
20	4160	1.20	0.65	0.02	1.26	2.40
25	4160	1.33	0.66	0.04	1.41	2.53
30	4160	1.40	0.66	0.04	1.50	2.58
40	4160	1.51	0.68	0.07	1.63	2.66

37th Conference on Neural Information Processing Systems (NeurIPS 2023).

3 Research Objective and Methodology

Research Objective Develop accurate and interpretable models to fit the yield curve and estimate interest rate levels and associated risks. Managing interest rate risk is crucial for financial firms. For insurance companies in particular, a new global capital regulation—the Insurance Capital Standard (ICS)—was adopted in December 2024 and will be implemented in 2027 following jurisdictional assessments. The ICS mandates that insurance companies implement robust internal models and calculate standard regulatory capital. In the ICS standard model, insurance risk calculation is performed using a model that combines the Dynamic Nelson-Siegel model with Monte Carlo simulation; however, this model is not straightforward and employs some market-inconsistent factors (e.g., it begins interpolating the yield curve from the 30-year tenor for JPY). Additionally, risk calculation parameters are updated only annually, which is insufficient for more granular risk assessment. Therefore, an alternative method for risk calculation is necessary, and we believe that a Gaussian Process approach, with its non-parametric estimation, will provide a more robust model.

Methodology We plan to compare two main approaches for yield curve estimation:

1. **Dynamic Nelson-Siegel (DNS) (regulatory model):** A parametric model capturing level, slope, and curvature factors. To enhance interpretability and incorporate parameter uncertainty into risk calculations, we will employ a Bayesian framework using the Kalman filter to estimate DNS parameters. To combine stress for each factor, we will use 'quasi simulation method' adopted in ICS calculation in which the stress is converted to level up-down stress and twist up-down scenario and then scaled and aggregated by independent gaussian random numbers.
2. **Gaussian Process (GP):** A non-parametric approach allowing flexible kernel selection and improving the interpretability of the estimated curves. As the hyperparameters are updated when new yield curve data become available, the model directly learns uncertainty from the data, which is expected to result in higher estimation accuracy. We will perform multivariate Gaussian Process regression using several tenors and then apply cubic spline interpolation to complete the yield curve. Stress (stressed yield curve) will be calculated directly from the yield curve estimation process.

4 Implications of Success

Success in developing an alternative risk calculation model will have the following implications:

- Straightforward interest rate level estimation and risk calculation will facilitate the implementation of company models, such as Asset Liability Management models and business simulations.
- Frequent updates and the elimination of market-inconsistent assumptions present in the regulatory model will provide additional insights into interest rate risk.
- Since no single model is perfect, comparing results obtained from different models will contribute to more robust decision making.

5 Evaluation and Metrics

- **RMSE:** Evaluate the difference between the actual curve and the fitted curve.
- **Backtesting:** Compare the model-based risk with historical VaR and/or Expected Shortfall to assess the frequency of breaches.

6 Challenges and Potential Risks

- **Hyperparameter Tuning:** Calibrating lambda parameters in the DNS model may be challenging.
- **Kernel Selection (GP):** The choice of kernel affects model flexibility and computational efficiency.
- **Calculation Time:** High-frequency or large-scale data may lead to computational bottlenecks, especially for non-parametric methods.

References

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