São Paulo 2025

Quantum-Enhanced Principle Component Analysis: Transforming Interest Rate Modeling with the Power of Quantum Computing

Alexander Bohnert
Alexander Dotterweich
Svenja Ernst

Munich University of Applied Sciences / PwC

Agenda

1. Introduction
2. Definition of the Problem Setting
3. Results
4. Conclusion and Outlook

São Paulo 2025

The international AI race needs quantum computing

Quantum synthetic data is key to addressing looming data availability gaps.

BY IDALIA FRIEDSON • FEBRUARY 19, 2025

Quantum computing in finance: A game-changer, eventually

As quantum computing matures, its impact is likely to be transformative, holding immense promise for the financial sector.

By Derik Breedt, Technical team lead, Retro Rabbit.
Johannesburg, 21 Feb 2025

Unlock the Future: How Quantum Computing is Revolutionizing Industries

20 February 2025 · by Haven Jorgens

Will quantum computers disrupt critical infrastructure?

14 hours ago

Share Save

Joe Fay
Technology Reporter

Powerful quantum computers in years not decades, says Microsoft

2 days ago

Share Save

Chris Vallance
Senior Technology Reporter

Nobel Laureate: Quantum Computing Won't Overtake Classical Machines Anytime Soon

Research Matt Swayne • February 19, 2025

https://www.bbc.com/news/articles/cj3e3252gj8o
https://crypto.news/river-ceo-warns-that-bitcoin-at-risk-from-quantum-computers-sees-no-danger-for-banking-stays/
https://www.bbc.com/news/articles/cpq9zxxn72qo
https://defensescoop.com/2025/02/19/international-ai-race-needs-quantum-computing/
https://thequantuminsider.com/2025/02/19/nobel-laureate-quantum-computing-wont-overtake-classical-machines-anytime-soon/
https://www.itweb.co.za/article/quantum-computing-in-finance-a-game-changer-eventually/xA9POvNEKe9qo4J8
https://lanoticiadigital.com.ar/news-en/unlock-the-future-how-quantum-computing-is-revolutionizing-industries/139940/

IAA AAI SECTIONS

IBA
INSTITUTO BRASILEIRO DE ATUÁRIA

INTRODUCTION

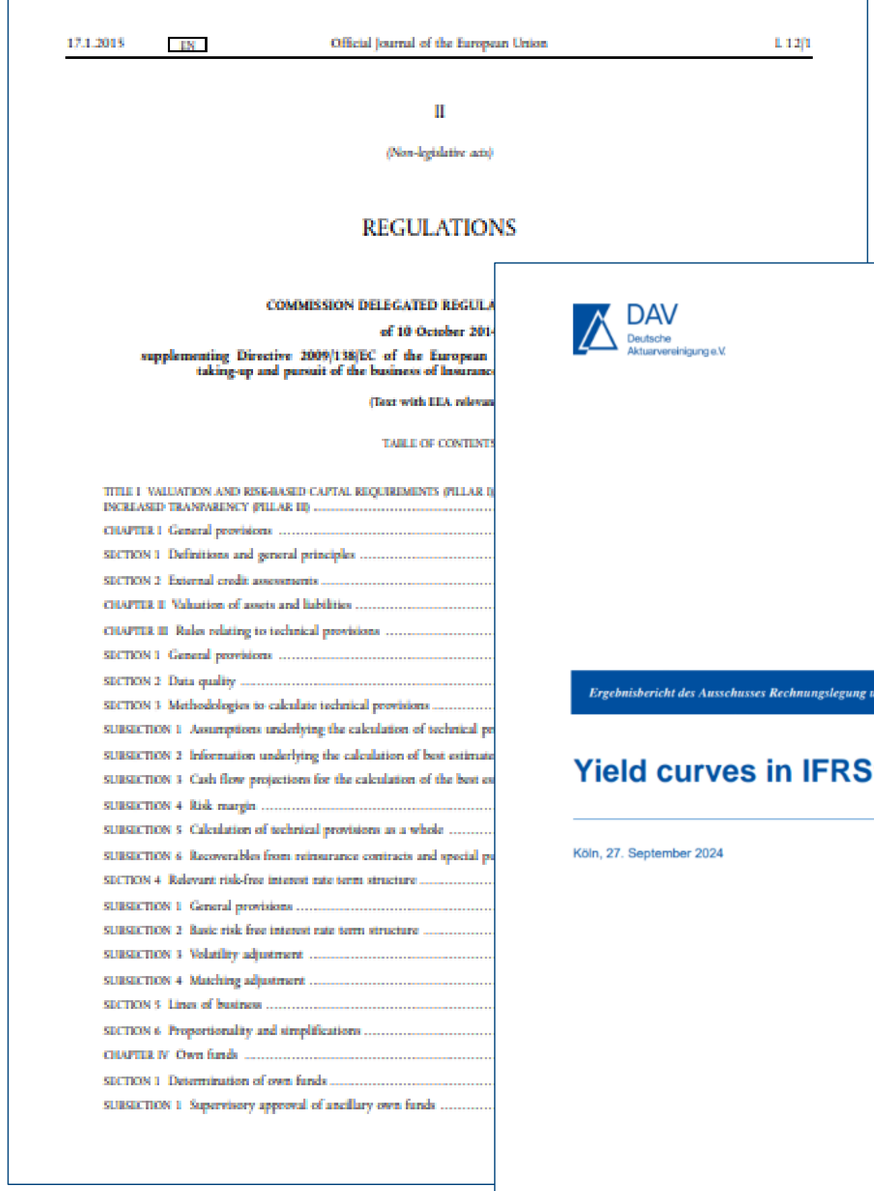
Interest Rate models

Yield curves are key for assessing interest rate risk.

Financial institutions utilize yield curves for regulatory compliance.

Interest rate models are essential for aligning asset and liability values in the ALM process.

PCA helps analyze key drivers of yield curve evolution.


17.1.2015 EN Official Journal of the European Union L 12/1

II

(Non-legislative acts)

REGULATIONS

COMMISSION DELEGATED REGULA

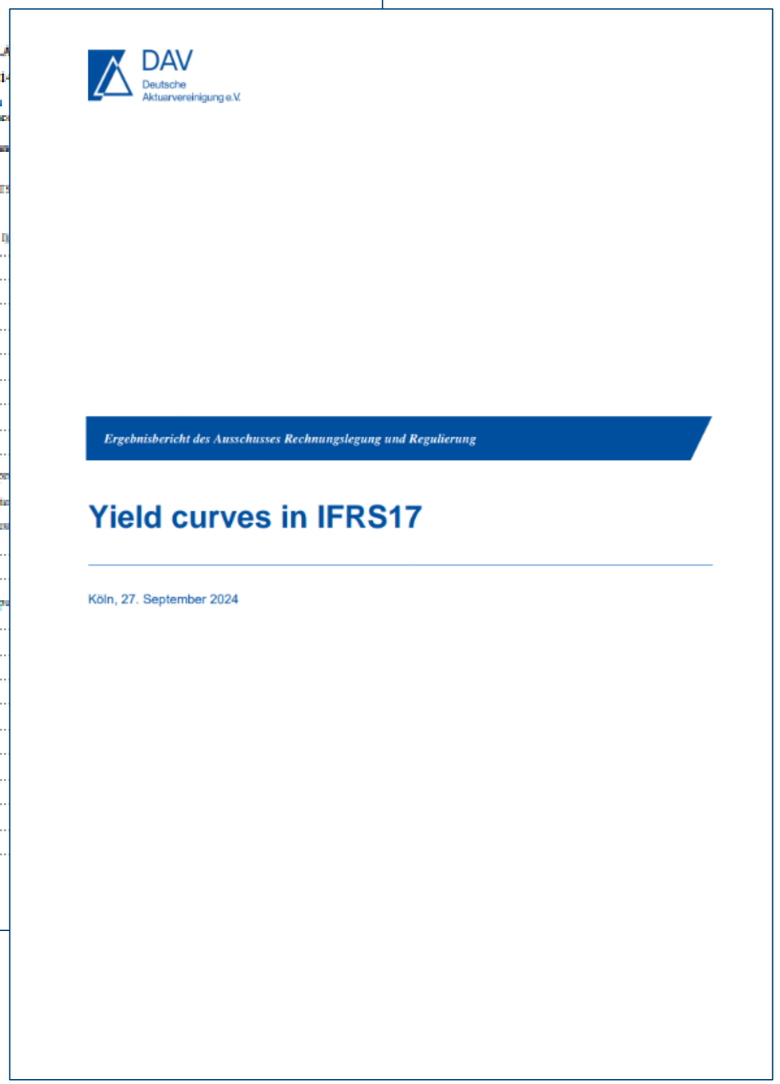
of 10 October 201

supplementing Directive 2009/138/EC of the European
taking-up and pursuit of the business of insurance

(Text with EEA relevan

TABLE OF CONTENTS

TITLE I VALUATION AND RISK-BASED CAPITAL REQUIREMENTS (PILLAR I)
INCREASED TRANSPARENCY (PILLAR III)
CHAPTER 1 General provisions
SECTION 1 Definitions and general principles
SECTION 2 External credit assessments
CHAPTER II Valuation of assets and liabilities
CHAPTER III Rules relating to technical provisions
SECTION 1 General provisions
SECTION 2 Data quality
SECTION 3 Methodologies to calculate technical provisions
SUBSECTION 1 Assumptions underlying the calculation of technical pr
SUBSECTION 2 Information underlying the calculation of best estimate
SUBSECTION 3 Cash flow projections for the calculation of the best es
SUBSECTION 4 Risk margin
SUBSECTION 5 Calculation of technical provisions as a whole
SUBSECTION 6 Recoverables from reinsurance contracts and special pu
SECTION 4 Relevant risk-free interest rate term structure
SUBSECTION 1 General provisions
SUBSECTION 2 Basic risk free interest rate term structure
SUBSECTION 3 Volatility adjustment
SUBSECTION 4 Matching adjustment
SECTION 5 Lines of business
SECTION 6 Proportionality and simplifications
CHAPTER IV Own funds
SECTION 1 Determination of own funds
SUBSECTION 1 Supervisory approval of ancillary own funds


DAV
Deutsche
Aktuarvereinigung e.V.

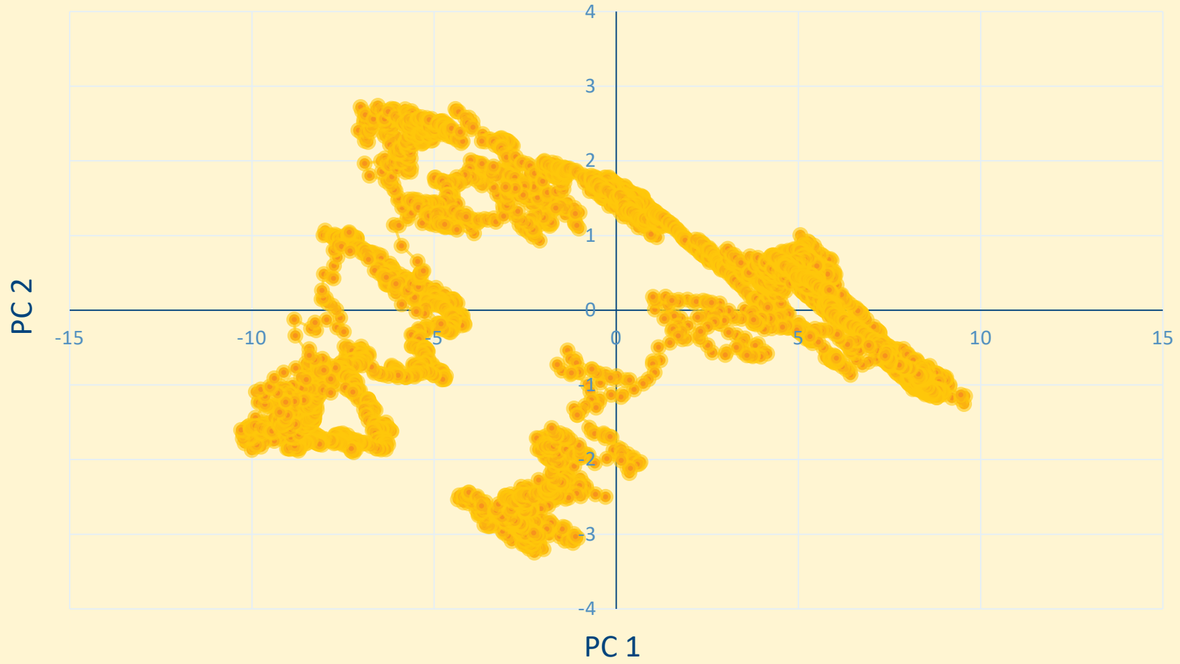
Ergebnisbericht des Ausschusses Rechnungslegung und Regulierung

Yield curves in IFRS17

Köln, 27. September 2024

https://eur-lex.europa.eu/eli/reg_del/2015/35/oj/eng
https://aktuar.de/content/PDF/Fachwissen/2024-09-27_DAV_Ergebnisbericht_Yield_curves_in_IFRS17.pdf

Classical PCA Approach



Challenges with classical PCA

Reduced computational accuracy with an increase in data size.

Increase in computation time with the increase in data size.

Increase in regulatory requirements.

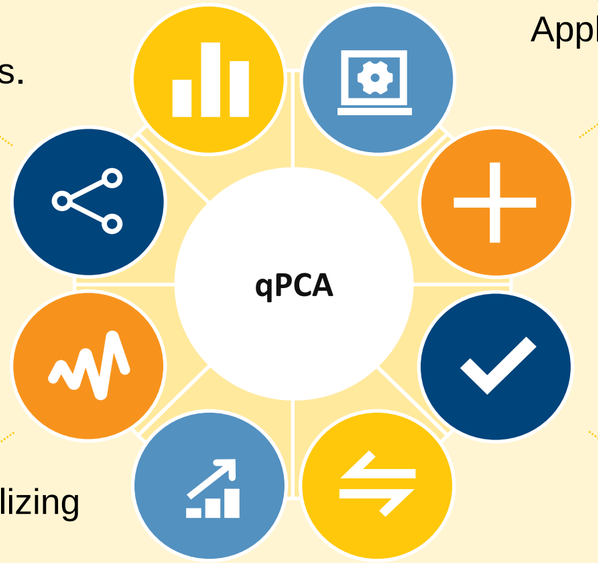
Our Contributions

Principle Component Insights
Evaluating the role of principle components in yield curve dynamics.

Term Structure Modeling
Assessing dimensional properties of the term structure of interest rates.

Capturing complex yield curve behaviors with quantum computing.
Yield Curve Dynamics

Improving interest rate forecasts utilizing quantum computing.
Forecasting Capabilities



Quantum Computing Applications
Applying qPCA to interest rate analysis.

Computational Advantages
Leveraging quantum methods for improved financial data analysis.

Comparing qPCA-generated interest rates with historical data.
Backtesting performance

Assessing qPCA's robustness vs. classical PCA.
Stability Evaluation

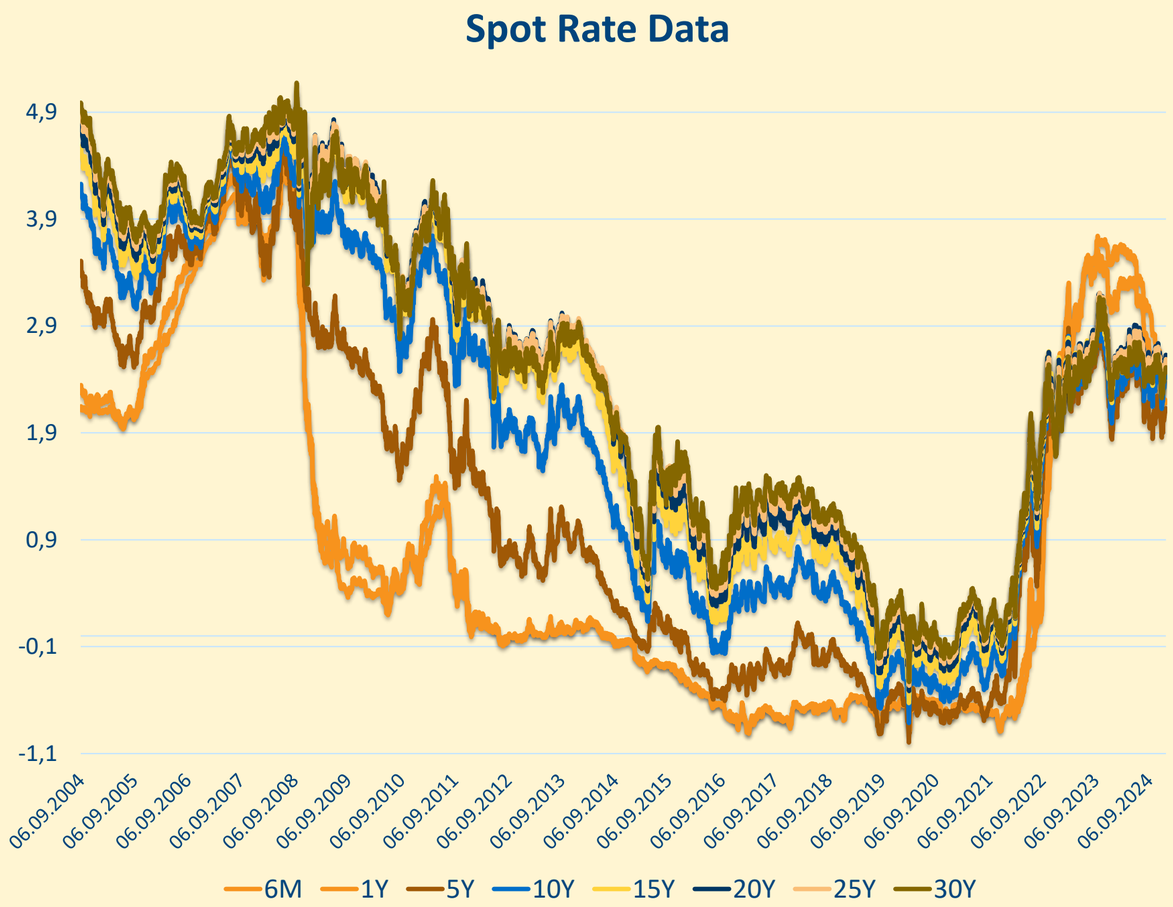
DEFINITION OF THE PROBLEM SETTING

Data

We gathered AAA-rated European government bond daily spot rate data from the ECB.

For the analysis, we consider the maturities 6 months, 1 year, 5 years, 10 years, 15 years, 20 years, 25 years and 30 years.

Our assessment is based on the correlation matrix of the interest rate data.



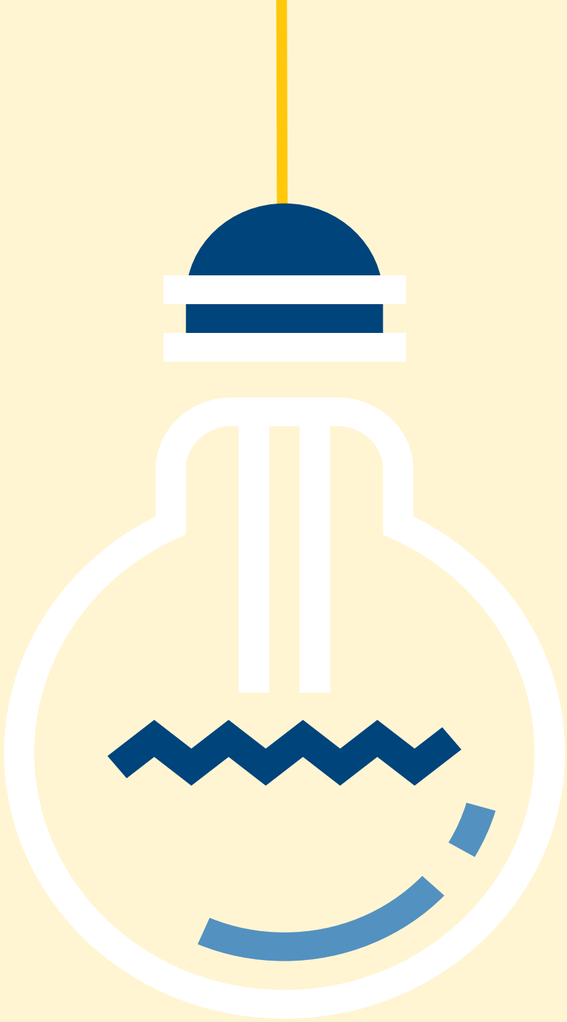
Quantum Data Representation

The quantum dataset is represented by a density matrix.

Density matrices capture statistical properties and correlations of the quantum features.

Implementation utilizing the Python IBM Qiskit package.

$$Cov(X) = \begin{pmatrix} 0.1250 & 0.1245 & 0.1123 & 0.0994 & 0.0932 & 0.0911 & 0.0910 & 0.0915 \\ 0.1245 & 0.1250 & 0.1155 & 0.1031 & 0.0969 & 0.0949 & 0.0948 & 0.0952 \\ 0.1123 & 0.1155 & 0.1250 & 0.1216 & 0.1182 & 0.1169 & 0.1167 & 0.1169 \\ 0.0994 & 0.1031 & 0.1216 & 0.1250 & 0.1243 & 0.1238 & 0.1236 & 0.1234 \\ 0.0932 & 0.0969 & 0.1182 & 0.1243 & 0.1250 & 0.1249 & 0.1247 & 0.1243 \\ 0.0911 & 0.0949 & 0.1169 & 0.1238 & 0.1249 & 0.1250 & 0.1249 & 0.1246 \\ 0.0910 & 0.0948 & 0.1167 & 0.1236 & 0.1247 & 0.1249 & 0.1250 & 0.1249 \\ 0.0915 & 0.0952 & 0.1169 & 0.1234 & 0.1243 & 0.1246 & 0.1249 & 0.1250 \end{pmatrix}$$

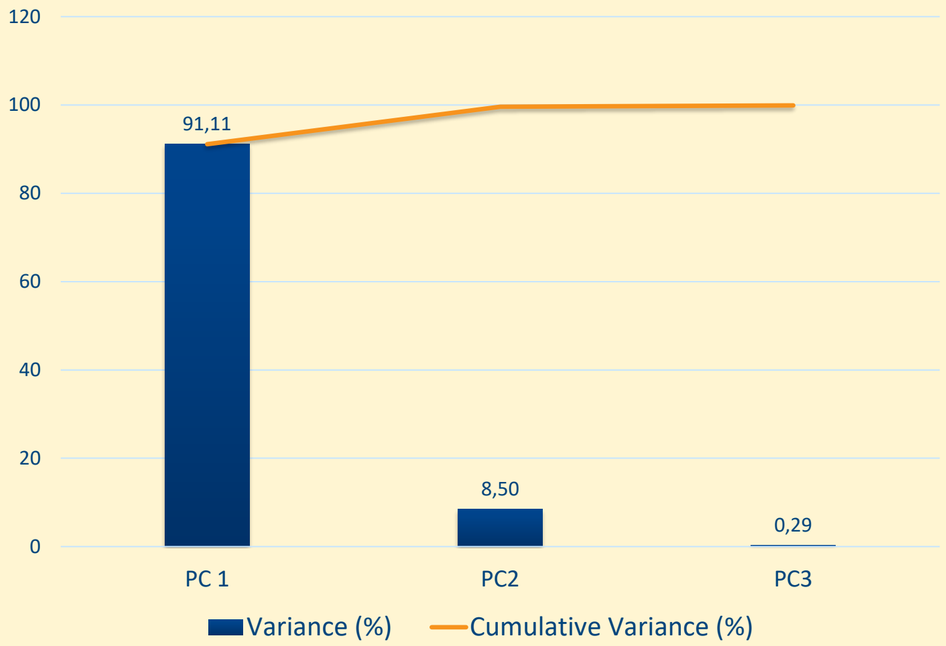


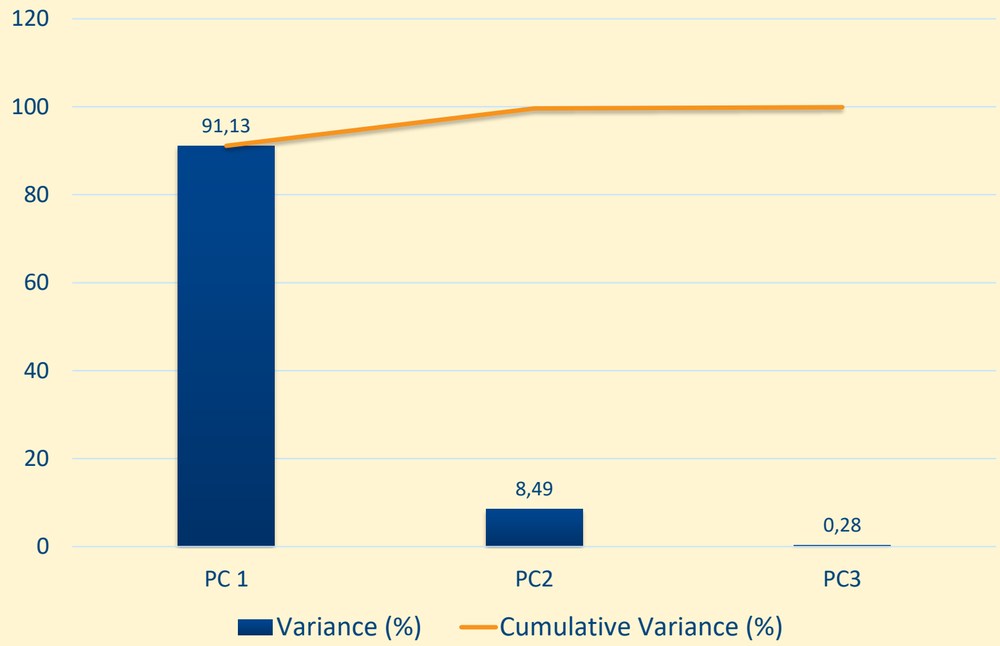
> In quantum mechanics, it's all about (state) vectors and (linear) operators.

Rodrigo Silva
https://medium.com/towards-data-science/quantum-mechanics-meets-pca-an-un-expected-convergence-5e04bcb16376

RESULTS

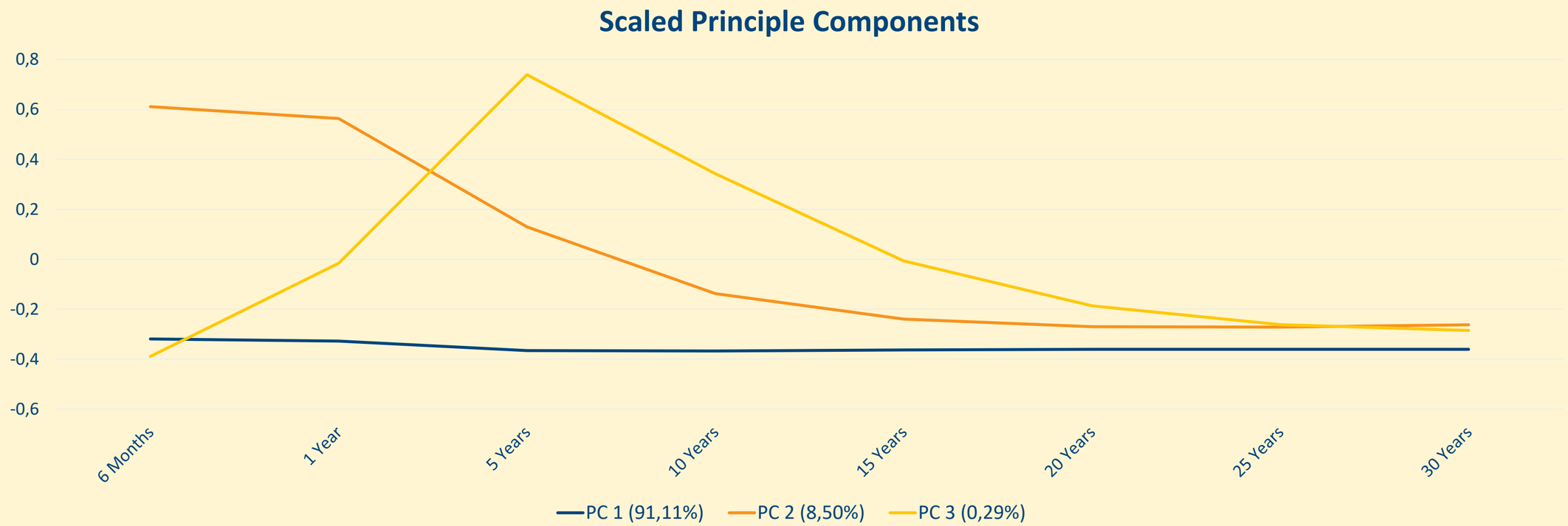
STABILITY OF QPCA





Closely aligned explained variances obtained with qPCA and PCA

PRINCIPLE COMPONENT DYNAMICS



Several dominant factors drive spot rate changes over time.

INTEREST RATE RECONSTRUCTION

Goodness of fit vs. **Efficiency**

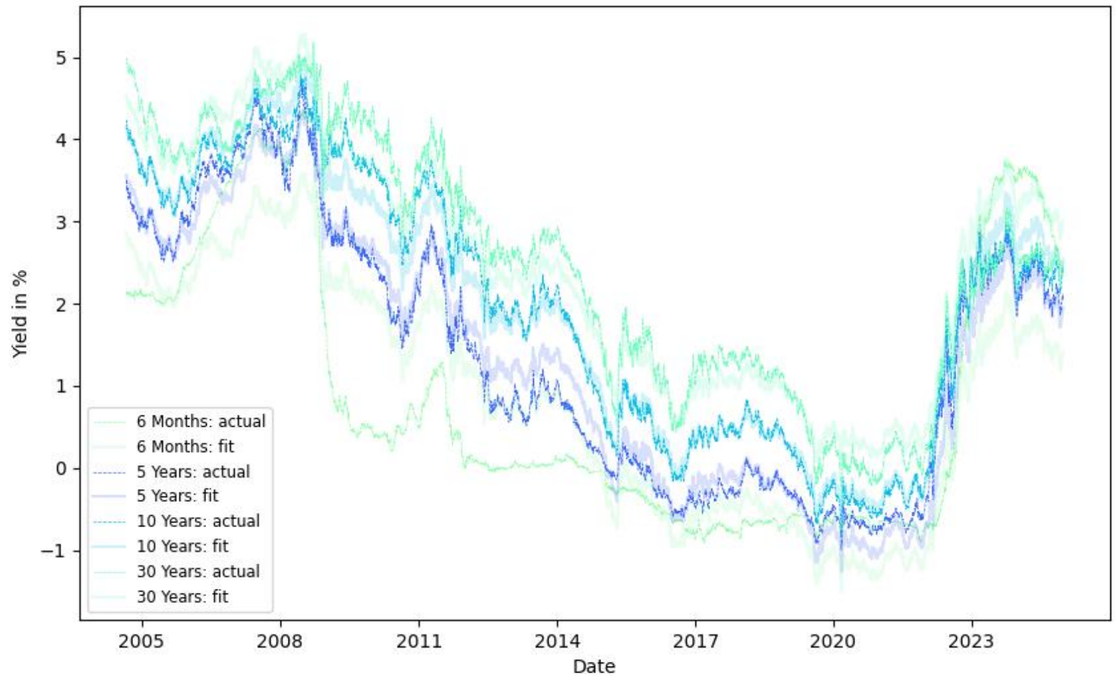
Optimization of the reconstruction of interest rate curves under consideration of computational efficiency

qPCA sequentially derives each PC.

The fewer PCs are retained the better the computational efficiency.

The more PCs are retained the better the goodness of fit of the reconstructed yield curves.

Fine-tuning necessary for efficient analysis of interest rate risks.



INTEREST RATE RECONSTRUCTION

Goodness of fit vs. **Efficiency**

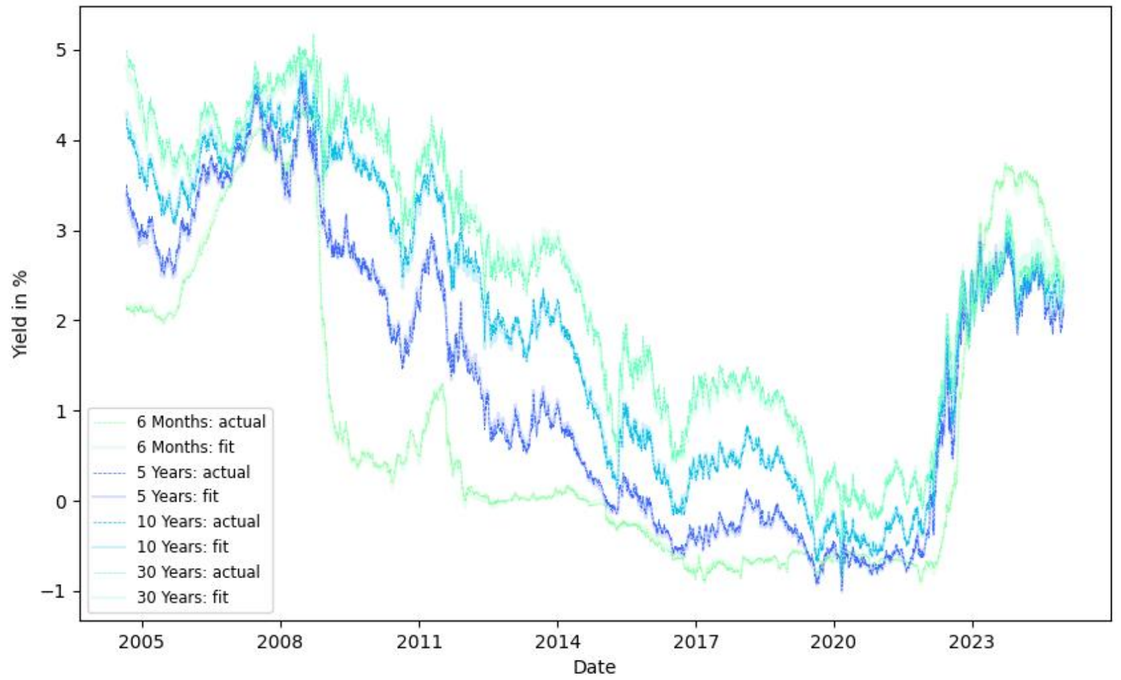
Optimization of the reconstruction of interest rate curves under consideration of computational efficiency

qPCA sequentially derives each PC.

The fewer PCs are retained the better the computational efficiency.

The more PCs are retained the better the goodness of fit of the reconstructed yield curves.

Fine-tuning necessary for efficient analysis of interest rate risks.



CONCLUSION AND OUTLOOK

Conclusion and Outlook

Key Contributions

Quantum Dimensionality Reduction: Quantum computing approach for efficient spot rate factor analysis.

Scalability: qPCA theoretically handles larger datasets with potential for improved analysis as quantum technology advances.

qPCA Insights: Captures key interest rate dynamics with 3 PCs explaining most of the variance.

Possible Extensions

Interest Rate Risk in Insurance: Apply qPCA to asset-liability management and solvency assessment.

Broader Insurance Applications: Utilize qPCA for capital assessments, hedging optimization, and liability-driven investment.

Integration with Actuarial Modeling: Integrate quantum algorithms into financial and actuarial modelling for enhanced risk management.

Thank you! Obrigado!

Questions?

Svenja Ernst
HM Professorship of Finance, Insurance Economics, and Risk Management

PwC Actuarial Risk Modelling Services

Mobil: +49 160 2791108
svenja.ernst@hm.edu

Prof. Dr. Alexander Bohnert
HM Professorship of Finance, Insurance Economics, and Risk Management

Tel: +49 89 12652769
alexander.bohnert@hm.edu

Dr. Alexander Dotterweich
PwC Actuarial Risk Modelling Services

Mobil: +49 171 8120538
alexander.dotterweich@pwc.com