28th International Congress on Insurance: Mathematics and Economics

Tartu, Estonia, on July 1-4, 2025

Programme and Abstracts

July 1, 2025

Co-funded by the European Union

Investing in your future

Contents

Timetable

Tuesday, July 1st

18:00–20:00	**Welcome reception at Delta**

Wednesday, July 2nd

KL : Keynote Lecture, Room 1037

PS : Parallel session, $n\times$ 20min

8:00	**Registration is open**		
9:00 Room 1037	**Opening**		
9:30–10:30 *Chair: Roger Laeven*	KL	**Phillip Yam** *Hong Kong*	CIBer in Action for FinTech, InsurTech, and Cyber Risk
10:30–11:00	Coffee break		
11:00–12:40	PS1	Room 1021	Risk modeling I
		Room 1020	Mortality modeling I
		Room 1019	Climate risk I
		Room 1018	Statistical and machine learning
12:40–14:00	Lunch break		
14:00–15:20	PS2	Room 1021	Regulatory development
		Room 1020	Pensions and retirement I
		Room 1019	Finance and investment
		Room 1018	Life insurance: asset allocation
15:20–15:40	Coffee break		
15:40–17:00	PS3	Room 1021	Reinsurance and pricing
		Room 1020	Health insurance
		Room 1019	Climate risk II
		Room 1018	Advances in property and casualty insurance

Parallel Session 1

Wednesday 11:00–12:00, Room 1021, Risk modeling I

Chair: Marek Teuerle	
Roger Laeven	Measuring financial resilience using backward stochastic differential equations
Joseph J. Tien	Natural hedging on overseas investment of insurance companies: application for copula functions between interest rate and exchange rate
Runhuan Feng	Capital-allocation-induced risk sharing

Wednesday 11:00–12:40, Room 1020, Mortality modeling I

Chair: Torsten Kleinow	
Fabio Viviano	Single and multi-population mortality models based on Linear Hypercubes
Michel Vellekoop	Minimum reversion in mortality models for multiple populations
Huiling Zheng	Fine-grained mortality forecasting with deep learning
Yin Yee Leong	Improving cluster detection for age-specific spatial mortality hotspots
I-Chien Liu	Mortality modeling comparison: using COVID-19 data

Wednesday 11:00–12:40, Room 1019, Climate risk I

Chair: Stephane Loisel	
Yi-Fan Chen	Insurance decisions under the threat of natural disasters
Herve Zumbach	Classification of extreme rainfall events in Switzerland
Aleksandr Pak	On the insurance of environmental risks: modeling and pricing with mean-reverting regime-switching Lévy processes
Mulah Moriah	Spatiotemporal data integration framework for improved flood cost and occurrence modeling in house insurance
Despoina Makariou	A hybrid machine learning approach for carbon price forecasting

Wednesday 11:00–12:40, Room 1018, Statistical and machine learning

Chair: Georgios Pitselis	
Freek Holvoet	Multi-view spatial embeddings for insurance portfolio analytics
Liivika Tee	Practical GenAI use cases in insurance analytics
Roel Verbelen	A practitioner's guide to interpretable machine learning
Paul Wilsens	Machine learning in an expectation-maximisation framework for nowcasting
Christian Kleiber	Variable importance in generalized linear models – A unifying view using Shapley values

Parallel Session 2

Wednesday 14:00–15:00, Room 1021, Regulatory development

Chair: Jae Youn Ahn	
Zhen Dong Chen	Value of Chapter 11 reorganization
Charlotte Jamotton	A multivariate energy distance approach to premium fairness adjustment
Joana Amorim	Rethinking actuarial education in a global world: the role of actuarial education companies

Wednesday 14:00–14:40, Room 1020, Pensions and retirement I

Chair: Iqbal Owadally	
Qixin Deng	Optimal investment–consumption and tax-favored private defined-contribution pension decision
Yung-Tsung Lee	Reverse mortgage pricing: a cross-country comparative study of product design

Wednesday 14:00–15:20, Room 1019, Finance and investment

Chair: Tahir Choulli	
Hongjun Ha	Smith-Wilson yield curves via a macro-driven ultimate forward rate
Shang-Yin Yang	Optimal consumption and investment problem incorporating the housing habits and the household's subjective beliefs
Shiqi Yan	Optimal asset allocation for a household with multi-claim insurance
Yevhen Havrylenko	Kihlstrom–Mirman preferences in continuous time: equilibrium control theory and applications to finance and insurance

Wednesday 14:00–15:20, Room 1018, Life insurance: asset allocation

Chair: An Chen	
Sander Van Eekelen	Optimal benefits, taxation, and asset allocation for a PAYG system with reserve fund under equity, longevity, and unemployment risks
Gabriele Stabile	On variable annuities with surrender charges
Hailiang Yang	Optimizing portfolios with surrender variable annuities: a deep reinforcement learning approach
Ko-Lun Kung	An analysis of the impact of liquidity premium estimation on the reserves of Taiwan's life insurance companies

Parallel Session 3

Wednesday 15:40–17:00, Room 1021, Reinsurance and pricing

Chair: Christian Kleiber	
Enej Kovač	Prioptions: An optional feature in an XL reinsurance treaty
Mai Zhang	Optimal insurance with two-dimensional adverse selection: risk exposure and probability distortion
Kelvin Tang	Optimal relativities in a Bonus-Malus System under frequency-severity dependence and different objective functions
Wei-Hua Tian	Mispricing and insolvency risk in property-liability insurance companies: a case study of Covid-19 pandemic insurance products

Wednesday 15:40–17:00, Room 1020, Health insurance

Chair: Hailiang Yang	
Philipp Hornung	Disability model with individual and collective health claims
Laura Iveth Aburto Barrera	Cost dynamics of multimorbidity: modeling health insurance costs across disease combinations
Joakim Alderborn	Life and health insurance for a household with two members
Rosario Maggistro	Valuation of GLWB riders in variable annuities with accumulation phase and long-term care option

Wednesday 15:40–17:00, Room 1019, Climate risk II

Chair: Herve Zumbach	
Stephane Loisel	Recommendations and challenges regarding the construction of climate change impact scenarios in health and life insurance
Nien-Hsuan Tang	How voluntary climate-related and ESG disclosures shape firm efficiency: evidence from Taiwan
Ryan Dai	Multi-regional integrated assessment under jump risk anduncertainty
Zhongyi Yuan	Why insurers price carbon low: An analysis of financed emissions and investment decisions

Wednesday 15:40–17:00, Room 1018, Advances in property and casualty insurance

Chair: Roel Verbelen	
Selim Gatti	Calibration bands for mean estimates within the exponential dispersion family
Tingdi Ren	The design of optimal insurance contracts: an approach of Lipschitz neural networks
Jae Youn Ahn	Interpretable generalized coefficient models integrating deep neural networks within a state-space framework for insurance credibility
Artur Tuttar	Amputation-imputation based generation of synthetic tabular data for ratemaking

Thursday, July 3rd

KL : Keynote Lecture, Room 1037

PS : Parallel session, $n\times$ 20min

9:00–10:00 *Chair:* *Julia Eisenberg*	KL	**Carmen Boado-Penas** *Edinburgh*	Insuring the future: My journey from pension sustainability to climate action
10:00–10:30	Coffee break		
10:30–11:50	PS4	Room 1021	Risk modeling II
		Room 1020	Mortality modeling II
		Room 1019	Analysis of climate and other risks
		Room 1018	Artificial intelligence
12:00–13:30	Lunch break		
12:00–13:30	Editorial Board meeting, room 2049		
13:30–15:10	PS5	Room 1021	Risk modeling III
		Room 1020	Developments in life insurance
		Room 1019	Technical innovations in insurance
		Room 1018	Ruin probabilities
15:10–15:30	Coffee break		
15:30–16:50	PS6	Room 1021	Insurance economics and market behavior
		Room 1020	Long-term care
		Room 1019	Catastrophic and cyber risks
		Room 1018	Statistical modeling
19:00	**Conference dinner at AHHAA**		

Parallel Session 4

Thursday 10:30–11:50, Room 1021, Risk modeling II

Chair: Arnold Shapiro	
Marek Teuerle	On the ruin probability of insurer-reinsurer model for phase-type distributed losses
Yukio Muromachi	Simultaneous valuation of liabilities on a Markovian regime switching interest rate and default intensity model
Si Cheng Fong	Optimal subsampling and EM algorithms for non-Markovian semiparametric regression with interval-censored multi-state data
Marcin Szatkowski	One-year and ultimate correlations in dependent claims run-off triangles

Thursday 10:30–11:50, Room 1020, Mortality modeling II

Chair: Michel Vellekoop	
Mindaugas Venckevičius	Several facts about Theodor Wittstein, Gaetano Balducci, and some expressions of the net single premiums under their mortality assumption
Torsten Kleinow	The short-term association between environmental variables and mortality
Jens Robben	Granular mortality modeling with temperature and epidemic shocks: a three-state regime-switching approach
Mark Van Lokeren	General bounds for functionals of the lifetime, compatible with life tables

Thursday 10:30–11:50, Room 1019, Analysis of climate and other risks

Chair: Despoina Makariou	
Kwangmin Jung	Insurance stress testing of climate change risk: The case of the Korean general insurance Industry
Yanfeng Li	Dynamic financial analysis (DFA) of general insurers under climate change
Daniel Nkameni	Parametric insurance under solvency and acceptability constraints
Simona Jokubauskienė	Multivariate Hipp-type compound Poisson approximations for lattice distributions

Thursday 10:30–11:50, Room 1018, Artificial intelligence

Chair: Pierre-O Goffard	
Jing Zou	Dynamic hierarchical graph neural networks for spatiotemporal prediction of flood-related claims
Qing Cong	Reinforcement learning of equilibrium investment strategy with delay effects
Salvatore Scognamiglio	The credibility transformer
Lluis Bermudez	A data-driven xAI approach to surrender risk management

Parallel Session 5

Thursday 13:30–15:10, Room 1021, Risk modeling III

Chair: Runhuan Feng	
Martynas Manstavičius	From aggregation functions to concordance measures
Weiran Li	Extremes of extended tail Gini functionals with application in systemic risk variability control
Renata Alcoforado	Risk model with dependent frequency and severity for liability and housing insurance
Yongzhao Chen	On the diversification effect in Solvency II for extremely dependent risks
Jiajun Liu	Extremes for tail-based gini risk variability measures with varying risk preferences

Thursday 13:30–15:10, Room 1020, Developments in life insurance

Chair: Yung-Tsung Lee	
Jingwen Zhang	The pension dilemma: financial sustainability versus inter-generational equity
Luke Servat	Optimal investment for retirement with intergenerational benchmarking
An Chen	Optimal consumption under smooth ambiguity
Oytun Hacariz	On technical bases and surplus in life insurance
Rune Buckinx	Tree-based machine learning survival models for right-censored actuarial time-to-event data

Thursday 13:30–14:50, Room 1019, Technical innovations in insurance

Chair: Lluis Bermudez	
Arnold Shapiro	The technical concepts and training approaches that power GPT models
Pierre-O Goffard	Collaborative and parametric insurance on the Ethereum blockchain
Xindi Fang	Using self-assessment data in automobile insurance risk assessment with dynamic modelling
Juan Sebastian Yanez	How does granularity affect motor insurance claim predictions in a telematics setting?

Thursday 13:30–15:10, Room 1018, Ruin probabilities

Chair: Manuel Guerra	
Oscar Peralta	Hybrid risk processes: a robust framework for modern ruin problems
Zbigniew Palmowski	Fluctuations of Omega-killed level-dependent spectrallynegative L'evy processes and the probability of bankruptcy
Ruizhe Bu	Numerical analysis of ultimate ruin probability in q-scale function under a Markov-modulated jump-diffusion risk model with hyperexponential jumps
Jamsher Ali	Quantized claims in approximate calculation of ruin probability: a stability result
Dimitrios Konstantinides	Heavy-tailed random vectors: theory and applications

Parallel Session 6

Thursday 15:30–16:50, Room 1021, Insurance economics and market behavior

Chair: Qihe Tang	
Hangsuck Lee	Optimal deductible to control the loss frequency
Fotios Mourdoukoutas	Competitive insurance pricing in a duopoly
Lingjia Yan	Research on the stock price differences of cross-listed companies – taking China Life A+H+N shares as an example
Mengjia Qi	Disentangling risk and time for optimal prevention

Thursday 15:30–16:30, Room 1020, Long-term care

Chair: Rosario Maggistro	
Lucien Lorenz	On the Determinants of long-term care intensity and duration in Switzerland: New insights from random forests modeling
Shuqi Lin	Research on long-term care insurance enrollment decisions and demand stratification in China based on deep learning
Hua Zhao	The impact of wealth shocks on elderly health: Evidence from the China Health and Retirement Longitudinal Study

Thursday 15:30–16:50, Room 1019, Catastrophic and cyber risks

Chair: Kwangmin Jung	
Manuel Guerra	A Bayesian approach to catastrophic risks
Krzysztof Burnecki	Construction and pricing of multi-region CoCoCat bonds
Xinyi Wang	Optimization of credit contracts with incomplete information: equilibrium and welfare analysis Statistical and machine learning applications in insurance.
Raj Bahl	Pricing the priceless cloud insurance: an expected utility perspective

Thursday 15:30–16:50, Room 1018, Statistical modeling

Chair: Jorge Yslas	
Liang Hong	Finite-sample valid prediction of future insurance claims in the regression problem
Emilio Luis Sáenz Guillén	Non-parametric free-knot spline density and distribution estimation for heavy-tailed data
Georgios Pitselis	Credible distribution estimation with deductible, policy limit and reinsurance layers
Rita Norbutaitė	Tennis model in betting: Grand Slam analysis

Friday, July 4th

KL : Keynote Lecture, Room 1037

PS : Parallel session, $n\times$ 20min

9:00–10:00 *Chair: Sheldon Lin*	KL	**Łukasz Delong** *Warsaw*	Universal inference for testing calibration of mean predictions for Exponential Dispersion Families
10:00–10:30	Coffee break		
10:30–11:50	PS7	Room 1021	Dividend and investment analysis
		Room 1020	Pensions and retirement II
		Room 1019	Quantitative finance
		Room 1018	Dependence modeling
11:50-12:00 Room 1037	Closing		
12:00–13:30	Lunch		

Parallel Session 7

Friday 10:30–11:30, Room 1021, Dividend and investment analysis

Chair: Zbigniew Palmowski	
Julia Eisenberg	Lump sum dividends for a mean-avoiding Ornstein-Uhlenbeck process: explicit solutions
Fabio Colpo	Optimal dividends for an insurance company with an Ornstein-Uhlenbeck surplus
Sliem El Ela	Quantification of intergenerational transfers due to the solidarity reserve in the new Dutch pension contract

Friday 10:30–11:30, Room 1020, Pensions and retirement II

Chair: Fabio Viviano	
Hamza Hanbali	Early pension withdrawals and homeownership
Yitian Xu	Longevity bond pricing in pension with positive jumps
Iqbal Owadally	Life-cycle investment under subjective survival beliefs with deferred annuities, housing and home equity release
Mengyi Xu	Modeling multi-state health transitions with a most-recent-event Hawkes process

Friday 10:30–11:50, Room 1019, Quantitative finance

Chair: Hangsuck Lee	
Yuhao Liu	Pricing credit default swaps under central clearing
Axel Araneda	Consistent option-implied risk measures
Tahir Choulli	Log-optimal portfolio under regime switching mechanisms
Jayen Tan	Memory in temperature and its impacts on weather insurance and derivatives under a fractional Ornstein-Uhlenbeck process

Friday 10:30–11:50, Room 1018, Dependence modeling

Chair: Yevhen Havrylenko	
Charalampos Passalidis	Multivariate strong subexponential distributions: properties and applications
Oskar Laverny	Non-parametric estimation of net survival under dependence between death causes
Jorge Yslas	Phase-type frailty models: A flexible approach to modeling unobserved heterogeneity in survival analysis
Woongchae Yoo	Statistical learning of trade credit insurance network data with applications to ratemaking and reserving

CIBer in Action for FinTech, InsurTech, and Cyber Risk

Phillip Yam

The Chinese University of Hong Kong, scpyam@sta.cuhk.edu.hk

KL

July 2
9:30
Room 1037

Predicting frequencies and classifying severities of risks has long been of vital importance, this is a major concern in InsurTech, FinTech, and the emerging field of cyber risk security. Among widely adopted classifiers in practical use, the application of Support Vector Machine, Neural Network (e.g. MLP), Generalized Linear Models and Linear Discriminant Analysis to insurance and finance datasets would lead to a potential substantial loss of information as these datasets usually involve a lot of categorical features, yet none of these classifiers handle them comprehensively; this issue is even more alerting in cyber risk datasets, with a majority of features as categorical, including but not limited to the types of entity, breach and industry. On the other hand, Classification and Regression Tree handles categorical and discrete feature variables well enough by its design, yet its mechanism copes with continuous features indirectly. Moreover, the relatively strong dependence structures among feature variables, especially among categorical features, in insurance and financial practices have not been explicitly accounted for in these prevalent classifiers.

In this talk, we propose to effectively model an implicit strong enough dependence by comonotonicity, and perform risk classification through our newly proposed Comonotone-Independence Bayes Classifier (CIBer), this leads to a very decent clustering of the predictive feature variables. As a result, CIBer can facilitate an effective classification, and it can also be enhanced to serve as a powerful regressor against all types of feature variables. We shall demonstrate the effectiveness and resulting profitability of CIBer as a tool in data analytics against all others through the empirical studies upon several representative datasets in finance and insurance. Finally, with a commonly used Cyber Security and Data Breaches dataset, we sketch out the possible aid of CIBer in the effective modelling via superposed marked Hawkes processes for cyber risk arrivals.

Bibliography

[1] Chen, S., Cheung, K.C., Yam, P. and Fan, K. (2024). Bayesian Learning. In: Chen, S., Cheung, K.C., Yam, P. and Fan, K. (eds), *Financial Data Analytics: with Machine Learning, Optimization and Statistics*, Wiley Finance Series; John Wiley & Sons. doi:10.1002/9781119863403.ch12
CIBer won a Silver Medal at the 48th International Exhibition of Inventions Geneva in 2023, and its Python code can be found at `https://github.com/kaiser1999/CIBer`

[2] Li, Malavasi, Sun, and Yam (2025+). Effective Cyber Risk Detection via Superposed Marked Hawkes Processes. Working paper.

Insuring the future: My journey from pension sustainability to climate action

KL

July 3
9:00
Room 1037

Carmen Boado-Penas

Heriot-Watt University and the Maxwell Institute for Mathematical Sciences, Edinburgh, UK, c.boado@hw.ac.uk

Keywords: Retirement, sustainability, climate pathways, transition risks, pension adequacy

Climate change is transforming the financial risk landscape for insurers and long-term financial institutions, introducing deep uncertainties that challenge traditional actuarial models.

Pension funds, as long-term investors with significant asset volumes, are uniquely positioned to support the transition to a greener economy. Yet they are also increasingly exposed to climate-related risks, which vary greatly depending on the specific climate scenario.

In an *orderly transition* scenario, climate policies are implemented early and gradually become more stringent, leading to increased investment in green equities. In contrast, a *hot-house world* scenario assumes that too little action is taken, too late. These scenarios will differentially impact returns on carbon-intensive and green equities, ultimately affecting the amount of retirement savings and pension adequacy.

Understanding the intersection of climate change and financial systems—especially in retirement security—is becoming increasingly urgent. Climate risks have the potential to deepen existing challenges such as population ageing, lower economic growth, and rising old-age poverty.

In my talk, I will begin with a general overview of why climate change matters to both life and non-life actuaries, as well as long-term financial planners. I will then reflect on my research journey—from an early focus on pension sustainability and demographic risks in state pensions to confronting climate change as a new and systemic threat to benefit outcomes within pension systems. Finally, I will present findings from recent scenario-based analysis exploring how four key climate pathways—*Current Policies*, *Below 2°C*, *Net Zero* 2050, and *Delayed Transition*—could shape outcomes for defined contribution pension plans across different generational cohorts.

Universal inference for testing calibration of mean predictions for Exponential Dispersion Families

KL

July 4
9:00
Room 1037

Łukasz Delong

University of Warsaw, l.delong@uw.edu.pl

Calibration of mean predictions is a critical property of predictive models in statistics and actuarial science, particularly in applications like non-life insurance pricing. This presentation addresses the problem of testing calibration of mean predictions for Exponential Dispersion Families. We first survey existing approaches to evaluating forecast calibration from statistical and actuarial literature. Next, we propose a split likelihood ratio test grounded in universal inference. The null hypothesis assumes that mean predictions are calibrated and the alternative employs isotonic regression to detect miscalibration. We investigate multiple e-values formulations within the framework of universal inference, analyze their statistical power, and compare their performance to state-of-the-art methods. Our new results provide practitioners with robust tools for diagnostic calibration assessment.

List of Abstracts

The abstracts are in alphabetical order according to the name of the submitting author.

The time shown beside each abstract indicates the scheduled start time of the speaker’s session.

The link in the right-hand margin allows you to navigate back to the session or daily schedule.

Cost dynamics of multimorbidity: modeling health insurance costs across disease combinations

PS3

July 2
15:40

Laura Iveth Aburto Barrera[1] **and Joël Wagner**[2]

[1]*Department of Actuarial Science, Faculty of Business and Economics (HEC), University of Lausanne, Lausanne, Switzerland, lauraiveth.aburtobarrera@unil.ch*
[2]*Department of Actuarial Science, Faculty of Business and Economics (HEC), University of Lausanne, Lausanne, Switzerland, joel.wagner@unil.ch*

Keywords: multimorbidity, health insurance modeling, outpatient costs, quantile regression, insured costs

Multimorbidity, the co-occurrence of multiple long-term health conditions in an individual, represents a considerable economic burden on healthcare systems, health insurers, and society. This burden is exacerbated by increased healthcare utilization and the complex cost interactions among specific disease combinations, particularly in older adults. Traditional cost estimation approaches primarily focus on individual diseases, often overlooking the compounded effects of multimorbidity, which lead to costs that go beyond simple additive estimates. Our study aims to model the impact of multimorbidity on health insurance costs by analyzing cost variations across different multimorbidity states, pharmacy cost group (PCG) combinations, age groups and gender. Using a large dataset of health insurance claims, we assess how an increasing number of PCGs influences healthcare expenditures and examine variations in the conditional distribution of average outpatient costs by multimorbidity patterns. Additionally, we investigate the role of aging and gender in driving healthcare costs in multimorbid people. By providing a more nuanced understanding of cost dynamics, our findings offer valuable insights for policymakers, health insurers, and healthcare providers, enabling more effective resource allocation, prevention strategies, and interventions tailored to the needs of diverse morbidity groups.

Interpretable generalized coefficient models integrating deep neural networks within a state-space framework for insurance credibility

PS3

July 2
15:40

Jae Youn Ahn

Ewha Womans University

Credibility methods in insurance provide a linear approximation, formulated as a weighted average of claim history, making them highly interpretable for estimating the predictive mean of the a posteriori rate. In this presentation, we extend the credibility method to a generalized coefficient regression model, where credibility factors—interpreted as regression coefficients—are modeled as flexible functions of claim history. This extension, structurally similar to the attention mechanism, enhances both predictive accuracy and interpretability. A key challenge in such models is the potential issue of non-identifiability, where credibility factors may not be uniquely determined. Without ensuring the identifiability of the generalized coefficients, their interpretability remains uncertain. To address this, we first introduce a state-space model (SSM) whose predictive mean has a closed-form expression. We then extend this framework by incorporating neural networks, allowing the predictive mean to be expressed in a closed-form representation of generalized coefficients. We demonstrate that this model guarantees the identifiability of the generalized coefficients. As a result, the proposed model not only offers flexible estimates of future risk—matching the expressive power of neural networks—but also ensures an interpretable representation of credibility factors, with identifiability rigorously established. This presentation is based on joint work with Mario Wüthrich (ETH Zürich) and Hong Beng Lim (Chinese University of Hong Kong).

Risk model with dependent frequency and severity for liability and housing insurance

PS5

July 3
13:30

Renata G. Alcoforado[1, 2, 4], **Alfredo D. Egídio dos Reis**[2] **and Denys Pommeret**[3, 4]

[1]*Department of Accounting and Actuarial Science, Universidade Federal de Pernambuco, Brazil, alcoforado.renata@ufpe.br*

[2]*ISEG & CEMAPRE, Universidade de Lisboa, Portugal, alfredo@iseg.ulisboa.pt*

[3]*Aix-Marseille Université - Institut de Mathématiques de Marseille (I2M), France, denys.pommeret@univ-amu.fr*

[4]*Chaire d'Excellence "ACTIONS" (Actuaries for Change in Technologies and Insurees Opportunities for Next Steps), France*

Keywords: dependent risks, insurance risk model, liability insurance, housing insurance, real data application, GAMLSS modeling

A common assumption in classical risk theory is the independence of "claim counts" and "claim severity," though this is often unrealistic. Recent studies have introduced dependence modeling, notably in motor insurance [3], [2], and [5]. Other works [1], [Andrade e Silva and Centeno, 2017], and [4] apply copulas and GLM to capture this dependence.

We analyze a real dataset of 15,665 claims dated from 01/01/2015 to 31/12/2019 from housing and liability insurance made available by an anonymous insurer. We search for dependence between claim counts and severity, as well as dependence across groups. Our database has the novelty of not coming from automobile insurance; it brings different challenges. We fitted the data using Poisson-Inverse Gaussian, Negative Binomial, Weibull, and Log-Normal distributions.

As a result, we were able to detect dependence, then we go beyond mean modelling and, using GAMLSS models, we show that in housing insurance, severity decreases as claim frequency increases, contrary to [2], who found a positive relationship in the USA. In liability insurance, severity increases with claim frequency. Finally, we make some conjectures about why this might happen.

Bibliography

[1] Albrecher, H., Constantinescu, C., and Loisel, S. (2011). Explicit ruin formulas for models with dependence among risks. *Insurance: Mathematics and Economics*, 48(2):265–270.

[Andrade e Silva and Centeno, 2017] Andrade e Silva, J. and Centeno, L. (2017). Ratemaking of Dependent Risks. *ASTIN Bulletin*, 47(3):875–894.

[2] Garrido, J., Genest, C., and Schulz, J. (2016). Generalized linear models for dependent frequency and severity of insurance claims. *Insurance: Mathematics and Economics*, 70:205–215.

[3] Li, B., Ni, W., and Constantinescu, C. (2015). Risk models with premiums adjusted to claims number. *Insurance : Mathematics and Economics*, 65(2015):94–102.

[4] Moura, A. and Centeno, L. (2020). Optimal Reinsurance of Dependent Risks. *Forthcoming: REVSTAT, https://www.ine.pt/revstat/pdf/OptimalReinsuranceofDependentRisks.pdf*.

[5] Ni, W., Constantinescu, C., Egidio dos Reis, A. D., and Maume-Deschamps, V. (2020). Pricing foreseeable and unforeseeable risks in insurance portfolios. *Working Papers, https://arxiv.org/pdf/2008.03123.pdf*.

Life and health insurance for a household with two members

PS3

July 2
15:40

Joakim Alderborn

Universitat de Barcelona

Keywords: life insurance, health insurance, life-cycle models, dynamic programming

I build a model of optimal consumption, investment, life insurance and health insurance in continuous time for a household with two members. The model builds upon earlier contributions in the literature of life and health insurance, in particular on [1] and [2].

I first derive an explicit analytic cooperative solution by using a mathematical framework in which the household can ensure itself against transition to any potential future health state. I then do numerical simulations to investigate parameter sensitivity and the average behavior of a population of households. One of the findings is that the household uses life insurance premiums as a means to finance health insurance premiums. The intuition behind this behavior is that the household would rather invest money in a potential future in which both members are alive than in a potential future in which one of them is dead.

The model is quite general and contains within it several simpler models that can easily be obtained by removing some of the building blocks, such as one of the agents, life insurance or health insurance. The mathematical framework that I use can also be applied to other situations in which agents transition between many different states at random times.

Bibliography

[1] Hambel, C., Kraft, H., Schendel, L.S. and Steffensen, M, 2017. Life insurance demand under health shock risk. The Journal of Risk and Insurance, volume 84, pages 1171-1202.

[2] Wang, T. and Chen, Z., 2024. Optimal portfolio and insurance strategy with biometric risks, habit formation and smooth ambiguity. Insurance: Mathematics and Economics 118, 195-222.

Quantized claims in approximate calculation of ruin probability: a stability result

PS5

July 3
13:30

Mohammad Jamsher Ali[1] **and Kalev Pärna**[1]

[1] *University of Tartu, Estonia, jamsher.ali@ut.ee, kalev.parna@ut.ee*

Keywords: risk process, ruin probability, Cramér-Lundberg asymptotic formula, phase type distribution, quantization

In ruin theory, exact solutions are the exception rather than the rule, making the development of approximation methods increasingly important. In this paper, we investigate the optimal quantization of claim sizes for the approximate calculation of ruin probabilities in the classical risk process. In the quantization step, the original claim sizes are replaced with discrete counterparts - referred to as *quantized* claims - which take on only K possible values chosen to minimize the mean squared error relative to the original claims [1]. We demonstrate how these quantized claims can be employed in conjunction with the well-known Cramér-Lundberg (CL) asymptotic formula. It is shown that as K approaches infinity, the approximate ruin probability obtained using the CL formula for the quantized risk process converges to the ruin probability of the original process. This convergence is illustrated through two numerical examples in which the original claims follow a phase-type distribution.

Bibliography

[1] Gersho, A. and Gray, R.M. (1992). *Vector Quantization and Signal Compression*. Kluwer, Boston.

Rethinking actuarial education in a global world: the role of actuarial education companies

PS2

July 2
14:00

Joana Amorim[1]

[1]*ACTEX Learning, US, joana@actexlearning.com*

Keywords: actuarial education, faculty development, affordability, accessibility

The actuarial profession is increasingly central to the global dialogue on creating a more equitable and sustainable world. The United Nations Development Program (UNDP), which works worldwide to eradicate poverty and reduce inequality, has identified the insurance sector as a key factor in achieving their Sustainable Development Goals (SDG). Insurance and risk protection mechanisms directly support six SDGs and are crucial to the successful implementation of five others.

At the heart of this dialogue is actuarial education. At ACTEX Learning, a leading global provider of actuarial education, we believe that Actuarial Education Companies (AECs) play a pivotal role in shaping a better future. In this presentation, we will discuss our approach to actuarial education within this global context, with a particular emphasis on the importance of partnerships. We will share case studies of successful programs that illustrate ways to achieve this mission, expanding affordability. In particular, we will share the impact of the first cohort of the Actuarial Faculty Development Program (AFDP), a program launched in 2024 with the GAIN Milliman-UNDP Initiative support and discuss how academics can get involved with it.

Consistent option-implied risk measures

PS7

July 4
10:30

Axel A. Araneda[1,2]

[1]*Masaryk University, Czechia, axelaraneda@mail.muni.cz*
[2]*University of Eastern Finland, Finland.*

Keywords: value-at-risk, expected shortfall, tail behavior, option pricing, quantile formula, continuous-time models, anomalous diffusion

Tail risk measures are key variables in risk management since they evaluate the potential losses for a certain threshold & time horizon. These indicators can be deducted from option quotes reflecting the market estimation for the quantile function. A non-parametric approach usually leads to some deficiencies and then a pre-assumed price dynamics is required matching the theoretical with the empirical risk-neutral distribution, and the consequent computation of the required percentile. However, the observation of fat tails and the term-structure of the implied volatility promote the use of alternative diffusion models where the volatility i) increases for lower strike prices and ii) scales differently to the square root rule. The computation of analytical pricing & quantile formulas for price models driven by anomalous diffusion, plus the calibration of a unique set of parameters will return robust tail-risk estimators offering consistent results to different levels of confidence and horizons.

Pricing the priceless cloud insurance: an expected utility perspective

PS6
July 3
15:30

Raj Kumari Bahl[1]

[1]*Department of Statistics, Ramjas College, University of Delhi, India, rajkumaribahl@ramjas.du.ac.in*

Keywords: cloud insurance, expected utility criterion, CARA, exponential utility function, loss distributions

In the modern times, life is unimaginable without the cloud. From governments to individuals, from military operations to apparel listing, from educational institutions to fashion houses, from air force to marine operations and shipping, all rely strongly on the cloud. With such strong dependence also come along massive challenges in the form of cyber threats such as cloud outages, ransomware attacks, espionage attempts, data breaches, hacking, cyber thefts, the list is so long that cyber losses are now being treated on the scale of a catastrophe. As a result, the need of the hour is to build resilient systems for cloud computing for smooth functioning of day to day life. An obvious methodology to cover up losses is to resort to insurance. However the insurer has to be alert enough to survey the cyber landscape to price such novel cloud insurance policies. In our approach we introduce a methodology by which the insurer can determine the exact premium based on the 'Expected Utility Criterion' and 'Constant Absolute Risk Aversion (CARA)'. Our research points out serious drawbacks including underestimation of premium in the earlier approaches and fills the gaps in the scanty literature on cloud insurance. Backtesting of this new strategy is then done for a plethora of loss distributions employed in insurance to obtain magnificent results.

A data-driven xAI approach to surrender risk management

PS4
July 3
10:30

Lluís Bermúdez[1], **David Anaya**[1] **and Jaume Belles-Sampera**[2]

[1]*Riskcenter-IREA, Universitat de Barcelona, Spain, lbermudez@ub.edu*
[2]*Riskcenter-IREA and Grupo Catalana Occidente, S.A., Spain*

Keywords: machine learning, Shapley values, Kohonen neural network, rare events, risk mitigation

Explainable Artificial Intelligence (xAI) is essential for improving transparency and understanding in black-box Machine Learning (ML) models. This study explores various xAI methodologies to equip risk managers with practical tools for model interpretation. To illustrate these concepts, we present a case study on managing surrender risk in insurance savings products. Using real-world data from universal life policies, we fitted several tree-based models to assess surrender risk. We applied a range of xAI techniques, including an innovative Kohonen Neural Network (KNN) approach leveraging Shapley values, to gain deeper insights into the decision-making process of our tree-based models and to facilitate the identification of groups with similar risk characteristics that can also require similar mitigation risk strategies. Finally, we examine various risk profiles within the portfolio to demonstrate how xAI-driven insights help insurers enhance their risk management strategies.

Tree-based machine learning survival models for right-censored actuarial time-to-event data

PS5

July 3
13:30

Rune Buckinx[1], **Katrien Antonio**[2], **Marie-Pier Côté**[3], **Ingrid Van Keilegom**[4]

[1]*KU Leuven, Belgium, rune.buckinx@kuleuven.be*
[2]*KU Leuven, Belgium & University of Amsterdam, The Netherlands, katrien.antonio@kuleuven.be*
[3]*Université Laval, Canada, marie-pier.cote@act.ulaval.ca*
[4]*KU Leuven, Belgium, ingrid.vankeilegom@kuleuven.be*

Keywords: tree-based machine learning, survival analysis, right-censored data

Tree-based machine learning methods are widely used in insurance applications with structured data. However, classical implementations of these tools are not directly applicable to modeling time-to-event outcomes, as they are often subject to censoring. Our study starts with classical time-to-event models, the Kaplan-Meier estimator and (regularized) Cox proportional hazard model, and proceeds to more flexible tree-based survival models tailored to continuous-time data with many explanatory variables, such as survival trees, random survival forests and gradient boosting. We contribute to the actuarial literature by evaluating these models in an insurance case study. We assess model performance on both discrimination and calibration metrics, and provide visualizations to obtain insights in the model predictions. Our results show that while tree-based machine learning methods do not always outperform classic models, they offer added value through their ability to uncover non-linear effects, and interactions.

Numerical analysis of ultimate ruin probability in q-scale function under a Markov-modulated jump-diffusion risk model with hyperexponential jumps

PS5

July 3
13:30

Ruizhe Bu[1] **and Zhengjun Jiang**[2]

[1]*Beijing Normal-Hong Kong Baptist University, China, buruizhe@uic.edu.cn*
[2]*Beijing Normal-Hong Kong Baptist University, China, zhengjunjiang@uic.edu.cn*

Keywords: Markov-modulated jump-diffusion risk model, ultimate ruin probability, banach contraction principle, q-scale function

The paper studies ultimate ruin probability that ruin time is finite for an insurance company with its risk reserves governed by a Markov-modulated jump-diffusion risk model with hyperexponential jumps. By using q-scale function and the method of Gajek and Rudź [1], the paper confirms that the ultimate ruin probability is indeed the unique fixed point of a contraction mapping with a closed-form Lipschitz constant and can be approximated via an iterative equation. Finally, we use a numerical example to show how to get regime-switching ruin probabilities by using the highly efficient iterative algorithm in MATLAB and then conduct a sensitivity analysis of regime- switching ruin probabilities to every parameter.

Bibliography

[1] Gajek, L. and Rudź, M (2018).Banach contraction principle and ruin probabilities in regime-switching models. *Insurance: Mathematics and Economics*. 80, 45–53.

Construction and pricing of multi-region CoCoCat bonds

PS6
July 3
15:30

Krzysztof Burnecki, Jacek Wszoła, Marek Teuerle and Martyna Zdeb

Wrocław University of Science and Technology, Poland, krzysztof.burnecki@pwr.edu.pl, jacek.wszola@pwr.edu.pl, marek.teuerle@pwr.edu.pl, martyna.zdeb@pwr.edu.pl

Keywords: natural catastrophe, catastrophe bond, contingent convertible bond, multidimensional risk assessment

We introduce a novel, multidimensional insurance-linked instrument: a contingent convertible bond (CoCoCat bond) whose conversion trigger is activated by predefined natural catastrophes across multiple geographical regions. We develop such a model, explicitly accounting for the complex dependencies between regional catastrophe losses. Specifically, we explore scenarios ranging from complete independence to proportional loss dependencies, both with fixed and random loss amounts. Utilizing change-of-measure techniques, we derive risk-neutral pricing formulas tailored to these varied dependence structures. By fitting our model to real-world natural catastrophe data from Property Claim Services, we demonstrate the significant impact of inter-regional dependencies on the CoCoCat bond's pricing, highlighting the importance of multidimensional risk assessment for this innovative financial instrument.

Optimal consumption under smooth ambiguity

PS5
July 3
13:30

An Chen[1] **and Shihao Zhu**[2]

[1]*Ulm University, Germany, an.chen@uni-ulm.de*
[2] *Ulm University, Germany, shihao.zhu@uni-ulm.de*

Keywords: contingent consumer choice, life insurance decisions, life annuity, irreplaceable commodities, ambiguity aversion

We examine an individual's contingent consumption plan in an ambiguous environment where the probability of state occurrences is uncertain, and utility depends on the state. Our analysis underscores the critical roles of ambiguity aversion in both atemporal and intertemporal smooth ambiguity models—specifically, in shifting the prior distribution and adjusting the discount factor. We provide a clear economic mechanism to explain how ambiguity aversion influences optimal consumption plans by analyzing its various effects. In particular, we establish clear-cut sufficient conditions that precisely characterize these effects, including how to define a worse prior in atemporal models and how to address the added complexity caused by shifts in consumption across time in intertemporal decisions. To demonstrate the practical significance of our findings, we apply them to key decision-making scenarios, such as life insurance (mortality risk), insurance for irreplaceable goods (e.g., health risks), and life annuities (longevity risk).

On the diversification effect in Solvency II for extremely dependent risks

PS5
July 3
13:30

Yongzhao Chen[1], **Ka Chun Cheung**[2], **Sheung Chi Phillip Yam**[3], **Fei Lung Yuen**[4] **and Jia Zeng**[5]

[1]*Hang Seng University of Hong Kong, Hong Kong SAR, China, ychen@hsu.edu.hk*
[2]*University of Hong Kong, Hong Kong SAR, China, kccg@hku.hk*
[3]*Chinese University of Hong Kong, Hong Kong SAR, China, scpyam@sta.cuhk.edu.hk*
[4]*University of Kent, United Kingdom, k.yuen@kent.ac.uk*
[5]*Meituan, niversity of Hong Kong, Hong Kong SAR, China, jiazeng@connect.hku.hk*

Keywords: diversification, extreme-value copula, spectral measure, Solvency II, Value-at-Risk

In this talk, we investigate the validity of diversification effect under extreme-value copulas, when the marginal risks of the portfolio are identically distributed, which can be any one having a finite endpoint or belonging to one of the three maximum domains of attraction. We show that Value-at-Risk (V@R) under extreme-value copulas is asymptotically subadditive for marginal risks with finite mean, while it is asymptotically superadditive for risks with infinite mean. Our major findings enrich and supplement the context of the second fundamental theorem of quantitative risk management in existing literature, which states that V@R of a portfolio is typically non-subadditive for non-elliptically distributed risk vectors. In particular, we now pin down when the V@R is super or subadditive depending on the heaviness of the marginal tail risk. According to our results, one can take advantages from the diversification effect for marginal risks with finite mean. This justifies the standard formula for calculating the capital requirement under Solvency II in which imperfect correlations are used for various risk exposures.

Value of Chapter 11 reorganization

PS2

July 2
14:00

Zhen Dong Chen[1], **Yang Shen**[1], **and Qihe Tang**[1]

[1]*UNSW Sydney, Australia, zhen.chen@unsw.edu.au*
[1]*UNSW Sydney, Australia, y.shen@unsw.edu.au*
[1]*UNSW Sydney, Australia, qihe.tang@unsw.edu.au*

Keywords: credit risk, default intensity, corporate bankruptcy

In 2020 alone, U.S. bankruptcy courts received approximately 22,000 business bankruptcy filings, with most companies filing for reorganization or liquidation. We investigate whether creditors genuinely benefit from reorganization during a default event, given the competing interests of equity holders and creditors. Both structural and reduced-form models are commonly used in the literature to analyze bankruptcy procedures, each offering distinct advantages in interpretability and tractability. Traditional structural models implicitly assume that a firm's financial information is fully available. In reality, however, much of this information remains unobservable to creditors, rendering the default time inaccessible to them. As a result, researchers often resort to reduced-form models. In this paper, we develop a hybrid model to assess the added value of potential reorganization to creditors. In doing so, we identify conditions under which creditors benefit from a firm's decision to enter reorganization upon default. Extensive numerical studies are conducted to illustrate our theoretical findings.

Insurance decisions under the threat of natural disasters

PS1

July 2
11:00

Yi-Fan Chen[1], **Jin-Lung Peng**[1], **Yen-Chih Chen**[2], **and Chen-Hsu Liao**[1]

[1]*Department of Risk Management and Insurance, National Chengchi University*
[2]*The Bachelor's Degree Program in Financial Engineering and Actuarial Science, Feng Chia University, Taiwan*

Keywords: natural disasters, risk perception, insurance purchasing decision, insurance amount

This study aims to determine the impact of natural disasters on individuals' insurance decisions. Based on actual insurance company data in Taiwan, we investigate whether natural disasters influence insurance purchase behavior by utilizing detailed information on insurance contracts. We find that natural disasters lead to a significant increase in the amount of insurance coverage purchased by policyholders. However, this effect tends to diminish over time. This result implies that risk perceptions are affected after a natural disaster, deepening our anxiety about future losses and increasing the amount of insurance. Then, we also find that responses to natural disasters vary depending on different psychological resilience between different residential area, occupations and early-life disasters experience. Moreover, different types of natural disasters elicit different reactions. Our results provide new evidence on the relationship between insurance amounts and natural disasters and reveal impacts from different natural disaster events.

Log-optimal portfolio under regime switching mechanisms

Tahir Choulli and Xunbai Yin

University of Alberta, Edmonton,Canada, tchoulli@ualberta.ca, xunbai@ualberta.ca

PS7

July 4
10:30

Keywords: log-optimal portfolio, Numéraire portfolio, regime switching, semimartingale characterization, deflators, jump-diffusion models, continuous-time Markov chain

In this paper, we consider a filtered probability space $(\Omega, \mathcal{F}, \mathbb{F}, \mathbb{P})$. On this stochastic basis, we consider given a pair $(\mathbb{X}, \alpha)$ of family of processes. Here, $\mathbb{X}$ is a finite family of some "generalized" jump-diffusion processes, while α is a continuous-time Markov Chain (CTMC hereafter for short). Precisely, $\mathbb{X} := (X^{(l)})_{l=1,...,D}$ represents D ($D \geq 2$) non-switching markets such that, for any $l \in \{1, ..., D\}$, $X^{(l)}$ is described by the following dynamics:

$$X^{(l)} = \mu_l \cdot t + \sigma_l \cdot W + \zeta_l \cdot \widetilde{N}_l, \tag{1}$$

where $\widetilde{N}_l := (N_{l1} - \int_0^{\cdot} \lambda_1(l)du, N_{l2} - \int_0^{\cdot} \lambda_2(l)du, ..., N_{ln_2} - \int_0^{\cdot} \lambda_{n_2}(l)du)^{tr}$ is an n_2-variate compensated Poisson process. The CTMC process $\alpha := (\alpha(t))_{t\geq 0}$ indicates the macroeconomic market conditions, and models *the regime switching regime* that will be considered throughout the paper. Hence, α is $\mathbb{F}$-adapted, RCLL, and takes values in $\{1, 2..., D\}$. Then the resulting regime-switching-market-model (RSJD model hereafter for short) considered takes the form of

$$S^{(\alpha)} = S(0) + \mathbf{diag}(S^{(\alpha)}_-) \cdot X^{(\alpha)}, \qquad \begin{aligned} X^{(\alpha)} &= (X_1^{(\alpha)}, X_2^{(\alpha)}, ...X_d^{(\alpha)})^{tr} \\ &= \mu_\alpha \cdot t + \sigma_\alpha \cdot W + \zeta_\alpha \cdot \widetilde{N}_\alpha + \gamma_\alpha \cdot \widetilde{J} \end{aligned}$$

Here, $\widetilde{J}$ is a compensated process of J, with respect to the natural filtration of α, while J a process that counts the number of transitions into states. In our RSJD model, the regime switching effects are numerous and are present in many places in the model as it can be seen in the equation above. Therefore, our RSJD model covers many switching models of the literature, namely it covers the models [3]), [2], [4], and beyond to cite a few.

For the resulting RSJD model $(\mathbb{X}, \alpha)$, we study the numéraire and log-optimal portfolios in different manners, and describe their computations in terms of the parameters our RSJD model. In particular, we single out the types of risks induced by the stochasticity of the regime swithcing α that really affect the numéraire portfolio, and address the the following: 1) What are the conditions on α (preferably in terms of information theoretic concepts such as entropy) and/or on the non-switching model $\mathbb{X}$ that guarantee the existence of log-optimal portfolio of $(\mathbb{X}, \alpha)$? 2) What are the factors that fully determine *the increment in maximum expected logarithmic utility from terminal wealth* for the RSJD model $S^{(\alpha)}$ and $S^{(1)}$? Herein, the non-switching model at sate one is considered as the initial state of our regime switching system. How to quantify these factors, and how to economically interpret them? This talk is based on the join paper [1].

Bibliography

[1] Choulli, T. and Yin, Xunbai (2024). Log-optimal portfolio for market models with regime switching. *preprint*.

[2] Naik, V. (1993). Option valuation and hedging strategies with jumps in the volatility of asset returns. *The Journal of Finance*, 48(5), 1969-1984.

[3] Norberg, R. (2003). The Markov chain market. . *ASTIN Bulletin: The Journal of the IAA*, 33(2), 265-287.

[4] Siu, T. K., and Elliott, R. J. (2022). American option pricing and filtering with a hidden regime-switching jump diffusion. *The Journal of Derivatives*, 29(3), 106-123

Optimal dividends for an insurance company with an Ornstein-Uhlenbeck surplus

PS7

July 4
10:30

Fabio Colpo[1] **and Julia Eisenberg**[2]

[1]*TU Wien, Austria, fabio.colpo@tuwien.ac.at*
[2]*TU Wien, Austria, julia.eisenberg@tuwien.ac.at*

Keywords: optimal control, optimal dividends, HJB, Ornstein-Uhlenbeck

We consider an insurance company whose surplus follows an Ornstein-Uhlenbeck (OU) process driven by a standard Brownian motion. The company pays dividends to its shareholders and seeks to maximise the expected value of the future discounted dividends. Late dividend payments are penalised/rewarded not only through the usual discounting, but through an additional exponential factor.

We find the optimal strategy for the case of mean-reverting and non-mean-reverting OU processes and illustrate our findings by a numerical example.

Joint work with Julia Eisenberg.

Bibliography

[1] S. Asmussen and M. Taksar (1997). Controlled diffusion models for optimal dividend pay-out. *Insurance: Mathematics and Economics* 20(1):1–15.

[2] B. Avanzi and B. Wong (2012). On a mean reverting dividend strategy with Brownian motion. *Insurance: Mathematics and Economics* 51(2):229–238.

[3] A. N. Borodin and P. Salminen (2012). *Handbook of Brownian motion-facts and formulae*. Birkhäuser.

[4] J. Eisenberg (2018). Unrestricted consumption under a deterministic wealth and an Ornstein– Uhlenbeck process as a discount rate. *Stochastic models* 34(2):139–153.

[5] F. Locas and J.-F. Renaud (2024). De Finetti's control problem with a concave bound on the control rate. *Journal of Applied Probability* pages 1–17.

[6] S. E. Shreve, J. P. Lehoczky, and D. P. Gaver (1984). Optimal consumption for general diffusions with absorbing and reflecting barriers. *SIAM Journal on Control and Optimization* 22(1):55–75.

Reinforcement learning of equilibrium investment strategy with delay effects

PS4
July 3
10:30

Qing Cong[1], **Mei Choi Chiu**[2], **Hoi Ying Wong**[3]

[1]*The Chinese University of Hong Kong, Hong Kong, qingcong@link.cuhk.edu.hk*
[2]*The Education University of Hong Kong, Hong Kong, mcchiu@eduhk.hk*
[3]*The Chinese University of Hong Kong, Hong Kong, hywong@cuhk.edu.hk*

Keywords: reinforcement learning, spike variation, equilibrium strategy, path-dependent effect, time-inconsistency

Reinforcement learning (RL) enables agents to learn sequential decision-making policies through environment interaction to maximize rewards. While RL has shown promise in quantitative finance for modeling nonlinear, non-stationary market dynamics, most existing continuous-time RL methods — such as q-learning [4] — depend on the dynamic programming principle (DPP), which fundamentally requires Markovian state transitions. However, financial systems often exhibit non-Markovian behaviors (e.g., path-dependent options, delayed information), undermining the performance of continuous-time DPP-based RL frameworks in real-world investment scenarios. To address the time-inconsistency, we propose a DPP-free paradigm inspired by subgame perfect Nash equilibrium (SPNE), where an investor's current and future selves coordinate to derive time-consistent strategies. Using spike variation techniques, we integrate RL with state-dependent mean-variance optimization, deriving equilibrium investment strategies under non-Markovian dynamics. Theoretical analysis establishes equilibrium existence under non-Markovian dynamics, while numerical experiments demonstrate robust performance in path-dependent environments with delayed feedback. This work unifies RL and stochastic control, expanding the theoretical toolkit for financial decision-making beyond Markovian assumptions.

Bibliography

[1] Dai, M., Dong, Y., Jia, Y. (2023). Learning equilibrium mean-variance strategy. *Mathematical Finance*, 33(4), 1166-1212.

[2] Hu, Y., Jin, H., Zhou, X. Y. (2012). Time-inconsistent stochastic linear–quadratic control. *SIAM journal on Control and Optimization*, 50(3), 1548-1572.

[3] Hu, Y., Jin, H., Zhou, X. Y. (2017). Time-inconsistent stochastic linear-quadratic control: Characterization and uniqueness of equilibrium. *SIAM Journal on Control and Optimization*, 55(2), 1261-1279.

[4] Jia, Y., Zhou, X. Y. (2023). q-Learning in continuous time. *Journal of Machine Learning Research*, 24(161), 1-61.

[5] Wang, T., Yong, J. (2023). Spike variations for stochastic Volterra integral equations. *SIAM Journal on Control and Optimization*, 61(6), 3608-3634.

Multi-regional integrated assessment under jump risk and uncertainty

PS3

July 2
15:40

Ryan Dai[1] **and Qihe Tang**[2]

[1] *UNSW, Australia, ryan.dai@unsw.edu.au*
[2]*UNSW, Australia, qihe.tang@unsw.edu.au*

Keywords: climate change, weather disasters, adaptation, mitigation, uncertainty, social cost of carbon

The world we live in is undergoing rapid and unprecedented changes, fraught with multi-layered uncertainties. One of the driving forces behind this is climate change. Adaptation and mitigation are two commonly used approaches for combating climate change. We consider a regional integrated climate-economy (RICE) model in which climate damages are categorized into chronic and acute ones. Regions highly vulnerable to climate disasters often prioritize adaptation over mitigation, which reduces global efforts to combat climate change. We derive the optimal regional adaptation and mitigation expenditures under this RICE model. In doing so, we account for multi-layered uncertainties, which raise both adaptation and mitigation expenditures and increase the global social cost of carbon. Extensive numerical studies are conducted to illustrate our theoretical findings.

Optimal investment–consumption and tax-favored private defined-contribution pension decision

PS2

July 2
14:00

Qixin Deng[1], **Hao Zhou**[2], **Jingzhen Liu** [1], **Jiaqin Wei** [3]

[1]*Central University of Finance and Economics, Beijing, China*
[2]*Renmin University of China, Beijing, China*
[3]*East China Normal University, Shanghai, China*

Keywords: defined-contribution pension scheme, tax incentive, asset allocation, martingale approach

This paper examines the optimal investment–consumption problem while considering a tax-favored private defined-contribution pension scheme that encourages individuals to participate in the scheme and allows them to invest risky assets in the pension account. This paper considers an individual's regular investment, private pension investment, consumption, and pension contribution decisions. To illustrate the role of tax incentives in pension contribution decisions, a continuous tax function concerning the individual's wage income is introduced. The optimal problems with two types of terminal utilities are solved using the martingale approach, and analytical solutions under constant relative risk-aversion utility are derived. Moreover, we conduct numerical experiments to investigate the effects of different parameters and compare our pension models with the classic Merton model. Whether the pension scheme member considers their regular and pension accounts as a single or two separate accounts determines their decisions, especially their consumption and pension contribution decisions.

Lump sum dividends for a mean-avoiding Ornstein-Uhlenbeck process: explicit solutions

PS7

July 4
10:30

Julia Eisenberg[1] **and Fabio Colpo**[2]

[1]*TU Wien, Austria, jeisenbe@fam.tuwien.ac.at*
[2]*TU Wien, Austria, fcolpo@fam.tuwien.ac.at*

Keywords: optimal dividends, mean-avoiding Ornstein-Uhlenbeck process, parabolic cylinder functions, Kummer functions

We consider an insurance company who models its surplus by a mean-avoiding Ornstein-Uhlenbeck (OU) process. The company seeks to maximise the value of expected discounted, with a constant discounting rate, dividends paid up to the time of ruin. One has to distinguish between three different cases, where: the speed of the OU process is smaller, equal or bigger than the discounting rate.
In the first case, we explicitly determine the value function and the optimal strategy. In the second case, the value function is finite only if the volatility is small enough, whereas the optimal strategy doesn't exist. In the third case, the value function is infinite.

Quantification of intergenerational transfers due to the solidarity reserve in the new Dutch pension contract

PS7

July 4
10:30

Sliem el Ela [1], **Servaas van Bilsen** [2], **Roel Mehlkopf** [3] **and Stephan van Stalborch** [4]

[1] *University of Amsterdam, RCLR, Netspar, The Netherlands, s.h.e.elela@uva.nl*
[2] *University of Amsterdam, Netspar, The Netherlands, s.vanbilsen@uva.nl*
[3] *Tilburg University, Cardano, The Netherlands, r.mehlkopf@cardano.com*
[4] *Actuarial Society of the Netherlands, The Netherlands, stephan_vs@hotmail.com*

Keywords: duration puzzle, lifecycle theory, retirement investment, solidarity reserve, intergenerational transfers, value-based generational accounting, redistribution financing, Dutch pension system, new pension contract, actuarial analysis

The solidarity reserve is a new instrument within the new Dutch pension system. Most pension funds intend to use the solidarity reserve to avoid nominal reductions in current pension payments as much as possible ([1]). Many pension funds plan to implement a structure where all age groups contribute to the solidarity reserve, but mainly retirees receive payouts from it. This approach appears to involve a structural "redistribution" of financial resources from active workers to retirees—essentially, a redistribution element. This paper provides a quantitative analysis of the research question: does the solidarity reserve exhibit characteristics of redistribution financing, and if so, what is the quantitative magnitude of these effects? We use the value-based generational accounting method. For each age group, we quantify the value of contributions to the solidarity reserve over their lifetime ("ex ante") and compare this to the value of payouts from the reserve over their lifetime. This paper presents results for various scenarios and examines sensitivity to different fund characteristics, such as the age composition of participants and the chosen investment strategy.

Bibliography

[1] de Groot, C. and Bakker, M. (2022). *Hogere en stabielere pensioenen dankzij solidariteitsreserve*, `https://www.ortecfinance.com/nl-nl/insights/blog/hogere-en-stabielere-pensioenen-dankzij-solidariteitsreserve`, Ortec Finance.

Using self-assessment data in automobile insurance risk assessment with dynamic modelling

PS5

July 3
13:30

Xindi Fang[1], **David Pitt, Xueyuan Wu**

[1]*University of Melbourne, Australia, xindif1@student.unimelb.edu.au*

Keywords: usage-based insurance, self-assessment, telematics, glm, gbm, cann, dynamic modelling

We present an improved risk assessment process for usage-based auto insurance that incorporates driver self-assessed risk perceptions alongside telematics data to improve risk frequency modelling. In the modelling set-up, a conventional GLM is used as the foundational "base rate" model, ensuring stability and interpretability in line with industry standards. Following that, we employ advanced predictive models, specifically Gradient Boosting Machines (GBM) and Combined Actuarial Neural Network (CANN) in the model, to facilitate a discounting or rewarding scheme with the self-risk assessments. These self-reported risk indicators, together with traditional rating factors, inform the initial underwriting decision and pricing. As the policy progresses, the process then sequentially evolves to telematics-based evaluation: rectifies the initial estimates with actual driving data captured by onboard devices. This ongoing risk assessment process incrementally updates the risk frequency model, refines pricing methods according to data accessibility and availability, and systematically breaks down the operational framework of usage-based insurance. Using the SHRP2 Naturalistic Driving Behavior Dataset, our dynamic modelling approach outperforms the baseline GLM, achieving a 42% improvement in the accuracy of the validation of the current year and 30% improvement in the prediction of the risk of the following year. It showcases the contribution of dynamic modelling, which incorporates self-assessment information and telematic data, to improve conventional automobile insurance pricing.

Capital-allocation-induced risk sharing

PS1

July 2
11:00

Wing Fung Chong[1], **Runhuan Feng**[2], **Kenneth Tsz Hin Ng**[3]

[1]*Maxwell Institute for Mathematical Sciences and Department of Actuarial Mathematics and Statistics, Heriot-Watt University, alfred.chong@hw.ac.uk*

[2]*School of Economics and Management, Tsinghua University, fengrh@sem.tsinghua.edu.cn*

[3] *Department of Mathematics, The Ohio State University, ng.499@osu.edu*

Keywords: risk sharing, capital allocation, distance-minimizing, value-at-risk, holistic principle

This article proposes a new class of risk sharing rules by exploring the relationship between capital allocation principles and risk-sharing rules. While the former is concerned with allocating capitals to different lines of business based on the relationship between the aggregated risk and individual risks within a corporation, the latter is an ex-ante arrangement which collects from and allocates risks to a group of participants. Drawing on this analogy, we introduce a novel idea of generating risk-sharing rules by randomizing existing capital allocation principles. Such a new approach generates new risk sharing rules complimentary to known results in the previous literature which were largely based on economic principles and Pareto-optimality.

Optimal subsampling and EM algorithms for non-Markovian semiparametric regression with interval-censored multi-state data

PS4

July 3
10:30

Si Cheng Fong[1], **Tony Sit**[2] **and Hoi Ying Wong**[3]

[1]*The Chinese University of Hong Kong, ryan.fong@link.cuhk.edu.hk*
[2]*The Chinese University of Hong Kong, tony.sit@cuhk.edu.hk*
[3]*The Chinese University of Hong Kong, hywong@cuhk.edu.hk*

Keywords: semiparametric regression, interval-censored multi-state state, EM algorithm, optimal subsampling

Interval-censored multi-state data, prevalent in credit rating transition modeling and insurance claims applications, capture transitions between states where exact transition times are unobserved and only known to occur within specific intervals. Estimating such processes faces two key challenges: (1) non-Markovian dynamics, where transition probabilities depend on historical trajectories, and (2) computational inefficiency in large-scale datasets. To address these, we propose a semiparametric proportional intensity model, incorporating B-spline estimators to flexibly model non-Markovian effects. We develop a stable expectation-maximization (EM) algorithm for nonparametric maximum likelihood estimation under general interval censoring and introduce an optimal subsampling framework to enhance both computational complexity and the efficiency of the estimated parameters. Theoretical results establish the consistency and asymptotic normality of the estimators, with the covariance matrix achieving semiparametric efficiency. Simulation studies demonstrate the robustness and scalability of the proposed methods, offering a practical and efficient approach for analyzing complex multi-state processes in insurance claims and credit rating transition modeling.

Calibration bands for mean estimates within the exponential dispersion family

PS3

July 2
15:40

Selim Gatti[1], **Łukasz Delong**[2] **and Mario V. Wüthrich**[3]

[1]*ETH Zürich, Switzerland, selim.gatti@math.ethz.ch*
[2]*University of Warsaw, Poland, l.delong@uw.edu.pl*
[3]*ETH Zürich, Switzerland, mario.wuethrich@math.ethz.ch*

Keywords: auto-calibration, calibration, calibration bands, exponential dispersion family, mean estimation, regression modeling, binomial distribution, Poisson distribution, negative binomial distribution, gamma distribution, normal distribution.

A statistical model is said to be calibrated if the resulting mean estimates perfectly match the true means of the underlying responses. Aiming for calibration is often not achievable in practice since one has to deal with finite samples of noisy observations. A weaker notion of calibration is auto-calibration, and it is important in actuarial applications as an auto-calibrated pricing system ensures that each cohort of policyholders paying the same premium is on average self-financing.

Testing for auto-calibration has only been considered recently in the literature. Denuit et al. [2] propose a test using Lorenz and concentration curves that requires the evaluation of a non-explicit asymptotic distribution using Monte-Carlo simulations, and simpler versions of this test are provided in Wüthrich [4] for discrete and finite regression functions. Additionally, Delong–Wüthrich [1] consider the use of bootstrap techniques to assess the auto-calibration of a model.

We take a different approach here. Our goal is to construct calibration bands for mean estimates within the exponential dispersion family. A calibration band denotes a set of lower and upper bounds on each mean estimate such that the probability of having simultaneously all the true means lying inside these bounds exceeds a given confidence level. Such bands were constructed by Yang–Barber [5] for sub-Gaussian distributions. Dimitriadis et al. [3] then introduced narrower bands for the Bernoulli distribution and we use the same idea in order to extend the construction to the entire exponential dispersion family that contains for example the binomial, Poisson, negative binomial, gamma and normal distributions. Moreover, we show that the obtained calibration bands allow us to construct various tests for calibration and auto-calibration, respectively.

Bibliography

[1] Delong, Ł., Wüthrich, M. V. (2024). Isotonic regression for variance estimation and its role in mean estimation and model validation. *North American Actuarial Journal*, 1-29.

[2] Denuit, M., Huyghe, J., Trufin, J., Verdebout, T. (2024). Testing for auto-calibration with Lorenz and concentration curves. *Insurance: Mathematics and Economics* 117, 130–139.

[3] Dimitriadis, T., Dümbgen, L., Henzi, A., Puke, M., Ziegel, J. (2023). Honest calibration assessment for binary outcome predictions. *Biometrika* 110/3, 663—680.

[4] Wüthrich, M.V. (2025). Auto-calibration tests for discrete finite regression functions. *European Actuarial Journal*.

[5] Yang, F., Barber, R. F. (2019). Contraction and uniform convergence of isotonic regression. *Electronic Journal of Statistics* 13/1, 646–677.

Collaborative and parametric insurance on the Ethereum blockchain

PS5
July 3
13:30

Pierre-O Goffard[1] **and Stéphane Loisel**[2]

[1]*Université de Strasbourg, Institut de Recherche Mathématique Avancée, Strasbourg, France, goffard@unisra.fr*

[2]*CNAM, Efab, Lirsa, Paris, France, stephane.loisel@lecnam.net*

Keywords: blockchain, parametric insurance, collaborative insurance

This paper introduces a blockchain-based insurance scheme that integrates parametric and collaborative elements. A pool of investors, referred to as surplus providers, locks funds in a smart contract, enabling blockchain users to underwrite parametric insurance contracts. These contracts automatically trigger compensation when predefined conditions are met. An actuarial framework for parametric insurance portfolios risk management is provided. The collaborative aspect is embodied in the generation of tokens, which are distributed to both surplus providers and policyholders. These tokens represent each participant's share of the surplus and grant voting rights for management decisions. The smart contract is developed in Solidity, a high-level programming language for the Ethereum blockchain, and deployed on the Sepolia testnet, with data processing and analysis conducted using Python. In addition, open-source code is provided and main research challenges are identified, so that further research can be carried out to overcome limitations of this first proof of concept.

A Bayesian approach to catastrophic risks

PS6
July 3
15:30

Manuel Guerra[1,2] **and Alexandra B. Moura**[1,3]

[1]*CEMAPRE and ISEG, Universidade de Lisboa, Portugal,*
[2]*mguerra@iseg.ulisboa.pt,* [3]*amoura@iseg.ulisboa.pt*

Keywords: catastrophe, Cox process, Bayesian estimation, partial observation

By definition, catastrophes are events with very low frequency causing very large losses highly correlated across a portfolio or a geographic area. These characteristics make catastrophic risks difficult to quantify. Since models are difficult to calibrate on available data, risk assessments often carry a substantial amount of unquantified model risk.

Cox processes are popular models for catastrophic risks. They are a generalization of the classical compound Poisson processes, with the claim arrivals intensity being a stochastic process instead of a constant. Catastrophes are modelled by large transient peaks in the intensity process, causing a large number of claim arrivals in a small interval of time. However, in many practical applications, the claim arrival intensity is not directly observable or it is imperfectly observable. For example, it is quite common that the time between the onset of a catastrophe and its observation is negligible, but the true extent of the catastrophe may take a considerable time to evaluate as data is collected and processed. This poses an additional challenge to the calibration of models.

We propose a Bayesian framework for the calibration of these models. This approach allows for the estimation of the probability law of the surplus process, and can be applied in near real time as new data arrives. By the choice of suitable priors, it internalizes the model risk which may thus be included in risk assessments.

Smith–Wilson yield curves via a macro-driven ultimate forward rate

PS2
July 2
14:00

Hangsuck Lee[1], **Minha Lee**[2], **Sunae Kim**[3] **and Hongjun Ha**[4]

[1]*Sungkyunkwan University, Republic of Korea, hangsuck@skku.edu*
[2]*Kyonggi University, Republic of Korea, minhalee@kyonggi.ac.kr*
[3]*Sungkyunkwan University, Republic of Korea, sunae.kim95@gmail.com*
[4]*Korea University, Republic of Korea, hha97@korea.ac.kr*

Keywords: term structure, ultimate forward rate, overlapping generations economy, Smith-Wilson model

We develop a macro-founded framework that endogenously determines the ultimate forward rate (UFR) for long-dated interest rate extrapolation. In contrast to the standard Smith–Wilson approach, which relies on an exogenous UFR, our heterogeneous-agent overlapping generations model integrates labor productivity, employment probabilities, survival rates, and consumption taxes to derive a structural long-term rate. Simulation results show that this approach yields more robust and economically consistent projections than fixed-UFR calibrations. Empirical estimations for multiple countries further demonstrate how fundamental economic factors, including demographic and fiscal parameters, shape the term structure of interest rates. Our findings underscore the importance of anchoring ultra-long-term discount rates in underlying macroeconomic conditions, especially for pension funds and insurers managing extended-duration liabilities.

On technical bases and surplus in life insurance

PS5
July 3
13:30

Oytun Haçarız[1], **Torsten Kleinow**[2] **and Angus S. Macdonald**[3]

[1]*Department of Actuarial Sciences, The Faculty of Business, Karabük University, Karabük, 78050, Turkey, and Institute of Applied Mathematics, Middle East Technical University, Ankara, 06800, Turkey, oytunhacariz@karabuk.edu.tr*

[2]*Research Centre for Longevity Risk, Faculty of Economics and Business, University of Amsterdam, t.kleinow@uva.nl*

[3]*Department of Actuarial Mathematics and Statistics, Heriot-Watt University, Edinburgh EH14 4AS, UK, and the Maxwell Institute for Mathematical Sciences, UK. A.S.Macdonald@hw.ac.uk.*

Keywords: counting process, life insurance, surplus, technical bases, Thiele's differential equation

Different jurisdictions often have different regulations. Different traditions might also have different pedagogies in teaching technical topics. Life insurance is possibly a good example of these practicalities. Almost all of the literature on Thiele's equation(s) and surplus in life insurance uses a model inspired by Scandinavian-style regulation with two technical bases, called first-order (pricing or safe-side) and second-order (experience or realistic). This is more restrictive than practice in many jurisdictions such as in the UK and North America. In this talk, we will (a) classify technical bases, satisfying boundary conditions in Thiele's equation(s) and allowing more general regulations than Scandinavian-style regulation first-order/second-order regimes; then (b) propose a canonical model with three technical bases (premium, valuation, and accumulation) and show how each pair of bases defines premium loadings and surplus. One key concluding remark in our proposition we show that the expected present value of total surplus under the experience basis does not depend on the choice of valuation basis, which is well-known in UK practice [1].

Bibliography

[1] Haçarız, O., Kleinow, T. & Macdonald, A. S. (2024). On technical bases and surplus in life insurance. *Scandinavian Actuarial Journal*, 2024(9), 881–909.

Early pension withdrawals and homeownership

PS7
July 4
10:30

Hamza Hanbali[1], **Gaurav Khemka**[2] **and Himasha Warnakulasooriya**[3]

[1]*Department of Economics, Centre for Actuarial Studies, University of Melbourne, hamza.hanbali@unimelb.edu.au*
[2]*Research School of Finance, Actuarial Studies & Statistics, Australian National University, gaurav.khemka@anu.edu.au*
[3]*Department of Econometrics and Business Statistics, Monash University, himasha.warnakulasooriya@monash.edu*

Keywords: pension, defined contribution, early withdrawal, homeownership

This paper examines the actuarial and distributional effects of allowing early pension withdrawals for homeownership. Unlike government-funded subsidies, this policy reallocates retirement savings without introducing new purchasing power, potentially accelerating homeownership but raising concerns over long-term financial security. Using a lifecycle model integrated with an econometric framework, the study tracks a cohort of renters across income percentiles, simulating homeownership transitions under two scenarios: relying solely on savings versus supplementing savings with pension withdrawals. Calibrated to Australian data, the model captures macroeconomic feedback through house prices, rents, wages, borrowing costs, and savings rates. The analysis evaluates the policy's impact on individual financial security, homeownership inequality, and fiscal sustainability. Results highlight the trade-offs between improving short-term housing access and preserving retirement adequacy, offering insights into the actuarial risks of pension liquidity for housing policy.

Kihlstrom–Mirman preferences in continuous time: equilibrium control theory and applications to finance and insurance

PS2

July 2
14:00

Luca De Gennaro Aquino[1], **Sascha Desmettre**[2],
Yevhen Havrylenko[3], **Mogens Steffensen**[4]

[1] *Reykjavik University, Iceland, lucaa@ru.is*
[2] *Johannes Kepler University Linz, Austria, sascha.desmettre@jku.at*
[3] *Ulm University, Germany, yevhen.havrylenko@uni-ulm.de*
[4] *University of Copenhagen, Denmark, mogens@math.ku.dk*

Keywords: time-inconsistency, equilibrium theory, separation of time and risk preferences

In intertemporal setting, the multi-attribute utility theory of Kihlstrom and Mirman suggests the application of a concave transform of the lifetime utility index. This construction, while allowing one to separate an agent's attitude toward time and risk, leads to dynamically inconsistent preferences. This invalidates the usage of the Bellman principle of optimality in the respective decision-making problem. Therefore, we formalize the equilibrium control theory for the decision-making problem of an agent who has Kihlstrom–Mirman preferences and controls a continuous-time Markovian process. In this setting, we describe an equilibrium strategy and an equilibrium value function via an extended Hamilton–Jacobi–Bellman system of partial differential equations. We provide a verification theorem for this characterization and examine the features of the system, which are novel in comparison to other systems known in the literature on time inconsistency. Finally, we showcase our approach for a consumption-investment problem of an agent with CRRA-CES utility and discuss potential applications of the Kihlstrom–Mirman framework to actuarial problems.

Bibliography

[1] Aquino, L.D.G., Desmettre, S., Havrylenko, Y., Steffensen, M. (2024). Equilibrium control theory for Kihlstrom-Mirman preferences in continuous time. *Preprint*. https://doi.org/10.48550/arXiv.2407.16525

[2] Kihlstrom, R.E., Mirman, L.J. (1974). Risk Aversion With Many Commodities. *Journal of Economic Theory*. 8(3), 361–388. https://doi.org/10.1016/0022-0531(74)90091-X

[3] Kihlstrom, R.E. (2009). Risk Aversion and the Elasticity of Substitution in General Dynamic Portfolio Theory: Consistent Planning by Forward Looking, Expected Utility Maximizing Investors. *Journal of Mathematical Economics*. 45(9-10), 634–663. https://doi.org/10.1016/j.jmateco.2008.08.008

Multi-view spatial embeddings for insurance portfolio analytics

PS1

July 2
11:00

Freek Holvoet[1], **Christopher Blier-Wong**[2] **and Katrien Antonio**[3]

[1]*Faculty of Economics and Business, KU Leuven, Belgium, freek.holvoet@kuleuven.be.*
[2]*Department of Statistical Sciences, University of Toronto, Canada, christopher.blierwong@utoronto.ca.*
[3]*Faculty of Economics and Business, KU Leuven, Belgium & Faculty of Economics and Business, University of Amsterdam, The Netherlands, katrien.antonio@kuleuven.be.*

Keywords: spatial data, embedding, machine learning, contrastive learning, geospatial representations

Accurate assessment of spatial risks, particularly those influenced by climate, weather, and demographic factors, is crucial for the insurance industry to improve underwriting precision and enhance risk management. This paper introduces a novel approach for constructing spatial embeddings using contrastive learning techniques in a multi-view setting. We combine two types of spatial data — satellite images and OpenStreetMap (OSM) tags — to generate coordinate-based spatial embeddings. By extending the spatial learning model from [1], our method effectively integrates multiple spatial data sources, producing embeddings that are compact, flexible, and easy to apply in predictive models. In a case study on French real estate prices, we demonstrate that the learned spatial representations capture underlying geographic structures. This leads to improved predictive accuracy and valuable spatial interpretation of the pricing model. Our findings highlight the potential of flexible, data-driven spatial embeddings to enhance models in fields where location plays a crucial role but is challenging to integrate effectively.

Bibliography

[1] Klemmer, K., Rolf, E., Robinson, C., Mackey, L., Rußwurm, M. (2023). SatCLIP: Global, general-purpose location embeddings with satellite imagery. *In arXiv [cs.CV]*. arXiv. http://arxiv.org/abs/2311.17179

Finite-sample valid prediction of future insurance claims in the regression problem

PS6

July 3
15:30

Liang Hong[1]

[1]*University of Texas at Dallas, USA, liang.hong@utdallas.edu*

Keywords: conformal prediction, explainable machine learning, insurance data science, predictive analytics

In the current insurance literature, prediction of insurance claims in the regression problem is often performed with a statistical model. This model-based approach may suffer from several drawbacks: (i) model misspecification, (ii) selection effect, and (iii) lack of finite-sample validity. This work addresses these three issues simultaneously by employing conformal prediction—a general machine learning strategy for valid predictions. The proposed method is both model-free and tuning-parameter-free. It also guarantees finite-sample validity at a pre-assigned coverage probability level.

Disability model with individual and collective health claims

PS3

July 2
15:40

Philipp Hornung[1]

[1] *University of Copenhagen, Denmark, pcho@math.ku.dk*

Keywords: semi-markov, mean-field approximation, integro-differential equations

The semi-Markov disability model is extended with individual and collective health claims to improve the model's explanatory and predictive power. The inclusion of collective health claims leads to a computationally challenging many-body problem. However, by adopting a mean-field approach, this many-body problem can be approximated by a non-linear one-body problem. This leads to a transparent method for pricing and reserving of disability insurances, since a high-dimensional system of Kolmogorov forward integro-differential equations can be replaced by a low-dimensional, non-linear counterpart. (Joint work with Christian Furrer from the University of Copenhagen).

A multivariate energy distance approach to premium fairness adjustment

PS2

July 2
14:00

Charlotte Jamotton[1] **and Donatien Hainaut**[2]

[1]*Université catholique de Louvain, Belgium, charlotte.jamotton@uclouvain.be*
[2]*Université catholique de Louvain, Belgium, donatien.hainaut@uclouvain.be*

Keywords: fairness, demographic parity, autocalibration, actuarial pricing, energy distance

Fairness in insurance has become increasingly critical, particularly in light of regulations calling for non-discriminatory premium estimation, such as the EU Gender Directive (2012), which prohibits gender-based pricing in insurance. This research explores group fairness mechanisms designed to mitigate group-level disparities. We introduce a group fairness adjuster based on the energy distance. The multivariate nature of the energy distance allows for the simultaneous fairness adjustment of premium distributions across multiple sensitive demographic groups from different (non-binary) sensitive variables, such as gender and age. Our method incorporates an autocalibration technique to correct biases in the total number of claims after fairness adjustments, ensuring overall balance in the predictions. Additionally, our approach allows for the adjustment of estimated discriminatory premiums for new policyholders without requiring retraining of the fairness adjustment model. We demonstrate the effectiveness (i.e., significant reductions in group-level disparities while maintaining near-initial model accuracy) of our adjustments in the context of car insurance, known to rely on demographic factors such as age and gender to assess risk and determine premiums.

Bibliography

[1] Charpentier, A. (2023). *Insurance, biases, discrimination and fairness*. Springer Actuarial.

[2] Côté, O., Côté, M.-P., & Charpentier, A. (2024). A fair price to pay: Exploiting causal graphs for fairness in insurance. *Journal of Risk and Insurance*.

[3] Frees, E. W., & Huang, F. (2023). The discriminating (pricing) actuary. *North American Actuarial Journal*, 27(1), 2–24.

Multivariate Hipp-type compound Poisson approximations for lattice distributions

PS4

July 3
10:30

Simona Jokubauskienė

Vytautas Magnus University, Lithuania, simona.jokubauskiene@vdu.lt

Keywords: local metric, lower estimates, multivariate compound Poisson approximation, non-uniform estimates, sums of random vectors

Compound Poisson (CP) approximations have a broad range of theoretical and practical applications. They can be used in actuarial mathematics, biology, extreme value theory, etc. (for a comprehensive review see [1, 2] and references therein). However, the absolute majority of research is done for one-dimensional cases. The multidimensional CP approximations are comparatively little researched. The subject of this talk is primarily inspired by the needs of actuarial mathematics. Let p_i be probability that risk i produces a claim and $V_i \in \mathcal{F}$ be the conditional distribution of the claims in risk i. Then claims amount has distribution $(1-p_i)I + p_iV_i$ and *aggregate claims distribution* for portfolio of n claims is convolution

$$\prod_{i=1}^{*n}((1-p_i)I + p_iV_i).$$

It is natural to assume that p_i are small (claims are rare). If we assume that the amounts of claims are independent and identically distributed, then $V_i \equiv V$.

Aggregate claims distribution plays very important role in actuarial mathematics, see discussion on p. 3 of [4]. However, to calculate aggregate claims distribution is not always easy even if all claim distributions are concentrated on integers. Therefore, approximations with better applicability are used. In [4], Ch. 10 it is shown that one-dimensional accompanying CP distribution and Hipp signed CP approximations can be calculated via modified De Pril recursion. In [4], Ch. 14.1 it is argued that multivariate claim distributions are also important actuarial models. For example, it make sense to investigate 3-dimensional claims distribution for health; home and car insurances. Hipp-type approximation was introduced in [3] and in terms of convolutions can be expressed as

$$\exp\left\{\sum_{i=1}^{n}\sum_{j=1}^{s}\frac{(-1)^{j+1}p_i^j(V_i-I)^{*j}}{j}\right\}.$$

Application of CP and SCP approximations typically consists of two parts: a) estimation of the accuracy of approximation in some metric; b) algorithms for numerical calculation of characteristics of interest. Monograph [4] deals with calculation algorithms. Our results are related to estimation of the accuracy of approximation. Remarkably, though all recursion algorithms deal with local probabilities, the majority of known approximation results in actuarial mathematics are proved for the total variation metric. There is obvious lack of local estimates.

Bibliography

[1] Barbour, A. D., Chryssaphinou, O. and Vaggelatou, E. (2001) Applications of compound Poisson approximation. — In: Charalambides, C. A., Koutras, M. V. and Balakrishnan, N. (Eds.) *Probability and Statistical Models with Applications*, 41–62. Chapman & Hall.

[2] V. Čekanavičius, S. Novak (2024). *Compound Poisson approximation.*, 319 pp., Chapman and Hall, ISBN 9781032762562.

[3] Hipp C. (1986) Improved approximations for the aggregate claims distribution in the individual model. — *ASTIN Bull.*, **16**(2), 89–100.

[4] Sundt B. and Vernic R. (2009) *Recursions for Convolutions and Compound Distributions with Insurance Applications*. — EAA Lecture Notes: Springer.

Insurance stress testing of climate change risk: The case of the Korean general insurance Industry

PS4

July 3
10:30

Kwangmin Jung[1], **Yejin Kim**[2], **Seungah Lee**[3], **Yong-Sang Choi**[4], **Minjeong Kong**[5]

[1]*POSTECH, South Korea, kwjung@postech.ac.kr*
[2]*POSTECH, South Korea, s2jin7090@postech.ac.kr*
[3]*POSTECH, South Korea, al1905@postech.ac.kr*
[4]*Ewha Womans University, South Korea, ysc@ewha.ac.kr*
[5]*Ewha Womans University, South Korea, mjkong@ewha.ac.kr*

Keywords: climate change risk, actuaries climate index, climate stress testing, conditional copula

Climate change risk emerges as a critical concern for Property & Casualty (P&C) insurers due to its causal effect on increasing natural disasters across the globe. However, a challenge to quantify ongoing climate change makes it difficult to assess how this progress may affect their underwriting performance.

To address this concern, we employ the Actuaries Climate Index (ACI) to examine the impact of climate change risk on P&C insurers' performance. We propose a local-level ACI by using meteorological information of regions in South Korea and employ a conditional copula simulation to implement a stress test to determine the impact of climate change on insurers' exposures.

Our findings reveal that large insurers may face a disproportionately high increase in Value-at-Risk (VaR) measures under extreme climate scenarios, whereas small and medium-sized insurers can experience moderate risk escalation. These results underscore the systemic nature of climate risk, where nonlinear spillovers can amplify financial instability.

By introducing a dynamic stress-testing framework, this study highlights the need for size-specific mitigation strategies and provides insurers and regulators with insights into risk-based pricing and tailored capital requirements against climate change risks.

Variable importance in generalized linear models – A unifying view using Shapley values

PS1

July 2
11:00

Christian Kleiber[1] **and Sinan Acemoglu**[1] **and Jörg Urban**[1]

[1]*Universität Basel, Basel, Switzerland, christian.kleiber@unibas.ch*
[1]*Universität Basel, Basel, Switzerland, sinan.acemoglu@unibas.ch*
[1]*Universität Basel, Basel, Switzerland, joerg.urban@unibas.ch*

Keywords: averaging over orderings, goodness of fit, hierarchical partitioning, Kullback-Leibler divergence, regression

The rise of algorithmic modelling in insurance and related fields has led to a growing interest in 'Explainable Machine Learning' (XML), including methods for assessing variable importance in regression models. There is no unique method for assessing variable importance. However, a substantial share of the available literature in statistics and machine learning employs Shapley values, explicitly or implicitly, to decompose a suitable goodness-of-fit measure; in the linear regression model typically the classical R^2. Beyond linear regression, there is no generally accepted goodness-of-fit measure, only a variety of pseudo-R^2s. We formulate and discuss desirable properties of goodness-of-fit measures that allow Shapley values to be interpreted in terms of relative and even absolute importance. We suggest to use a pseudo-R^2 based on the Kullback-Leibler divergence, which has a convenient form for generalized linear models (GLMs) and permits to unify and extend previous work on variable importance for linear and nonlinear models. We also consider more flexible regression models with GLM building blocks. Several examples are presented, using data from health economics and car insurance.

The short-term association between environmental variables and mortality

PS4
July 3
10:30

Torsten Kleinow[1], **Jens Robben**[1] **and Katrien Antonio**[1,2]

[1]*Research Centre for Longevity Risk, University of Amsterdam*
[2]*KU Leuven*

Keywords: environmental data, high-resolution gridded datasets, weekly mortality modelling

Using fine-grained, publicly available data, we study the short-term association between environmental factors, i.e. weather and air pollution characteristics, and weekly mortality rates in small European regions. Hereto, we develop a mortality modelling framework where a baseline model captures a region-specific, seasonal trend observed within the historical weekly mortality rates. Using a machine learning algorithm, we then explain deviations from this baseline using features constructed from environmental data that capture anomalies and extreme events. We illustrate our proposed modelling framework through a case study on more than 550 NUTS 3 regions (Nomenclature of Territorial Units for Statistics, level 3) in 20 European countries. We show that temperature-related features are most influential in explaining mortality deviations from the baseline over short time periods. Furthermore, we find that environmental features prove particularly beneficial in southern regions for explaining elevated levels of mortality, and we observe evidence of a harvesting effect related to heat waves.

Heavy-tailed random vectors: theory and applications

PS5
July 3
13:30

Dimitrios G. Konstantinides[1] **and Charalampos D. Passalidis**[1]

[1]*University of the Aegean, Greece, konstant@aegean.gr*

Keywords: multivariate positively decreasing distributions, multivariate subepxonential distributions, convolution: convolution roots, scale mixtures, linear single big jump principle, time-dependent risk model, precise large deviations

In this paper we introduce and study several multivariate, heavy-tailed distribution classes, and we explore their closure properties and their applications. We consider the class of multivariate, positively decreasing distributions, and its intersection with other multivariate distribution classes. Next, we show that the smallest of these classes contains the standard multivariate regular variation class and we provide necessary and sufficient conditions for the closure property with respect to convolution in the class of multivariate, subexponential, positively decreasing distributions, and the conditional closure property with respect to convolution roots, in the class of multivariate, subexponential distributions. Further, we study the closure properties with respect to scale mixtures, under the assumption that the random variable, that produces the scale mixture is weakly dependent to primary random vector. We give also a multivariate, dependent version of the Breiman's lemma. Under similar conditions, we establish the single big jump principle in scale mixture sums, under several conditions on the distributions of primary random vectors. Next, we present the asymptotic estimation of the ruin probability over finite horizon, in a multivariate, time-dependent Poisson risk model. More precisely, we consider constant interest force, and common Poisson, counting process, to any line of business, with any claim vector to be weakly dependent with inter-arrival times. Finally we give the lower bound of the precise large deviations in multivariate set up. In case of non-random sums, the lower bound is estimated uniformly, the random vectors have some weak dependence structure, and we do not assume some condition for the distribution of the random vectors. In case of random sums, we provide similar estimations, under the additional condition that the random vectors are weak-equivalent on the chosen rare set.

Prioptions: An optional feature in an XL reinsurance treaty

PS3

July 2
15:40

Enej Kovač[1], **Hansjörg Albrecher**[2] **and Frank Cuypers**[3]

[1] *University of Lausanne, Switzerland, enej.kovac@unil.ch*
[2] *University of Lausanne, Switzerland, hansjoerg.albrecher@unil.ch*
[3] *Prime Re Solutions, Switzerland, frank.cuypers@prs-zug.com*

Keywords: reinsurance, excess-of-loss reinsurance, reinsurance pricing, risk-sharing

We introduce an option embedded within an excess-of-loss (XL) reinsurance treaty that allows the cedent to choose the deductible and pay the respective reinsurance premium retrospectively, once all claims are realized. We show that the optimal deductible is contained in a finite set of candidate values, and we derive their concrete values and provide bounds for the a-priori probability for each such value to be eventually chosen. Using these bounds, we estimate bounds for the implied risk premium. A numerical example then illustrates the theoretical findings and the behavior of cash flows under such a "prioption" arrangement, and a comparison with a conventional XL treaty is carried out. The latter indicates that with an appropriately chosen option price, both parties can benefit from this option: the cedent reduces overall expected costs, while the reinsurer achieves better risk-adjusted profit and lower capital requirements. Finally, we discuss extensions to multi-class portfolios.

An analysis of the impact of liquidity premium estimation on the reserves of Taiwan's life insurance companies

PS2

July 2
14:00

Ko-Lun Kung[1], **Wei-Che Tsai**[2], **and Chenghsien Jason Tsai**

[1]*Feng-Chia University, klkung@fcu.edu.tw*
[2]*National Sun Yat-sen University, weiche@mail.nsysu.edu.tw*
[3]*National Chengchi University, ctsai@nccu.edu.tw*

Keywords: IFRS 17 standard, liquidity premium, life insurance reserves, insurance regulation

We estimate liquidity premiums under the International Financial Reporting Standard 17 (IFRS 17) framework in Taiwan's life insurance market. We used unique firm-level data from two major life insurance companies in Taiwan to show that the liquidity premium should depend on policy characteristics. In this paper, we estimate the liquidity premium with both top-down and bottom-up approaches. We examine the quantitative impact of liquidity premium fluctuations on life insurance liability reserve calculations. The result suggested that the volatility of liquidity premiums has a sizeable impact on the best estimate.

Measuring financial resilience using backward stochastic differential equations

PS1

July 2
11:00

Roger J. A. Laeven[1], **Matteo Ferrari**[2], **Emanuela Rosazza Gianin**[3] **and Marco Zullino**[4]

[1]*University of Amsterdam, CentER and EURANDOM, The Netherlands, R.J.A.Laeven@uva.nl*
[2]*University of Amsterdam, The Netherlands, M.Ferrari@uva.nl*
[3]*University of Milano-Bicocca, Italy, emanuela.rosazza1@unimib.it*
[4]*University of Amsterdam, The Netherlands, M.Zullino@uva.nl*

Keywords: financial resilience, bouncing drift, backward stochastic differential equations, generator, stopping time, dynamic risk measures, acceptance sets.

We propose the *resilience rate* as a measure of financial resilience that captures the rate at which a dynamic risk measure recovers, *i.e.*, bounces back, after the risk-acceptance set is breached. We develop the associated stochastic calculus by establishing representation theorems of a suitable time-derivative of solutions to backward stochastic differential equations (BSDEs) evaluated at stopping times. These results reveal that our resilience rate can be represented as an expectation of the generator of a BSDE. We also introduce *resilience-acceptance sets* and study their properties in relation to both the resilience rate and the dynamic risk measure. The definition of the resilience rate is generalized from a Brownian filtration to the case of dynamic risk measures induced by BSDEs with jumps. We illustrate our results in several examples.

Non-parametric estimation of net survival under dependence between death causes

PS7

July 4
10:30

Oskar Laverny[1], **Nathalie Grafféo**[1] **and Roch Giorgi**[2]

[1]*Aix Marseille Univ, INSERM, IRD, SESSTIM, Sciences Economiques & Sociales de la Santé & Traitement de l'Information Médicale, ISSPAM, Marseille, France. oskar.laverny@univ-amu.fr*

[2]*Aix Marseille Univ, APHM, INSERM, IRD, SESSTIM, Sciences Economiques & Sociales de la Santé & Traitement de l'Information Médicale, ISSPAM, Hop Timone, BioSTIC, Biostatistique et Technologies de l'Information et de la Communication, Marseille, France.*

Keywords: survival analysis, net survival, non-parametric estimators, copulas

Relative survival methodology [3, 4, 7] deals with a competing risks survival model where the cause of death is unknown. This lack of information occurs regularly in population-based cancer studies. Non-parametric estimation of the net survival is possible through the Pohar Perme [6] estimator. Derived similarly to Kaplan-Meier, it nevertheless relies on an untestable independence assumption. We propose here to relax this assumption and provide a generalized non-parametric estimator that works for other dependence structures, using copulas [5, 2], by leveraging the underlying stochastic processes and martingales. We formally derive asymptotics of this estimator, providing variance estimation and log-rank-type tests. Our approach provides a new perspective on the Pohar Perme estimator and the acceptability of the underlying independence assumption. We highlight the impact of this dependence structure assumption on simulation studies, and illustrate them through an application on registry data relative to colorectal cancer, before discussing potential extensions of our methodology.

Bibliography

[1] Adatorwovor, R., Latouche, A., and Fine, J. P. (2023). A parametric approach to relaxing the independence assumption in relative survival analysis. *The international journal of biostatistics*, 18(2), 577-592.

[2] Czado, C. and Van Keilegom, I. (2023). Dependent censoring based on copulas. *Biometrika* 110(3), 721-738.

[3] Ederer, F. (1961). The relative survival rate: a statistical methodology. *Natl. Cancer Inst. Monogr.*, vol. 6, p. 101-121, 1961.

[4] Hakulinen, T. (1982). Cancer survival corrected for heterogeneity in patient withdrawal. *Biometrics* 38, 933–942.

[5] Nelsen, R. B. (2006). *An introduction to copulas*. Springer.

[6] Pohar Perme, M., Stare, J., and Estève, J. (2012). On estimation in relative survival. *Biometrics*, vol. 68, no 1, p. 113-120

[7] Wolski, A., Grafféo, N., Giorgi, R., and the CENSUR working survival group (2020). A permutation test based on the restricted mean survival time for comparison of net survival distributions in non-proportional excess hazard settings. *Stat Methods Med Res*, vol. 29, no 6, p. 1612-1623

Optimal deductible to control the loss frequency

PS6
July 3
15:30

Hangsuck Lee[1], **Yisub Kye**[2], **Minha Lee**[3] **and Jimin Hong**[4]

[1]*Sungkyunkwan University, Republic of Korea, hangsuck@skku.edu*
[2]*Northern Illinois University, USA, ykye1@niu.edu*
[3]*Kyonggi University, Republic of Korea, minhalee@kyonggi.ac.kr*
[4]*Soongsil University, Republic of Korea, jmhong@ssu.ac.kr*

Keywords: moral hazard, repeated losses, $(a, b, 0)$ or $(a, b, 1)$ class of distribution, per-occurrence deductible, aggregate deductible

This study presents the optimal form of insurance when repeated losses occur within an insurance period, with insurers providing indemnity for each loss as it occurs. First, we verify that a per-occurrence deductible is optimal in the presence of moral hazard related to efforts to reduce loss frequency. Specifically, each deductible level is affected by the cumulative sum of losses, even under a per-occurrence deductible system. Second, for individuals with higher risk aversion, both the deductible for the first loss and the cumulative sum of deductibles are lower than for those with lower risk aversion. Third, as the loss frequency increases, the per-occurrence deductible may either increase or decrease, depending on the relative size between the change in absolute risk aversion (ARA) due to the subsequent loss and the marginal productivity of efforts. Numerical examples using the loss frequency distribution belonging to the $(a, b, 0)$ or $(a, b, 1)$ class distribution, widely utilized in actuarial models, are provided to validate our findings.

Reverse mortgage pricing: a cross-country comparative study of product design

PS2

July 2
14:00

Yung-Tsung Lee[1], **Tianxiang Shi**[2], **and I-Chien Liu**

[1]*Department of Banking and Finance, National Chiayi University, Taiwan, engtsong@mail.ncyu.edu.tw*
[2]*Department of Risk, Actuarial Science, and Legal Studies, Temple University.*
[3]*Department of Insurance and Finance, National Taichung University of Science and Technology*

Keywords: reverse mortgages, pricing, cross-country comparative

Reverse mortgages (RMs) have different product designs across countries. For example, in the U.S., the non-negative equity guarantee (NNEG) cost is insured by the HECM program. In contrast, the RM issuer suffers the NNEG cost in the U.K. Furthermore, an RM in the U.K. and the U.S. has a non-recourse clause, but it is a recourse loan in Taiwan. This study derives a universal pricing framework for RMs across countries and uses a continuous model for the convenience of mathematical treatment. Under the universal pricing framework, we investigate the effect on the lender's profitability and risk profile, the borrower's benefit, and the insurer's net premium income and risk among different RM designs. Besides, RMs in Taiwan have unique properties, such as "monthly interest repayment" and "simple interest is charged for the unpaid interest." We will discuss the effect on the RM's cash flow distribution and the NNEG cost of the unique properties and investigate the potential improvement on HECM loans.

Improving cluster detection for age-specific spatial mortality hotspots

PS1

July 2
11:00

Yin Yee Leong[1]

[1]*Department of Risk Management and Insurance, Feng Chia University, Taiwan, yyleong@fcu.edu.tw*

Keywords: mortality hotspot detection, spatial analysis, small area estimation.

Spatial analysis in the context of insurance has gained increasing attention in actuarial research due to its potential to reveal critical risk factors across different locations. Recent studies have identified geographical variations in mortality rates, particularly among the elderly, highlighting the importance of spatial mortality hotspot detection in life table construction. Such hotspots, frequently observed in rural areas, underscore the need for spatial methodologies in actuarial modeling. Traditional cluster detection techniques, such as scan statistics (SaTScan), have been widely applied in identifying mortality clusters.

In life insurance practice, recognizing age-specific mortality hotspots is particularly relevant for products like short-term life insurance. However, sparse data within specific age groups often reduce the statistical power of traditional scan statistics. To address this limitation, small area estimation techniques, including Partial SMR, Whittaker graduation, and Whittaker ratio, have been employed to enhance the robustness of cluster detection. Our study indicates that these graduation methods improve statistical power. Additionally, using Taiwan's mortality data, empirical findings reveal distinct mortality curves and cause-of-death distributions in hotspot regions. These insights offer valuable contributions to insurance risk assessment, pricing strategies, and policy management, facilitating more informed actuarial decision-making.

Extremes of extended tail Gini functionals with application in systemic risk variability control

PS5

July 3
13:30

Weiran Li[1] **and Jiajun Liu**[2]

[1]*Xi'an Jiaotong-Liverpool University, China, Weiran.Li18@student.xjtlu.edu.cn*
[2]*Xi'an Jiaotong-Liverpool University, China, Jiajun.Liu@xjtlu.edu.cn*

Keywords: tail Gini functional, extreme value theory, tail dependence and independence, measure of risk variability

Measuring the tail risk of financial or insurance entities in response to extreme scenarios of a benchmark or systemic variable is of considerable interest to both academics and practitioners. While much of the existing literature focuses on the magnitude of extreme losses, relatively fewer attention addresses measurements of the tail risk variability and its sequential inference, despite its importance in pricing, premium-principle construction, and portfolio selection for investments. Building on the tail Gini functionals, we consider a family of measures of tail risk variability capturing the extreme co-movements between systemic variable and individual losses in and of itself, where the degree of risk aversion of policy-makers towards the systemic risk could be controlled over a new parameter. An asymptotic result is explored through an integration of extreme value techniques and tail dependence conditions, as the limit behaviors of the proposed risk measures are of great interest under stringent regulatory requirements. Moreover, we develop estimators applicable at both intermediate and extreme levels and demonstrate the practical utility of our approach in real data analysis.

Dynamic financial analysis (DFA) of general insurers under climate change

PS4
July 3
10:30

Benjamin Avanzi [1], **Yanfeng Li** [2], **Greg Taylor** [3], **Bernard Wong** [4]

[1] *University of Melbourne, Australia, b.avanzi@unimelb.edu.au*
[2] *University of New South Wales, Australia, yanfeng.li@student.unsw.edu.au*
[3] *University of New South Wales, Australia, gregory.taylor@unsw.edu.au*
[4] *University of New South Wales, Australia, bernard.wong@unsw.edu.au*

Keywords: climate change, dynamic financial analysis, general insurance

Climate change is expected to significantly affect the physical, financial, and economic environments over the long term, posing risks to the financial health of general insurers. To navigate these challenges, general insurers need a comprehensive understanding of the impact of climate change. General insurers typically use Dynamic Financial Analysis (DFA) for a comprehensive view of financial impacts, but traditional DFA in academic literature often does not consider the impact of climate change. To address this gap, this study introduces a climate-dependent DFA approach that integrates climate risk into DFA, providing a comprehensive assessment of the long-term impact of climate change on the general insurance industry.

The proposed framework has three key features. First, it captures the long-term impact of climate change on the assets and liabilities of general insurers by considering both physical and economic dimensions across different climate scenarios within an interconnected structure. Second, it addresses the uncertainty of climate change impacts using stochastic simulations within climate scenario analysis that are useful for actuarial applications. Finally, the framework is tailored to the general insurance sector by addressing its unique characteristics.

To demonstrate the practical application of our model, we conduct an extensive empirical study using Australian data to assess the long-term financial impact of climate change on the general insurance market under various climate scenarios, which is enabled by our modelling design. The results show that the interaction between economic growth and physical risk plays a key role in shaping general insurers' risk-return profiles.

Research on long-term care insurance enrollment decisions and demand stratification in China based on deep learning

PS6

July 3
15:30

Shuqi Lin[1] **and Xiaolin Li**[2]

[1]*Central University of Finance and Economics, China, shuqilin@email.cufe.edu.cn*
[2]*Central University of Finance and Economics, China, lixl@cufe.edu.cn*

Keywords: long-term care insurance , deep learning, risk stratification, enrollment decisions

With the profound transformation of the global demographic structure, population ageing has become an increasingly pressing issue. In China, the proportion of individuals aged 65 and above has surpassed 14% Simultaneously, family structures are becoming smaller, and the traditional caregiving function of families is weakening, leading to an explosive surge in the demand for long-term care. However, conventional medical and pension insurance systems struggle to address long-term care needs comprehensively.

From an international perspective, long-term care insurance (LTCI) has evolved differently across various countries. Nations such as Germany and Japan have implemented mandatory insurance models, accumulating extensive experience in long-term care protection. In contrast, China remains in the pilot phase, where different cities are actively experimenting and exploring development paths that align with national conditions. Against this backdrop, conducting in-depth research on LTCI is both highly relevant and urgently needed.

In the field of LTCI, studies on enrollment decision-making mechanisms have long remained on the periphery, and there are substantial gaps in the application of risk stratification for precise demand forecasting. This study addresses these critical issues, offering significant practical implications. A thorough analysis of the enrollment decision-making process can illuminate the factors influencing consumer choices regarding LTCI and their behavioural logic, providing empirical support for policymakers in refining relevant policies. Meanwhile, applying scientific risk stratification for accurate demand forecasting enables the insurance industry to allocate resources more effectively. This study takes an innovative approach by integrating enrollment decision-making with risk stratification, applying them to LTCI demand prediction, thereby filling an important research gap.

This research utilizes data from the Chinese Longitudinal Healthy Longevity Survey (CLHLS) spanning 1998 to 2018 to obtain health indicators such as ADL/IADL disability levels, chronic disease prevalence, and family structure data. Additionally, data from the National Bureau of Statistics is incorporated to analyze per capita disposable income and the proportion of medical expenditures. International data, including LTCI lapse rates in the United States, the HRS database, and demographic structures in Singapore, are also referenced for comparative analysis.

Health status is categorized into five levels: healthy, mildly disabled, moderately disabled, severely disabled, and deceased. Based on this classification, risk stratification is conducted across three dimensions: health risk (ADL/IADL disability levels, chronic disease prevalence), economic risk (income levels, medical expenditure burden), and social risk (family support capacity, accessibility of community services). A logistic model is employed to analyze the factors influencing enrollment decisions and explain enrollment behaviours. Furthermore, the XGBoost model is used for feature selection and risk classification. Clustering analysis is applied to segment individuals into high-, medium-, and low-risk groups. Subsequently, the Markov process and logit model are utilized to estimate transition probabilities between different health states. Based on these transition probabilities, combined with a deep neural network model, this study assesses LTCI demand across different risk groups and forecasts enrollment demand for the next decade.

This paper proposes a "health-economic-social" three-dimensional risk stratification framework, integrating deep learning and actuarial models to enhance the accuracy of demand prediction. One limitation of this study is the inability to quantify the impact of cultural differences on enrollment willingness. Future research directions include exploring the application of artificial intelligence (such as large language models) in text mining for long-term care risk assessment and conducting cross-national comparative studies.

Mortality modeling comparison: using COVID-19 data

PS1

July 2
11:00

I-Chien Liu[1], **Ko-Lun Kung**[2]

[1]*Department of Insurance and Finance, National Taichung University of Science and Technology, Taichung, Taiwan, icliu@nutc.edu.tw*
[2]*Department of Risk Management and Insurance, Feng Chia University, Taichung, Taiwan, klkung@fcu.edu.tw*

Keywords: mortality model, COVID-19, predictive ability

The study attempts to find a good forecasting mortality model for COVID-19 (Coronavirus Disease 2019) data. We compare the Lee-Carter model and Mitchell et al. (2013) mortality model (M1 Model, M2 Mode, M3 Model), using Taiwan and U.S.A. mortality data from Human Mortality Database. We separate the in-sample and out-sample periods by 2019. Using RSSE (Root Sum Squared Error), RMSE (Root Mean Squared Error), and MAPE (Mean Absolute Percentage Error) criteria to determine the fitting and forecasting performance. We find Mitchell et al. (2013) mortality model is better than the Lee Carter Model for most of the data, but the Lee Carter Model is better than Mitchell et al. (2013) mortality model if the data with huge variations. Because of COVID-19, the U.S.A. mortality data is bigger, and the predictive ability of the Lee Carter Model is better than Mitchell et al. (2013) mortality model by MAPE.

Bibliography

[1] Mitchell, D., Brockett, P., Mendoza-Arriaga, R., Muthuraman K. (2013). Modeling and forecasting mortality rates. *Insurance: Mathematics and Economics* 52, 275–315.

Extremes for tail-based gini risk variability measures with varying risk preferences

PS5

July 3
13:30

Jiajun Liu[1] **and Haizhong Yang**[2]

[1]*Department of Financial and Actuarial Mathematics, Xi'an Jiaotong-Liverpool University, China, Jiajun.liu@xjtlu.edu.cn*

[2]*School of Statistics, Xi'an University of Finance and Economics, China, h.yang@163.com*

Keywords: tail-gini, regular variation, measure of variability, risk preferences

The crucial role of tail risk measures was highlighted by the global financial crisis of 2007-2009. However, the measurement of tail risk variability is less addressed in the literature. Covariance-based co-monotonically additive coherent variability measures is proposed by [1] with one popular measure of risk and variability called the Gini functional. [2] explores the extremes of the Tail-Gini functional based on the tail scenarios of a benchmark variable. In this paper, to reflect individual risk preferences towards the benchmark risk factor, we further studies Tail-based Gini functionals by incorporating a distortion function to the tail distribution of the benchmark variable, respectively, which allows for a more detailed evaluation of different tail risk events, accommodating varying levels of risk preferences. Asymptotic studies of these tail-based Gini functionals are conducted to provide a transparent way of investigating the interplay between heavy-tailedness, tail dependence, and the risk aversion parameter, as confidence levels approach extremities. We also offer numerical illustrations, including an analysis of the accuracy of our asymptotic results in various scenarios.

Bibliography

[1] Furman, E., Wang, R., Zitikis, R. (2017). Gini-type measures of risk and variability: Gini shortfall, capital allocations, and heavy-tailed risks, *Journal of Banking & Finance* 83, 70–84.

[2] Hou, Y., Wang, X. (2021). Extreme and inference for tail gini functionals with applications in tail risk measurement, *Journal of the American Statistical Association* 116(535), 1428–1443.

Pricing credit default swaps under central clearing

PS7
July 4
10:30

Haibo Liu[1], **Yuhao Liu**[2], **and Qihe Tang**[2]

[1]*Purdue University, USA, haiboliu@purdue.edu*
[2]*UNSW Sydney, Australia, yuhao.liu@unsw.edu.au*
[2]*UNSW Sydney, Australia, qihe.tang@unsw.edu.au*

Keywords: central counterparty, counterparty risk, credit default swaps, risk neutral pricing

In the aftermath of the global financial crisis, regulators worldwide have promoted the use of central clearing counterparties (CCPs) for credit default swaps (CDS) and other credit derivatives. While CCPs have greatly reduced counterparty risk and enhanced financial stability, they have simultaneously created a new risk channel, where a CCP's failure, though unlikely, could lead to catastrophic, systemically relevant consequences. To protect themselves, modern CCPs often implement loss-sharing rules to mutualize default losses among surviving members. Consider a centrally cleared CDS, where the buyer may be required to absorb losses from a CCP default as part of the recovery process. Consequently, the buyer is exposed to two layers of risk, stemming from both the default of the reference entity and the default of the CCP. Our goal is to develop a rigorous pricing framework for such CDS contracts. To achieve this, we model both losses from the reference entity's default and the CCP's default in a hybrid structure composed of two components: one contingent on historical information up to the time of default, and the other linked to the economic regime at the default and subject to additional unpredictability risk. Following the reduced-form approach, we assume that default intensities and interest rate jointly follow an affine jump-diffusion model, governed by the regime shifts of the economy. Extensive numerical studies are conducted to assess the impacts of regime-shift risk, unpredictability risk, and central clearing on CDS valuation.

Recommendations and challenges regarding the construction of climate change impact scenarios in health and life insurance

PS3

July 2
15:40

Stephane Loisel[1], **Adeline Stephan**[2] **and Rayane Vigneron**[3]

[1]*Conservatoire National des Arts et Métiers, Efab, Lirsa, Paris, France, stephane.loisel@lecnam.net*
[2]*Guy Carpenter, Paris, France*
[3]*UCBL,LSAF, Lyon, France, rayane.vigneron@yahoo.fr*

Keywords: climate change, stress tests, insurance

Following initial pilot stress test exercises proposed by insurance and banking regulators, insurance and reinsurance companies face the challenge to design climate change impact scenarios up to time horizons ranging from 2050 to 2100, much beyond the traditional 3 to 5-year view usually provided in their Own Risk and Solvency Assessment. We provide general recommendations for the construction of such scenarios and illustrate them in the context of health and mortality risks of a Metropolitan France insurer.

On the Determinants of long-term care intensity and duration in Switzerland: New insights from random forests modeling

PS6
July 3
15:30

Lucien Lorenz[1] **and Joël Wagner**[2]

[1]*Université de Lausanne, Switzerland, lucien.lorenz@unil.ch*
[2]*Université de Lausanne, Switzerland, joel.wagner@unil.ch*

Keywords: long-term care, random forest, empirical data

This study investigates the intensity of care and duration of stay of elder residents in long-term care institutions in the canton of Geneva, Switzerland. Available data span the years from 1998 to 2024 and include 26 060 individuals characterized by 54 covariates, including demographic information, medical records, and quality of life indicators, recorded upon entry into the institution. We propose a random forest model to select the most important variables and determine their marginal impact. Using the forest estimate and its distance measure, we apply HDBSCAN clustering. We identify the main determinants of the care intensity and stay duration by applying a classification task with respect to the covariates. We find a set of ten clusters for the intensity of care and five for the duration of stay. Our results indicate that the individual's level of dependence is consistently the most important predictor. While medical diagnoses are important, we find that other covariates, including gender and quality of life variables, are better predictors. When comparing the performance of our random forest approach with classical models, we find that it is superior in terms of R-squared to a beta regression for the intensity of care. For the duration of stay, it is more accurate in CRPS but yields a lower C-index than an accelerated failure time model. Our findings provide economic insights and guidance for optimizing resource allocation.

Valuation of GLWB riders in variable annuities with accumulation phase and long-term care option

PS3

July 2
15:40

Rosario Maggistro[1] **and Ivan Zoccolan**[2]

[1] *University of Trieste, Italy, rosario.maggistro@deams.units.it*
[2] *Generali Italia S.p.a., Milano, Italy, ivanzoccolan@gmail.com*

Keywords: long-term care, GLWB pricing, dynamic withdrawals, bang-bang condition, Lévy processes

In this paper, we propose a model for pricing GLWB variable annuities that consist of an initial accumulation phase followed by an income phase and explicitly incorporate the policyholder's health status through the long-term care (LTC) option. The latter implies the use of different guaranteed withdrawal rates depending on the policyholder's health status, which is modelled by a discrete random variable indicating whether the policyholder is healthy or in a state of permanent disability. Such insurance products also allow for additional purchases in the accumulation phase, dynamic withdrawals in the income phase, and complete surrender rights throughout the whole life of the contract. Following a risk-neutral approach, we define the initial contract value through a stochastic optimal control problem that is solved by exploiting dynamic programming. Another contribution of our study lies in verifying, via backward induction, the bang-bang condition for the set of dynamic withdrawal strategies that vary according to the policyholder's health status and the contract's phase. This verification will cover not only the income phase (as in Bacinello et al. [1]) but also the accumulation phase, showing that the optimal withdrawal strategies for policyholders are limited to a finite set of choices. This result, proven in our discrete time framework for the evolution of the policy account value, is particularly remarkable since, in the insurance literature, the existence of optimal bang-bang controls is either assumed or requires convexity and monotonicity of the contract value function for all times (as, e.g. Haung et al. [3]). In the numerical implementation of the model, we consider an exponential Lévy process for the asset price and use the technical bases for LTC insurance provided by Baione et al. [2], which are based on real data from the Italian Institute of Social Security (INPS). Moreover, by assuming a constant interest rate, we present an in-depth sensitivity analysis of the initial contract value, the contract fair fee and the optimal withdrawal strategy with respect to the contract parameters and gender.

Bibliography

[1] Bacinello, A.R., Maggistro, R., Zoccolan, I. (2024.) Risk-neutral valuation of GLWB riders in variable annuities. *Insur. Math. Econ.* 114, 1–14.

[2] Baione, F., Conforti, C., Levantesi, S., Menzietti, M., Tripodi, A. (2016). *Assicurazioni sulla salute: caratteristiche, modelli attuariali e basi tecniche*. chapter 4, Il Mulino, 123–196.

[3] Huang, Y.T., Zeng, P., Kwok, Y.K. (2017). Optimal initition of guaranteed lifelong withdrawal benefit with dynamic withdrawals. *SIAM Journal on Financial Mathematics* 8(1), 804–840

A hybrid machine learning approach for carbon price forecasting

PS1

July 2
11:00

Zezhun Chen[1], **Dimitris Christopoulos**[2], **Despoina Makariou**[3], **Joe Meagher**[4], **Andreas Tsanakas**[5], **George Tzougas**[6], **and Rui Zhu**[7]

[1]*Heriot-Watt University, UK*
[2]*Heriot-Watt University, UK, d.christopoulos@hw.ac.uk*
[3]*University of St Gallen, Switzterland, despoina.makariou@unisg.ch*
[4]*Hymans Robertson, UK, joe.meagher@hymans.co.uk*
[5]*City University of London, UK, a.tsanakas.1@citystgeorges.ac.uk*
[6]*Heriot-Watt University, UK, george.tzougas@hw.ac.uk*
[7]*City University of London, UK, rui.zhu@citystgeorges.ac.uk*

Keywords: hybrid ARIMA-LSTM model, carbon pricing forecasting, post-Brexit carbon market divergence

In this study, we develop a novel hybrid ARIMA-LSTM machine learning model to forecast carbon prices in the UK and EU Emissions Trading Systems (ETS). By combining linear time-series techniques with deep learning, the model captures complex dynamics in carbon pricing with improved accuracy over traditional benchmarks. We apply this model to investigate the impact of Brexit on the two ETS markets, identifying a post-Brexit divergence in carbon pricing behaviour. This divergence highlights the risk of carbon leakage driven by differing carbon pricing mechanisms and regulatory fragmentation. Our findings underscore the need for coordinated policies to address these disparities and emphasizing the importance of accurate forecasting models to manage carbon pricing risks and promote fair competition.

From aggregation functions to concordance measures

PS5

July 3
13:30

Martynas Manstavičius[1]

[1]*Vilnius University, Lithuania, martynas.manstavicius@mif.vu.lt*

Keywords: concordance measures, aggregation functions, copulas

Motivated by the work of Borroni [1], in this talk we will elaborate on a construction of new bivariate concordance measures from aggregation functions. Provided examples are generalizations of the well-known Spearman's ρ, Kendall's τ, Blomqvist's β, Gini's γ, etc., and facilitate in modeling dependence among random variables – a crucial aspect in risk management.

Bibliography

[1] Borroni, C. G. (2019). Mutual association measures, *Stat. Methods Appl.*, 28(4), 571–591.

Spatiotemporal data integration framework for improved flood cost and occurrence modeling in house insurance

PS1

July 2
11:00

Mulah Moriah[1], **Franck Vermet**[1], **Pierre Ailliot**[1] **and Philippe Naveau**[2]

[1]*Université de Bretagne Occidentale, France, mulah-chukwumam.moriah@etudiant.univ-brest.fr*
[2]*Laboratoire des Sciences du Climat et de l'Environnement LSCE-CNRS, France*

Keywords: flood modeling, spatial data integration, INLA approach, house insurance

Flooding is one of the most destructive climate hazards worldwide, causing nearly $100 billion in damages between 2013 and 2023. Insurers play a crucial role in mitigating the financial burden on affected communities, yet accurately modeling flood risk remains a challenge due to the complex interactions between environmental, geographic, and structural factors. Traditionally, insurers rely on generalized linear models (GLMs) in a two-step approach, where flood occurrence and cost are modeled separately, often supplemented with external spatial data in a second step. Spatial data integration has long been a key component of insurance modeling, significantly improving risk assessment across various lines of business. However, in the context of climate-related risks, where exposure is inherently linked to geography and environmental conditions, leveraging spatial data becomes even more critical.

In this presentation, we propose a spatiotemporal Bayesian hierarchical model that allows for a more comprehensive integration of diverse data sources, including insurer data, meteorological observations, expert climate assessments, and structural characteristics of buildings and their surroundings. This model accounts for spatial heterogeneity and temporal dynamics by leveraging a latent Gaussian process and a structured dependency framework. It is calibrated using claims and contracts data provided by an insurer, and we assess its performance in comparison to the conventional two-step GLM framework, focusing on predictive accuracy, spatial segmentation, and the added value of richer data integration.

Competitive insurance pricing in a duopoly

PS6
July 3
15:30

Fotios Mourdoukoutas[1], Tim J. Boonen[2], Bonsoo Koo[3] and Athanasios A. Pantelous[4]

[1]*University College Dublin, Ireland, fotios.mourdoukoutas@ucd.ie*
[2]*The University of Hong Kong, Hong Kong SAR, China, tjboonen@hku.hk*
[3]*Monash University, Australia, bonsoo.koo@monash.edu*
[4]*Monash University, Australia, athanasios.pantelous@monash.edu*

Keywords: risk management, game theory, Stackelberg equilibrium, Nash equilibrium, insurance duopoly

A single-period stochastic insurance duopoly is formulated to examine the pre-assignment of roles to the insurance game's players. This paper considers two information structures. In the first structure, one insurer assumes the role of the Stackelberg leader by setting the premium first, while the competitor, acting as the Stackelberg follower, responds after observing the leader's premium. In the second structure, both insurers act as Nash players, setting premiums simultaneously without considering the competitor's premium. This paper shows the existence of Stackelberg and Nash equilibria in these settings and identifies which information structure leads to superior utility when the decision to disclose the premium to the competitor is endogenous. A decision game is developed to determine the conditions under which both insurers prefer sequential over simultaneous premium setting in terms of utility.

Simultaneous valuation of liabilities on a Markovian regime switching interest rate and default intensity model

PS4

July 3
10:30

Yukio Muromachi[1]

[1] *Tokyo Metropolitan University, Japan, muromachi-yukio@tmu.ac.jp*

Keywords: interest rate, credit quality, term structure, regime switching, Asset Liablity Management

In certain financial regulations, formula-based approaches are used to calculate the values associated with financial risk. However, to understand and assess the risk better, it would be beneficial for each financial institution to simultaneously simulate the states of various assets and liabilities using a unified stochastic model. This model should consistently represent both normal and highly stressed economic conditions. We have already proposed one such model in which an economic regime changes stochastically. We demonstrated numerically that these regime changes can sometimes lead to drastic behaviors in the term structures of interest rates. In this talk, we present several numerical examples that demonstrate the joint evaluation of assets and liabilities based on the model.

A financial institution has different types of assets and liabilities. They cannot be consistently evaluated by a single measure such as market price, but their risk characteristics are highly dependent on different interest rates with different maturities and credit ratings. Our stochastic model is based on the framework proposed by Kijima and Muromachi [2], which uses no-arbitrage pricing (based on market prices). We use this concept to construct term structures of interest rates for evaluating assets and liabilities. The economic regime with Markovian switching property has such a strong impact on the interest rate and default intensity processes that different shapes of term structures of interest rates would appear in the future. For example, many are positive normal yield curves, but some are negative up to several years, some are humped, some are inverted with high short rates and low long rates, and so on.

For theoretical and mathematical details, see Muromachi [3], who extended the regime-switching stochastic short rate model of Elliott and Siu [1] to a stochastic short rate and default intensity model. He discussed (a) the dynamics of regime, short rate, and default intensity under the physical probability measure P, and (b) the dynamics of changing the measure, from P to the pricing (risk-neutral) probability measure Q, represented by the market prices of intrinsic stochastic factors. The dynamics under Q are derived from (a) and (b) and can be used to generate the term structures of interest rates using no-arbitrage theory. Although the excellent calibration results were difficult to obtain for all model parameters, we have found consistent estimates with observed data, such as time series data of short rates and credit spreads, and term structures of cumulative default rates with different credit ratings.

Following the framework of Kijima and Muromachi [2], we use a Monte Carlo simulation to evaluate future financial risk. The future yield curves generated by the simulations are used in common to evaluate all assets and liabilities. For example, prices (fair values) are calculated for bonds and corporate loans, interest rate sensitive prepayment cash flows for mortgages, and volumes for term and non–maturity deposits. The calculated values are combined into a joint distribution of the characteristic features (prices, losses, volumes...) of the asset and liability classes. This information is not sufficient for financial risk management, especially asset liability management (ALM), but we hope it will be useful for future discussions.

Bibliography

[1] Elliott, R. J. and Siu, T. K. (2009). On Markov-modulated exponential-affine bond price formulae. *Applied Mathematical Finance*, 3 (1), 1–15.

[2] Kijima,M., Muromachi, Y. (2000). Evaluation of credit risk of a portfolio with stochastic interest rate and default processes. *Journal of Risk*, 3 (1), 5–36.

[3] Muromachi, Y. (2023). *A term structure model of default-free and defaultable interest rates with regime-switching properties: useful tool for risk evaluation*. Research Paper Series 46, Graduate School of Management, Tokyo Metropolitan University.

Parametric insurance under solvency and acceptability constraints

PS4
July 3
10:30

Daniel Nkameni[1], **Antoine Heranval**[2] **and Olivier Lopez**[3]

[1]*CREST Laboratory, Polytechnic Institute & Detralytics, France, daniel.nkameni@ensae.fr*
[2] *INRAE BioSP, France, antoine.heranval@inrae.fr*
[3] *CREST Laboratory, Polytechnic Institute, France, olivier.lopez@ensae.fr*

Keywords: parametric insurance, expected utility, demand in insurance, acceptability of insurance

Parametric insurance is often cited as a way to reduce protection gaps, particularly in the context of emerging risks. Unlike traditional insurance, compensation is determined based on a parameter (or index) that can be measured shortly after a claim event occurs. The key advantage is the speed of payment, which can be highly appealing to policyholders who need immediate funds to recover after an incident, rather than waiting for an on-site assessment by an expert. For insurers, claim management costs are significantly reduced. Additionally, risk volatility is generally controlled since, by design, the selected parameter is a quantity for which a substantial amount of data has been collected, allowing for a statistically robust estimation of its distribution. As with any insurance product, the viability of index insurance depends on its acceptability by policyholders and, consequently, on its ability to achieve risk mutualization. Indeed, mutualization is possible only if a sufficiently large number of policyholders choose to subscribe. The objective of this paper is to introduce a model for parametric insurance demand and to establish the conditions, in terms of the number of subscribers, under which portfolio solvency is ensured. Additionally, we propose an algorithm to identify policyholders likely to accept compensation through parametric insurance in situations where they have the option of receiving either parametric or traditional indemnification. The framework developed in this study aims to leverage the advantages of both approaches.

Tennis model in betting: Grand Slam analysis

PS6
July 3
15:30

Rita Norbutaitė[1]

[1]*Vilnius University, Lithuania, rita.norbutaite@mif.stud.vu.lt*

Keywords: insurer's ruin, ruin probability, variance, mean-variance analysis

Tennis is a racket sport played in a rectangular area, called court, by individual players (singles) on each side or teams of two players (doubles). Due its hierarchical complexity, tennis is a widely analyzed sport in mathematics and there are many ways to predict tennis matches. Talking from bookmakers side it is important to find the most reliable model to maximize profit and minimize risk. For this purpose we applied both investors and actuarial approaches to the selected tennis mathematical model to evaluate expected profit and risk. For our analysis, we used data of Grand Slam (Australian Open, Roland Garros, US Open, and Wimbledon) tournaments. We predicted the results of the tournaments in 2024 using data of each tournament qualification and past years' performance. Using different betting techniques and several different model parameters we predicted bookmaker's expected profit, risk and ruin probability.

Life-cycle investment under subjective survival beliefs with deferred annuities, housing and home equity release

PS7

July 4
10:30

Iqbal Owadally[1] **and Chul Jang**[2] **and Seung Yeon Jeong**[3]

[1]*Bayes Business School, City St George's, University of London, UK, iqbal@city.ac.uk*
[2]*Nottingham University Business School, Nottingham, UK, Chul.Jang@nottingham.ac.uk*
[3]*Sungkyunkwan University, South Korea, Seung.Jeong@city.ac.uk*

Keywords: portfolio optimization, consumption, reverse mortgage, stochastic programming

We examine life-cycle consumption, investment, and housing decisions when a risk-averse individual holds subjective survival beliefs which deviate from actuarial survival probabilities. Younger individuals often exhibit pessimistic survival beliefs, whereas older individuals tend to be more optimistic [1]. Numerical analysis using multistage stochastic programming [2, 3] shows that subjective survival beliefs can lead young individuals to save less, invest less in equity, and prefer renting to ownership for housing. This results in lower wealth accumulation over their lifetime and reduced consumption in retirement. We also investigate how the decisions change when deferred annuities and home equity release are available as retirement income sources. Availability of these products can lead individuals with subjective beliefs to reduce consumption in early ages, increase housing ownership, and improve wealth accumulation over their lifetime. Overall, these products narrow the welfare gaps between individuals with subjective and objective survival beliefs across different ages.

Bibliography

[1] Jeong, S. Y., Owadally, I., Haberman, S., Wright, D. (2025). Subjective survival beliefs and the life-cycle model. *Insurance: Mathematics and Economics*, 122, 11–29.

[2] Jang, C., Owadally, I., Clare, A., Kashif, M. (2022). Lifetime consumption and investment with housing, deferred annuities and home equity release. *Quantitative Finance*, 22(1), 129–145.

[3] Owadally, I., Jang, C., Clare, A. (2021). Optimal investment for a retirement plan with deferred annuities. *Insurance: Mathematics and Economics*, 98, 51–62.

On the insurance of environmental risks: modeling and pricing with mean-reverting regime-switching Lévy processes

PS1

July 2
11:00

Aleksandr Pak,[1] **Olivier Le Courtois,** [2] **Lorenz Schneider** [3]

[1]*EM Lyon, France, pak@em-lyon.com*
[2]*EM Lyon, France, lecourtois@em-lyon.com*
[3] *EM Lyon, France, SCHNEIDER@em-lyon.com*

Keywords: climate risk, non-life insurance, temperature, rainfall, soil, Lévy process, regime-switching, mean-reversion, seasonality

The insurance business is a core component of the economic system, which is faced with expanding environmental challenges. By adequately protecting against climate risks, insurance companies are an important factor in ensuring that other businesses persist and grow. The claims associated with environmental risks, such as shrinking soils or hail, are quickly increasing in both severity and frequency, where predictability is an additional key concern for insurance companies. This paper constructs and compares several models to tackle and price environmental risks. These models mean-revert towards a seasonality function, present jumps with infinite arrival rates - via Lévy processes, and display a regime switching nature to allow for a variety of scenarios for the coming future years. We introduce structural and reduced-form frameworks, that is, frameworks that are more phenomenological or more efficiency-based. An empirical illustration and a sensitivity analysis conclude the paper.

Fluctuations of Omega-killed level-dependent spectrally negative Lévy processes and the probability of bankruptcy

PS5

July 3
13:30

Zbigniew Palmowski[1], **Meral Şimşek**[2], **and Apostolos D. Papaioannou**[3]

[1]*Wrocław University of Science and Technology, Poland, zbigniew.palmowski@pwr.edu.pl*
[2]*Middle East Technical University, Turkey, smeral@metu.edu.tr*
[3] *University of Liverpool, Great Britain, papaion@liverpool.ac.uk*

Keywords: ruin probability, level-dependent risk process, Lévy process

In this talk we show how to solve exit problems for a level-dependent Lévy process which is exponentially killed with a killing intensity that depends on the present state of the process. Moreover, we analyse the respective resolvents. All identities are given in terms of new generalisations of scale functions (counterparts of the scale function from the theory of Lévy processes), which are solutions of Volterra integral equations. Furthermore, we obtain similar results for the reflected level-dependent Lévy processes. The existence of the solution of the stochastic differential equation for reflected level-dependent Lévy processes is also discussed. Finally, the probability of bankruptcy is obtained for an insurance Lévy risk process.

Multivariate strong subexponential distributions: properties and applications

PS7

July 4
10:30

Charalampos D. Passalidis[1]

[1]*University of the Aegean, Greece, sasm23002@sas.aegean.gr.*

Keywords: multivariate heavy-tailed distributions, convolution of random vectors, randomly stopped sums, precise large deviations in multivariate set up, nonstandard risk model, uniformity

In this paper we introduce and study the class of multivariate strong subexponential distributions and of multivariate strongly subexponential distributions. Some first properties are verified, as a type of multivariate analogue of Kesten's inequality, the closure property with respect to the convolution and the conditional closure property with respect to convolution roots. Next, we establish the the single big jump principle for the randomly stopped sums, under the assumption that the random vectors in the summation belong to the class of multivariate strong subexponential distributions. Here the conditions of the counting random variable are weaker in comparison with them in multivariate subexponential class. Further, we establish uniform asymptotic estimates for the precise large deviations in multivariate set up, both for random and non-random sums, when the distribution of the summands belongs to the class of multivariate strongly subexponential distributions. Finally, we provide an application in a non-standard risk model, with independent and identically distributed claim vectors, from the class of multivariate strong subexponential distributions and in the presence of constant interest force. Namely, the common counting process of the claim vectors constitutes of inter-arrival times, that are independent but not necessarily identically distributed. Under some additional condition, on the 'heavyness' of the counting process tail, we establish a uniform asymptotic estimate for the ruin probability in this model.

Hybrid risk processes: a robust framework for modern ruin problems

PS5

July 3
13:30

Oscar Peralta[1] **and Hansjoerg Albrecher**[2]

[1]*Autonomous Technological Institute of México, México, oscar.peralta@itam.mx*
[2]*University of Lausanne, Switzerland, hansjoerg.albrecher@unil.ch*

Keywords: ruin probabilities, hybrid stochastic differential equations, reserve-dependent risk processes, diffusion risk processes

Based on [1], we introduce a novel class of risk processes that employs hybrid stochastic differential equations, providing a unified framework which captures a wide range of actuarial models. This class accommodates both jump and diffusion dynamics, allowing for features such as reserve-dependent adjustments, dividend strategies, and other structural complexities commonly encountered in insurance risk modeling. The framework also facilitates the analysis of generalized notions of ruin, including Parisian, Omega, and Poissonian ruin. Moreover, it enables the efficient computation of key risk measures, making it a versatile tool for both theoretical and practical applications.

Bibliography

[1] Albrecher, H., Peralta, O. (2022). Space-grid approximations of hybrid stochastic differential equations and first passage properties. *arXiv preprint arXiv:2211.01844*.

Credible distribution estimation with deductible, policy limit and reinsurance layers

PS6

July 3
15:30

Georgios Pitselis

University of Piraeus, Greece, pitselis@unipi.gr

Keywords: credible distribution, deductible, policy limit, reinsurance layers

The purpose of this paper is to approximate the true distribution of the next observation using credibility theory for ordinary (and franchise) policy deductibles, as well as for policies that include both limits and deductibles. The credibility methodology is also extended to excess-of-loss reinsurance policies with multiple reinsurance layers. Additionally, credibility estimators are established, and a numerical example is provided by using insurance loss data.

Disentangling risk and time for optimal prevention

PS6
July 3
15:30

Yichun Chi[1], **Richard Peter**[2] **and Mengjia Qi**[3]

[1]*China Institute for Actuarial Science, Central University of Finance and Economics, Beijing 102206, China. E-Mail: yichun@cufe.edu.cn*

[2]*Tippie College of Business, University of Iowa, Iowa City 52242, USA. E-Mail: richard-peter@uiowa.edu*

[3]*School of Insurance, Central University of Finance and Economics, Beijing 102206, China. E-Mail: qimengjia33@163.com*

Keywords: Kreps–Porteus-Selden preferences, prevention, self-protection, risk preference, prudence

We examine the effect of prudence on prevention in two periods using [Kreps and Porteus(1978)] and [Selden(1978)] (KPS) preferences, with consumption smoothing as the benchmark. In this framework, prudence has a positive effect on prevention, extending the findings of [Menegatti(2009)]. We generalize our results to risk lovers and comparative risk aversion. When saving is endogenized, the preference over the timing of uncertainty resolution becomes irrelevant, and only the curvature of marginal utility matters. This result allows us to identify a class of (im)prudent decision-makers whose effort choice is identical to that of the risk-neutral agent. Our findings highlight that the structure of intertemporal preferences critically shapes the link between prudence and prevention.

Bibliography

[Kreps and Porteus(1978)] Kreps, D.M., Porteus, E.L. (1978). Temporal resolution of uncertainty and dynamic choice theory. *Econometrica*, **46(1)**, 185-200.

[Menegatti(2009)] Menegatti, M. (2009). Optimal prevention and prudence in a two-period model. *Mathematical Social Sciences*, **58(3)**, 393-397.

[Selden(1978)] Selden, L.(1978). A new representation of preferences over “certain x uncertain" consumption pairs: The “ordinal certainty equivalent" hypothesis. *Econometrica*, **46(5)** 1045–1060.

The design of optimal insurance contracts: an approach of Lipschitz neural networks

PS3

July 2
15:40

Yichun Chi[1], **Tingdi Ren**[2] **and Jingong Zhang**[3]

[1]*Central University of Finance and Economics, China, yichun@cufe.edu.cn*
[2]*Central University of Finance and Economics, China, tingdiren@email.cufe.edu.cn*
[3]*Nanyang Technological University, Singapore, jgzhang@ntu.edu.sg*

Keywords: insurance design, incentive-compatible constraint, algorithm efficiency, neural networks, endogenous default

Many optimal insurance design problems with incentive-compatible (IC) constraints lack closed-form solutions and efficient numerical methods. This paper proposes a novel algorithm to obtain numerical solutions by parameterizing the indemnity function using a Lipschitz Multilayer Perceptron (MLP) architecture. To incorporate the principle of indemnity and IC constraints, we introduce constrained affine transformation layers and a specialized activation function while preserving the MLP's universal approximation capability. Our proposed architecture can be trained using a standard gradient descent algorithm to derive optimal indemnity functions with an acceptable error margin. We demonstrate the accuracy and efficiency of this approach by comparing its solutions to analytical ones in several classic insurance design models. In addition, we apply our method to the optimal insurance problem with a dependent endogenous default background risk—an open problem in the literature—demonstrating its effectiveness in solving general optimal insurance design problems.

Granular mortality modeling with temperature and epidemic shocks: a three-state regime-switching approach

PS4

July 3
10:30

Jens Robben[1], **Karim Barigou**[2], **and Torsten Kleinow**[3]

[1]*Research Centre for Longevity Risk (RCLR), University of Amsterdam, The Netherlands, j.robben@uva.nl*
[2]*Institute of Statistics, Biostatistics and Actuarial Science (ISBA), Louvain Institute of Data Analysis and Modeling (LIDAM), UCLouvain, Louvain-la-Neuve, Belgium, karim.barigou@uclouvain.be*
[3]*Research Centre for Longevity Risk (RCLR), University of Amsterdam, The Netherlands, t.kleinow@uva.nl*

Keywords: granular mortality modeling, regime-switching, environmental shocks, respiratory shocks

This presentation introduces a granular regime-switching framework to model mortality deviations from seasonal baseline trends driven by temperature and epidemic shocks. The framework features three states: (1) a baseline state that captures observed seasonal mortality patterns, (2) an environmental shock state for heat waves, and (3) a respiratory shock state that addresses mortality deviations caused by strong outbreaks of respiratory diseases due to influenza and COVID-19. Transition probabilities between states are modeled using covariate-dependent multinomial logit functions. These functions incorporate, among others, lagged temperature and influenza incidence rates as predictors, allowing dynamic adjustments to evolving shocks. Calibrated on weekly mortality data across 21 French regions and six age groups, the regime-switching framework accounts for spatial and demographic heterogeneity. Under various projection scenarios for temperature and influenza, we quantify uncertainty in mortality forecasts through prediction intervals constructed using an extensive bootstrap approach. These projections can guide healthcare providers and hospitals in managing risks and planning resources for potential future shocks.

Bibliography

[1] Robben, J., Barigou, K., Kleinow, T. (2025). Granular mortality modeling with temperature and epidemic shocks: a three-state regime-switching approach. *arXiv preprint arXiv:2405.18020*

Non-parametric free-knot spline density and distribution estimation for heavy-tailed data

PS6

July 3
15:30

Dimitrina S. Dimitrova[1], **Vladimir K. Kaishev**[1] **and Emilio L. Sáenz Guillén**

[1]*Faculty of Actuarial Science and Insurance, Bayes Business School, City St George's, University of London, D.Dimitrova@citystgeorges.ac.uk, Vladimir.Kaishev.1@citystgeorges.ac.uk, Emilio.Saenz-Guillen@citystgeorges.ac.uk*

Keywords: nonparametric density estimation, variable-knot splines, boundary bias, heavy-tailed distributions, risk measures

We introduce a novel free-knot spline method for the simultaneous estimation of the probability density function (pdf) and cumulative distribution function (cdf) of a random variable based on a given data sample. The proposed method, named DDFS, uses the property that both the pdf and cdf share a common set of knots and coefficients that are connected. The method comprises a sequential estimation of the knots using minimum distance, followed by maximum likelihood estimation of the coefficients, and it is readily applicable to both univariate and bivariate cases. We further show, that the underlying spline representation of the pdf (cdf) can be viewed as a mixture of linear combinations of Dirichlet random variables. This allows us to establish strong consistency and asymptotic normality of the DDFS estimates. Furthermore, numerical and graphical results demonstrate that the DDFS method constitutes a highly competitive alternative to well-established, state-of-the-art density estimation methods, such as kernel density estimation and logsplines (see [2]).

We illustrate the flexibility of the DDFS method through an application to modelling heavy-tailed insurance claims data, an area where composite and mixture distributions have gained particular attention in the recent actuarial literature (see, e.g., [1] and [3]). In this regard, DDFS proves to be capable of handling heavy tails effectively, while eluding cumbersome model selection.

Bibliography

[1] Abu Bakar, S.A., Hamzah, N.A., Maghsoudi, M., Nadarajah, S. (2015). Modeling loss data using composite models. *Insurance: Mathematics and Economics* 61, 146–154.

[2] Kooperberg, C., Stone, C.J. (1991). A study of logspline density estimation. *Computational Statistics & Data Analysis* 12(3), 327–347.

[3] Miljkovic, T., Grün, B. (2016). Modeling loss data using mixtures of distributions. *Insurance: Mathematics and Economics* 70, 387–396.

The credibility transformer

PS4
July 3
10:30

Ronald Richman[1], **Salvatore Scognamiglio**[2] **and Mario V. Wüthrich**[3]

[1]*InsureAI and University of the Witwatersrand, ronald.richman@ominsure.co.za*
[2]*Department of Management and Quantitative Sciences, University of Naples "Parthenope", salvatore.scognamiglio@uniparthenope.it*
[3]*RiskLab, Department of Mathematics, ETH Zurich, mario.wuethrich@math.ethz.ch*

Keywords: transformer, credibility, tabular data, feature-engineering, entity embedding

Inspired by the remarkable success of Transformer architectures [3] in the development and advancement of Large Language Models, there has been a growing interest in applying these powerful architectures to the domain of tabular data. The key to this adaptation lies in the effective transformation of tabular data into low-dimensional Euclidean spaces, allowing them to assume similar structures as time-series data [2].

In this work, we propose an innovative enhancement to the Transformer architecture through the introduction of a novel credibility mechanism [1]. This mechanism is designed to improve the model's ability to integrate and balance prior knowledge with new observational data, thereby enhancing its robustness and predictive performance. At the core of this credibility mechanism is a specialized token, which functions as an encoder that captures a weighted average of two distinct types of information: prior information derived from historical data or domain knowledge, and observation-based information obtained from the current input features. The weights assigned to each type of information reflect their respective credibility, ensuring that the model can dynamically adjust the importance of prior beliefs versus new evidence based on the context of the data.

Bibliography

[1] Bühlmann, H., Straub, E. (1970). Glaubwürdigkeit für Schadensätze. *Bulletin of the Swiss Association of Actuaries* **1970**, 111-131.

[2] Gorishniy, Y., Rubachev, I., Khrulkov, V., Babenko, A. (2021). Revisiting deep learning models for tabular data. In: Beygelzimer, A., Dauphin, Y., Liang, P., Wortman Vaughan, J. (eds). *Advances in Neural Information Processing Systems*, **34**. Curran Associates, Inc., New York, 18932-18943.

[3] Vaswani, A., Shazeer, N., Parmar, N., Uszkoreit, J., Jones, L., Gomez, A.N., Kaiser, Ł., Polosukhin, I. (2017). Attention is all you need. *arXiv*:1706.03762v5.

Optimal investment for retirement with intergenerational benchmarking

PS5
July 3
13:30

Luke Servat [1] **and Antoon Pelsser**[2]

[1]*Maastricht University and Netspar, The Netherlands, luke.servat@maastrichtuniversity.nl*
[2]*Maastricht University and Netspar, The Netherlands, a.pelsser@maastrichtuniversity.nl*

Keywords: optimal investment, intergenerational comparisons, retirement, external habit formation

Over the last few decades, more and more countries have seen their second pillar transition to a defined contribution scheme. As this results in pensions that are highly sensitive to market returns, this can create large differences between generations. Therefore, we investigate in this paper whether we can already prevent unlucky generations, by changing only the investment strategy during the accumulation phase. More specifically, we consider generations in *autarky*, i.e., where every generation only invests for themselves, without any wealth transfers between generations. We include the presence of unlucky generations (or cohorts) in our model by assuming a "catching up with the Joneses" utility function [1]. This means that we adapt the utility function such that a cohort not only looks at their own accumulated wealth at retirement, but also compares this to the wealth of the preceding cohort at retirement, bearing a strong resemblance to external habit formation models.

We solve this model in closed form and find that the solution differs substantially from the optimal investment that is found for standard CRRA utility. First, we observe a much lower exposure to the market at the start and end of the accumulation phase. Then, we increase the level of exposure in the large interval in between to compensate for the lower exposure in these other intervals. The more importance a cohort attaches to this external habit, the longer the period of lower exposure takes and the higher the exposure during the intermediate interval. Furthermore, if we consider the investment strategy in terms of financial wealth, rather than total wealth, we observe a strong similarity to the rule of thumb that tells us we need to invest $(100 - \text{age})\%$ in the risky asset.

To demonstrate the effect of the new investment strategy on pensions, we include a few scenario trajectories and conduct an impulse-response analysis. These simulations show that differences between closely following cohorts are indeed strongly reduced. Whereas the classical CRRA strategy can lead to a volatile movement of pensions over generations, the "catching up with the Joneses" strategy smooths these pensions out, while on average the level of pension capital is not reduced. We also see that the CUJ investment strategy spreads the effect of a shock in the asset value over multiple years, meaning the differences in pension capitals between consecutive cohorts are reduced. In total, the simulations show that the CUJ investment strategy effectively reduces the probability of unlucky generations. Finally, we show that the CUJ strategy is robust to misspecification of the utility function.

Bibliography

[1] Abel, A. B. (1990). Asset prices under habit formation and catching up with the Joneses. *American Economic Review*, 80(2), 38–42.

The technical concepts and training approaches that power GPT models

PS5

July 3
13:30

Arnold Shapiro[1]

[1]*Penn State University, U.S.A., afs1@psu.edu*

Keywords: Generative Pre-trained Transformer (GPT), fine-tuning, tokenization, attention, positional encoding, vector representation, embedding

Generative Pre-trained Transformer (GPT) technology is increasingly becoming a part of the insurtech industry, where GPT models are used to enhance various features of risk management [2] and insurance models [1].

Such applications notwithstanding, empirical evidence seems to indicate that users who had previously been exposed to GPT models like Chat GPT, or one of the ensuing links, CoPilot (Microsoft) or Gemini (Google), usually did not know how and why these GPT models work.

Assuming this to generally be the case, this presentation addresses this lack of knowledge issue by providing an overview of the technical concepts and training approaches that power GPT models. In addition to the topics mentioned in the keywords, the following topics will also be discussed: data collection and preprocessing, human-in-the-loop, parameters, pre-training, reinforcement learning, and residual connection.

The talk will conclude with a commentary.

Bibliography

[1] Biswas, S. (2023). Using ChatGPT for insurance: current and prospective roles. *SSRN Electronic Journal*, available at https://ssrn.com/abstract=4405394.

[2] Hofert, M. (2023). Assessing ChatGPT's proficiency in quantitative risk management. *SSRN Electronic Journal*, available at *https://papers.ssrn.com/sol3/papers.cfm?abstract_id=4444104*.

On variable annuities with surrender charges

PS2
July 2
14:00

Gabriele Stabile[1], **Tiziano De Angelis**[2] **and Alessandro Milazzo**[2]

[1]*University Sapienza of Roma, Italy, gabriele.stabile@uniroma1.it*
[2]*University of Torino, Italy, tiziano.deangelis@unito.it, alessandro.milazzo@unito.it*

Keywords: variable annuities, surrender option, surrender charge, optimal stopping

In this paper we provide a theoretical analysis of Variable Annuities (VAs) with a focus on the holder's right to an early termination of the contract. Motivated by risk-management considerations, and in line with existing literature (see [2], [1] among others), we assume that the surrender option is optimally exercised from a purely financial perspective (i.e., we consider the worst-case scenario for the insurer). In this context, we rigorously derive the pricing formula for the VA and characterise the optimal surrender time. We also illustrate our theoretical results with extensive numerical experiments.

The pricing problem is formulated as an optimal stopping problem with a time-dependent payoff which is discontinuous at the maturity of the contract and non-smooth. This structure leads to non-monotonic optimal stopping boundaries which we prove nevertheless to be continuous and regular in the sense of diffusions for the stopping set. From an actuarial and financial perspective we contribute: (i) rigorous derivations of a pricing formula for the VA and of an optimal surrender strategy (in terms of an optimal surrender boundary), and (ii) an extensive numerical sensitivity analysis of the VA's price and surrender boundary with respect to model parameters.

Bibliography

[1] Kirkby, J.L., Aguilar, J.P. (2023). Valuation and optimal surrender of variable annuities with guaranteed minimum benefits and periodic fees. *Scand. Actuar. J.* 6, 624–654.

[2] MacKay, A. , Augustyniak, M., Bernard, C., Hardy, M.R. (2017). Risk management of policyholder behavior in equity-linked life insurance. *J. Risk Insurance* 84, 661–690.

One-year and ultimate correlations in dependent claims run-off triangles

PS4
July 3
10:30

Łukasz Delong[1] **and Marcin Szatkowski**[2]

[1]*University of Warsaw, Poland, lukasz.delong@sgh.waw.pl*
[2]*Infiro Foundation and Modelarium, Poland, marcin.szatkowski@infiro.pl*

Keywords: ultimate correlation, one-year correlations, claims reserving, Hertig's lognormal model, Solvency II, IFRS 17

We investigate bottom-up risk aggregation applied by insurance companies facing reserve risk from multiple lines of business. Since risk capitals should be calculated in different time horizons and calendar years, depending on the regulatory or reporting regime (Solvency II vs IFRS 17), we study correlations of ultimate losses and correlations of one-year losses in future calendar years in lines of business. We consider a multivariate version of a Hertig's lognormal model, see e.g. in [1] and [2], and we derive analytical formulas for the ultimate correlation and the one-year correlations in future calendar years. Our main conclusion is that the correlation coefficients which should be used in a bottom-up aggregation formula depend on the time horizon and the future calendar year where the risk emerges. We investigate analytically and numerically properties of the ultimate and the one-year correlations, their possible values observed in practice and the impact of misspecified correlations on the diversified risk capital.

Bibliography

[1] Merz, M., Wüthrich, M. V., Hashorva, E. (2012). Dependence modelling in multivariate claims run-off triangles. Annals of Actuarial Science 7, 3-25.

[2] Wüthrich, M. V. (2015). Stochastic Claims Reserving Manual: Advances in Dynamic Modeling. SSRN.

Memory in temperature and its impacts on weather insurance and derivatives under a fractional Ornstein-Uhlenbeck process

PS7

July 4
10:30

Jayen Tan[1,2]

[1]*Cornell University, jt734@cornell.edu*
[2]*Nanyang Technological University*

Keywords: weather insurance and derivatives, fractional Ornstein-Uhlenbeck process, long-range dependency, temperature modeling, climate change

Despite the high persistence observed in temperature series, most prevailing statistical temperature models and weather contract valuation methodologies do not adequately account for long-range dependency, potentially leading to suboptimal temperature forecasts and mispricing of weather-related contracts. In response, we propose the generalized fractional Ornstein-Uhlenbeck (gfOU) process, which captures the trends, seasonality, mean reversion, and long-range dependence inherent in temperature data. We further derive a simplified covariance formula for the stationary fractional Ornstein-Uhlenbeck process and evaluate the consequences of model misspecification when memory effects are erroneously omitted.

For the valuation of temperature-linked contracts, we derive closed-form expressions for both the payoff frequency and the expected payoff based on the gfOU temperature process. We demonstrate that our model yields more accurate payoff predictions and enhances insurer profitability within a Bertrand competitive game. Our empirical analysis further validates the presence of temperature persistence across the United States and reveals significant regional variations over recent decades. Additionally, we present evidence that the restricted gfOU model outperforms its benchmark gOU counterpart and the Burn approach in forecasting the payoffs of temperature-linked contracts.

Practical GenAI use cases in insurance analytics

PS1

July 2
11:00

Liivika Tee[1]

[1]*Finity Consulting, Sydney, Australia, Liivika.Tee@finity.com.au*

Keywords: generative AI, large language models, insurance analytics, text classification, unstructured data, predictive modelling

Generative AI (GenAI) is rapidly becoming part of the analytics toolkit in insurance, supporting use cases such as streamlining underwriting processes and enhancing customer interactions. This presentation shares lessons learned from real-world implementations, focusing on applications like classifying unstructured text into meaningful categories, clustering textual data to uncover insights, and creating features that strengthen predictive models. Through concrete examples, the session explores how GenAI methods can complement existing analytical practices, highlighting both their potential and the practical challenges involved in their integration.

On the ruin probability of insurer-reinsurer model for phase-type distributed losses

PS4

July 3
10:30

Krzysztof Burnecki, Zbigniew Palmowski, Aleksandra Wilkowska, Marek A. Teuerle [1],

[1] *Wrocław University of Science and Technology, Poland*
marek.teuerle@pwr.edu.pl

Keywords: two-dimensional risk process, quota-share reinsurance, ruin probability, phase-type distribution

We consider a specific model of multidimensional risk process that describes a capitals of insurer and reinsurer that agreed for a quota-share proportional reinsurance treaty over an unique line of business [1, 2, 3]. It means that both companies are subjected to the same losses that are covered by them in some fixed percentage parts given by the quota-share parameter. The proposed model of the capitals of insurer and reinsurer is the following

$$\begin{pmatrix} R_1(t) \\ R_2(t) \end{pmatrix} = \begin{pmatrix} x_1 \\ x_2 \end{pmatrix} + \begin{pmatrix} p_1 \\ p_2 \end{pmatrix} t - \begin{pmatrix} \delta \\ 1-\delta \end{pmatrix} \sum_{i=1}^{N(t)} X_i, \tag{1}$$

where x_1 and x_2 denote the initial capitals of the insurer and reinsurer, p_1 and p_2 are their premium income rates, $(N(t))_{t\geq 0}$ is a common claim counting Poisson processes with intensity $\lambda > 0$ that is independent of the claim amount sequence $\{X_i\}_{i\geq 1}$. The parameter $\delta \in [0,1]$ defines the split proportions $(\delta, 1-\delta)$ originitaing from quota-share treaty for the insurer and the reinsurer, respectively.

Our main attention is devoted to the problem of deriving an explicit formula for a probability that at least one of two company capitals become negative. The latter is recognized in the classical sense as the ruin probability of so-called 'or' type for the considered two-entity system that is

$$\psi(u_1, u_2) = \mathbb{P}(\inf\{t \geq 0 : R_1(t) < 0 \vee R_2(t) < 0\} < \infty).$$

This study [4] examines the ruin probability within insurer-reinsurer models, specifically focusing on a subclass of phase-type loss distributions, including exponential, mixtures of exponential, Erlang, and mixtures of Erlang. We derive analytical solutions for the risk process, offering insights into the dynamics of financial stability. To validate our findings, we utilize real-world loss data, demonstrating the practical applicability of our model. Through rigorous statistical testing, encompassing goodness-of-fit tests and graphical analyses, we establish that a mixture of Erlang distributions provides a significantly superior fit compared to other considered distributions. This empirical validation highlights the model's accuracy in capturing the complex loss patterns inherent in insurance risk. Our results contribute to a more precise understanding of risk assessment, offering valuable tools for insurance companies engaged in collaborative risk-sharing agreements. This enhanced model enables improved decision-making and strengthens the resilience of cooperating insurance entities.

Bibliography

[1] Avram, F., Palmowski, Z., Pistorius, M. (2008). A two-dimensional ruin problem on the positive quadrant. *Insurance: Mathematics and Economics* 42(1), 227–234.

[2] Burnecki, K., Teuerle, M.A., Wilkowska, A. (2019). De Vylder type approximation of the ruin probability for the insurer-reinsurer model, *Mathematica Applicanda* 47(1), 5–24.

[3] Burnecki, K., Teuerle, M.A., Wilkowska, A. (2021). Ruin probability for the insurer-reinsurer model for exponential claims, *Risks* 9(5), 86.

[4] Burnecki, K., Palmowski, Z., Teuerle, M.A., Wilkowska, A. (2025). Ruin probability for the quota share model with phase-type distributed claims. *https://arxiv.org/abs/2303.07705*.

How voluntary climate-related and ESG disclosures shape firm efficiency: evidence from Taiwan

PS3

July 2
15:40

Nien-Hsuan Tang[1] **and Vivian Jeng**[2] **and Chia-Cheng Chang**[3]

[1]*National Chengchi University, Taipei, Taiwan, gotonien@gmail.com*
[2]*National Chengchi University, Taipei, Taiwan, vjeng@nccu.edu.tw*
[3]*National Chengchi University, Taipei, Taiwan, b0919532867@gmail.com*

Keywords: data envelopment analysis, materiality ESG, SASB, TCFD

While sustainability or environmental, social, and governance (ESG) issues become more prevalent, the climate-related disclosure as well as the ESG materiality issue are two key issues that have received great attention. Using Taiwanese firms from 2012 to 2019 as an example, we examine the impact of voluntary disclosures of these issues on the operating efficiency of the firm using data envelopment analysis (DEA) methods. We present the second-stage Tobit regression results as endogeneity is a concern. We compare the results of the climate-related disclosures between firms following recommendations of the Global Reporting Initiative (GRI) and following Task Force on Climate-related Financial Disclosures (TCFD). We also examine how firm efficiency is influenced by ESG material scores based on the classifications of materiality provided by the Sustainability Accounting Standards Board (SASB).

Our findings are as follows. First, firms voluntarily disclosing TCFD have higher pure technical efficiency but have lower scale efficiency. Such effect cannot be observed for firms disclosing through the GRI. Second, for voluntary ESG disclosures, a firm's ESG score has a non-linear relationship with its pure technical efficiency, but if a firm voluntarily discloses the material ESG issues, the impact to its efficiency is straightforward. In other words, materiality issues are crucial to a firm's efficiency performances, and too much or too less disclosure of ESG not focusing on the material issues deteriorates the efficiency instead. Finally, we find that the scale efficiency of the firm is not affected no matter the firm focuses on disclosing its ESG information or material ESG information.

Optimal relativities in a Bonus-Malus System under frequency-severity dependence and different objective functions

PS3

July 2
15:40

Kelvin Tang[1], **Eric C.K. Cheung**[2] **and Jae-Kyung Woo**[3]

[1]*University of New South Wales, Australia, kelvin.tang@unsw.edu.au*
[2]*University of New South Wales, Australia, eric.cheung@unsw.edu.au*
[3]*University of New South Wales, Australia, j.k.woo@unsw.edu.au*

Keywords: bonus-malus system, optimal relativity, frequency-severity dependence, objective function, a posteriori ratemaking

Automobile insurers in many countries use a Bonus-Malus System (BMS) that relies primarily on policyholders' claim frequency to determine merit ratings, assuming independence between claim frequency and severity. With all claims being penalised regardless of claim size, a rational policyholder may withhold small claims to prevent any larger increases to their premium. Park and colleagues [1] found that this behavioural aspect known as bonus hunger can induce dependence in the reported frequency and severity of claims, even when the original processes are independent. Thus, differentiating the claims by their severity also plays an important role in separating the risks and improving the overall efficacy of the BMS. We consider a bivariate random effects model allowing for dependence between frequency and severity. In addition to the traditional mean squared error objective function for calculating the optimal relativities, we propose new symmetric and asymmetric absolute error objective functions. The resulting optimal relativities can be interpreted as statistical functionals for the asymptotic distribution of risk within the Bonus-Malus levels, offering a novel approach to assessing the performance of the BMS.

Bibliography

[1] Park, S.C., Kim, J.H.T., Ahn, J.Y. (2018). Does hunger for bonuses drive the dependence between claim frequency and severity? *Insurance: Mathematics and Economics* 83, 32–46.

Mispricing and insolvency risk in property-liability insurance companies: a case study of Covid-19 pandemic insurance products

PS3

July 2
15:40

Wei-Hua Tian[1] **and Joseph J. Tien**[2]

[1] *National Cheng Kung University, Taiwan, whtian@mail.ncku.edu.tw*
[2] *Tamkang University, Taiwan, 131715@o365.tku.edu.tw*

Keywords: Covid-19, SIR model, risk management

The novel coronavirus spread globally at the end of 2019. In Taiwan, the insurance industry has offered COVID-19 epidemic insurance products. Although these products were well-intentioned, the gradual relaxation of quarantine products and severe information asymmetry have led to significant losses for insurance companies. However, it's important to note that insurance companies are crucial in managing the risks associated with epidemic products. In Taiwan, the total claims from COVID-19 epidemic products have reached nearly NT 270 billion. Therefore, managing the risks associated with epidemic products is a critical issue.

This study aims to use the Susceptible (S), Infected (I), and Recovered (R) model, known as the SIR Model, to explore the changes in claim payments and their impact on the asset-liability management of insurance companies that issue epidemic insurance products during an outbreak. Based on Monte Carlo simulations, the calibration results show that non-life insurance companies increase insurance premiums or their initial asset value or reduce the claim payments; the insolvency probability has only decreased slightly. However, it's crucial to note that a higher virus transmission rate significantly leads to a greater risk of insolvency probability. That is to say, because the new virus variation or relaxation of the NPI restrictions will increase the transmission rate, the insolvency probability of non-life insurance companies will rise significantly, highlighting the potential risks that need to be managed. This study's results can provide risk management recommendations for future epidemic insurance products.

Natural hedging on overseas investment of insurance companies: application for copula functions between interest rate and exchange rate

PS1

July 2
11:00

Joseph J. Tien[1]

[1] *Tamkang University, Taiwan, 131715@o365.tku.edu.tw*

Keywords: copula, exchange rate, overseas investment

Copula functions have been widely used in finance to construct joint distributions of multiple functions, providing a better understanding of the correlation between two random variables. This paper aims to use Copula functions to explore the relationship between interest rates and exchange rates and further explore their impact on overseas investment of life insurance companies in Taiwan. By using data on the interest rate yield and the exchange rate, the Frank Copula is the most fitting in capturing the relationship between these two variables. Since there is typically a negative relationship between the interest rate and the exchange rate, this relationship may serve as the basis for natural hedging on the asset side of insurance companies. We found that this relationship truly has a natural hedging effect on overseas investment by insurance companies in Taiwan.

Amputation-imputation based generation of synthetic tabular data for ratemaking

PS3

July 2
15:40

Artur Tuttar[1], **Meelis Käärik**[2] **and Yevhen Havrylenko**[3]

[1] *University of Tartu, Estonia, artur.tuttar@ut.ee*
[2] *University of Tartu, Estonia, meelis.kaarik@ut.ee*
[3] *Ulm University, Germany, yevhen.havrylenko@uni-ulm.de*

Keywords: generative adversarial networks, autoencoders, multivariate imputation by chained-equations, synthetic data, data augmentation

Machine learning models have seen widespread application across many fields in recent years. However, the insurance pricing field has been slow to adopt machine learning models partially due to strict regulations imposed on this field and the unique structure and availability of insurance data. Our research addresses the problem of data availability by leveraging existing synthetic data generation machine learning techniques. We propose a data generation method based on amputation-imputation via MICE [1]. We compare our methodology with other techniques explored in actuarial literature, e.g., conditional tabular GAN [2][3], variational autoencoders [4].

Our case study uses these methods to generate synthetic data for publicly available French motor third-party liability insurance data. The methods are trained to generate new synthetic rows in this data set, after which the synthetic data sets are assessed for their ability to capture data structure and internal structure of variable dependence present in the original data.

Additionally, the raw synthetic datasets, but also different combinations of synthetic and original true data (*data augmentation*), are used to train generalized linear models (GLMs) to predict the claim count of each observation. The model accuracy, structure, and coefficients are studied further to distinguish the efficacy of different synthetic data generation methods.

Bibliography

[1] Buuren, S. & Groothuis-Oudshoorn, K. mice: Multivariate Imputation by Chained Equations in R. *Journal Of Statistical Software*. **45**, 1-67 (2011), https://www.jstatsoft.org/index.php/jss/article/view/v045i03

[2] Kuo, K. Generative Synthesis of Insurance Datasets. (2020), https://arxiv.org/abs/1912.02423

[3] Cote, M., Hartman, B., Mercier, O., Meyers, J., Cummings, J. & Harmon, E. Synthesizing Property & Casualty Ratemaking Datasets using Generative Adversarial Networks. (2020), https://arxiv.org/abs/2008.06110

[4] Jamotton, C. & Hainaut, D. Variational AutoEncoder for synthetic insurance data. *Intelligent Systems With Applications*. **24** pp. 200455 (2024), https://www.sciencedirect.com/science/article/pii/S2667305324001297

Optimal benefits, taxation, and asset allocation for a PAYG system with reserve fund under equity, longevity, and unemployment risks.

PS2

July 2
14:00

Sander van Eekelen[1,2], **Frank van Berkum**[1,2], **Torsten Kleinow**[1,2], **Michel Vellekoop**[1,2].

[1] *University of Amsterdam*
[2] *Research Centre for Longevity risk*

Keywords: pay-as-you-go, buffer fund, longevity risk, unemployment risk, dynamic optimization

We develop a model to optimally control a PAYG pension system with a reserve fund under equity, longevity, and unemployment risks. We investigate the effect of these stochastic factors on the optimized taxation, benefits, and asset allocation, and compare PAYG systems with and without a reserve fund in terms of expected utility and optimal policies. The reserve fund improves outcomes for both the retired and working population, even when a reserve fund needs to be established and capitalized to a target level. This indicates that incorporating a reserve fund benefits stakeholders while keeping the pension system design largely intact.

General bounds for functionals of the lifetime, compatible with life tables

PS4
July 3
10:30

Mark Van Lokeren[1]

[1]*Imperial College London, United Kingdom, m.van-lokeren@imperial.ac.uk*

Keywords: lifetime, life tables, fractional age, optimal control

In life insurance, life tables are used to estimate the survival distribution of individuals from a certain population. The tables only provide survival probabilities at integer values. Information about the distribution of deaths between two consecutive integer values is not available.

Many actuarial quantities are functionals of the lifetime, and computing them requires full information about the lifetime. A possible solution to this problem is the introduction of fractional age assumptions. However, the results of these computations depend strongly on the assumptions, which makes it quite difficult to compare them to each other. How good are they?

In this talk, we propose upper and lower bounds for actuarial quantities which hold for any fractional age assumption. Moreover, we obtain these bounds using a general method.

Our method draws on optimal control, in particular Pontryagin's maximum principle. As the method does not rely on any other assumptions, the obtained bounds are the most general one can obtain using the available information. We also show that the bounds are sharp and provide an example of a lifetime that achieves them.

To the best of our knowledge, this is the first time that techniques from optimal control are applied in the context of life tables.

Minimum reversion in mortality models for multiple populations

PS1

July 2
11:00

Michel Vellekoop[1] **and Torsten Kleinow**[2]

[1]*University of Amsterdam & Research Centre for Longevity Risk, the Netherlands, m.h.vellekoop@uva.nl*

[2]*University of Amsterdam & Research Centre for Longevity Risk, the Netherlands, t.kleinow@uva.nl*

Keywords: human mortality models, time series analysis, cause of death statistics

After rescaling the period effects in an empirical study of mortality data in twenty countries over six decades, we observe that those effects show a pattern which is not always consistent with standard time series specifications that have been studied in the literature.

We therefore propose a new multivariate time series model which incorporates the possibility that countries learn from others with lower mortality rates. This phenomenon corresponds to a "reversion to the minimum" which is interesting to study as a phenomenon in time series in its own right.

The model allows us to generate consistent mortality scenarios for multiple populations, and we find in simulation studies that our modification has a stabilizing effect on simulated future mortality rates. We look at all-cause mortality statistics but also investigate minimum reversion effects per cause of death, for a subset of countries and time periods for which data per cause are available.

Several facts about Theodor Wittstein, Gaetano Balducci, and some expressions of the net single premiums under their mortality assumption

PS4

July 3
10:30

Mindaugas Venckevičius[3] (jointly with Andrius Grigutis[1] and Eglė Matulevičiūtė[2])

[1]*University of Vilnius, Lithuania, andrius.grigutis@mif.vu.lt*
[2]*University of Vilnius, Lithuania, egle.matuleviciute@mif.stud.vu.lt*
[3]*University of Vilnius, Lithuania, mindaugas.venckevicius@mif.stud.vu.lt*

Keywords: survival function, future lifetime, Balducci's assumption, net single premium, exponential integral

The mathematical essence in life insurance spins around the search of the numerical characteristics of the random variables T_x, ν^{T_x}, $T_x\nu^{T_x}$, etc., where ν (deterministic) denotes the discount multiplier and T_x (random) is the future lifetime of an individual being of $x \in \{0,\, 1,\, \ldots\}$ years old. We provide some historical facts about T. Wittstein and G. Balducci and their mortality assumption. We also develop some formulas that make it easier to compute the moments of the mentioned random variables, assuming that the survival function is interpolated according to Balducci's assumption. Derived formulas are verified using some hypothetical mortality data.

Perhaps, the most common and simple interpolation of survival function $s(x),\, x \in \mathbb{N}_0$ is the assumption of **uniform distribution of deads** (UDD):

$$s(x+k+t) = (1-t)s(x+k) + ts(x+k+1),\, x,\, k \in \mathbb{N}_0,\, t \in [0,\, 1].$$

In work [4], we develop some formulas to compute the net single premiums under another widely known assumption on $s(x),\, x \in \mathbb{N}_0$ interpolation, called **Balducci's** assumption:

$$\frac{1}{s(x+k+t)} = \frac{1-t}{s(x+k)} + \frac{t}{s(x+k+1)},\, x,\, k \in \mathbb{N}_0,\, t \in [0,\, 1].$$

Bibliography

[1] Batten, R.W.: Mortality Table Construction. Risk, Insurance and Security Series. Prentice-Hall, New Jersey (1978).

[2] Bowers(Jr.), N.L., Gerber, H.U., Hickman, J.C., Jones, D.A., Nesbitt, C.J.: Actuarial Mathematics, 1st edn. Society of Actuaries, Itasca (1986)

[3] Giao, P.H.: Revisit of well function approximation and an easy graphical curve matching technique for theis' solution. Groundwater 41(3), 387–390 (2003) *https://doi.org/10.1111/j.1745-6584.2003.tb02608.x*

[4] A. Grigutis, E. Matulevičiūtė, M. Venckevičius, Several facts about Theodor Wittstein, Gaetano Balducci, and some expressions of the net single premiums under their mortality assumption, preprint, arXiv:2501.03794

A practitioner's guide to interpretable machine learning

PS1

July 2
11:00

Roel Verbelen[1]

[1]*Finity Consulting*, *Sydney*, *Australia*, *Roel.Verbelen@finity.com.au*

Keywords: insurance pricing, interpretable machine learning, explainable AI, variable importance, partial dependence, individual conditional expectation, H-statistics, SHAP analysis

Machine learning (ML) is increasingly used in insurance pricing, offering enhanced predictive power but at the cost of reduced transparency. This talk explores the interpretability trade-off and demonstrates how practitioners can use techniques such as partial dependence plots, SHAP (SHapley Additive exPlanations) analysis, and interaction detection to better understand ML models. Beyond explaining individual predictions, we show how these methods can provide deeper insights into pricing structures, interactions, and portfolio shifts over time. Interpretable ML techniques not only enhance model transparency but also support actuaries in refining pricing models, improving risk segmentation, and identifying emerging trends in insurance data.

Single and multi-population mortality models based on Linear Hypercubes

PS1

July 2
11:00

Domenico De Giovanni[1], **Marco Pirra**[2] **and Fabio Viviano**[3]

[1]*Department of Economics, Statistics and Finance, University of Calabria, Italy, ddegiovanni@unical.it*
[2]*Department of Economics, Statistics and Finance, University of Calabria, Italy, marco.pirra@unical.it*
[3]*Department of Economics, Statistics and Finance, University of Calabria, Italy, fabio.viviano@unical.it*

Keywords: mortality model, multi-population, polynomial diffusion, life insurance, guaranteed annuity options

Exploiting the parallelism between mortality and credit-risk, we propose a mortality modeling approach based on the Linear Hypercube Model of [1], originally developed for credit-derivatives. This approach is particular attractive due to its analytical tractability while keeping always nonnegative mortality intensities. This approach can be used on a variety of applications, such as the explicit computation of standard actuarial quantities, the pricing of guaranteed annuity options and the estimation of multi-population mortality surfaces. Estimation can be performed using quasi-maximum likelihood in conjunction with the well-known Kalman Filter. We conduct extensive experiments to evaluate the adequacy of the proposed approach on the fitting of mortality surfaces.

Bibliography

[1] Ackerer, D., Filipović, D. (2020). Linear credit risk models. *Finance and Stochastics*, 24(1):169–214.

Optimization of credit contracts with incomplete information: equilibrium and welfare analysis

Xinyi Wang[1] **and Nanjun Zhu**[2]

[1]*Peking University, China, wangxinyicg@stu.pku.edu.cn*

[2]*Peking University, China, zhunanjun@163.com*

PS6

July 3
15:30

Keywords: contracts optimization, incomplete information, welfare analysis, separating equilibrium

Internet finance has brought shocks to traditional financial institutions (Hong et al., 2023; Buchak et al., 2018). In terms of risk pricing, banks have a weak ability to screen customer risks, while Internet lending platforms have strong risk pricing capabilities (Hu et al., 2025; Hau, 2024; Berg et al., 2020). In terms of product design, Internet platform lending contracts are more personalized (Wang et al., 2020), charging lower interest rates for low-risk customers and crowding low-risk customers out of the bank market (Maggio and Yao, 2021). This study, from a banking perspective, enhances the ability to price risks through machine learning algorithms, optimizes lending contracts based on game theory.

Existing studies considered the impact of single-factor on repayment and welfare (Campbell et al., 2020; Benetton et al., 2023; Boutros et al., 2024; Catherine et al., 2024; Fishman et al., 2024; Fisher et al., 2024). We comprehensively consider the impact of multiple factors to determine the optimal loan contracts for different borrowers. Similar issues exist in the insurance market. Rothschild and Stiglitz (1976), considering a perfectly competitive market, proposed the RS equilibrium. There are few studies related to the credit market, and China's banking market is closer to an oligopoly.

This paper derives the equilibrium contract design for the credit market based on a game-theoretic model, compares welfare under different equilibriums, and optimizes credit contracts to achieve the optimal equilibrium. In the empirical part, we construct a credit contract optimization model based on data from a commercial bank, and quantify the welfare improvement after contract optimization.

Currently, China's market is closer to a pooling equilibrium, where the variation in credit product data is not high enough. To address this issue, we innovatively propose a new mechanism for model extrapolation—model extrapolation based on extrapolation rule learning. Compared with traditional methods, which directly apply the model to out-of-sample prediction, model extrapolation based on extrapolation rule learning considers that as the sample range expands, the model rules will change.

Model setup: Oligopoly in the credit market. The total utility U that borrowers obtain from borrowing consists of three parts: the baseline utility of obtaining the loan u, $u > 0$, the utility derived from the interest rate $u(r)$, $u(r) \geq 0,\ u'(r) < 0$, and the utility changes resulting from default γ, $\gamma < 0$, including the contraction of credit channels and moral stigma. There are two types of customers in the loan market: high-risk and low-risk. Let $p(r, \theta)$ denote the probability of default. The probability of default depends on the interest rate r and default costs θ. Under the same interest rate r and default costs θ, the default probabilities of high-risk and low-risk customers are different, i.e., $p_H(r, \theta) > p_L(r, \theta)$. The utility functions are expressed as follows: $U = u(r) \cdot [1 - p(r, \theta)] + \gamma \cdot p(r, \theta) + u$.

First, draw the indifference curves for borrowers. Next, consider the bank's iso-profit lines. The implicit expression for the iso-profit lines is further derived from the loan profitability function. Since the banking market is characterized by oligopoly, banks do not operate at zero profit at equilibrium. The numerical value of the iso-profit lines depends on the banks' pricing power. Finally, consider the optimality conditions. The final equilibrium should satisfy both parties achieving optimality and a transaction occurring, which is the intersection point of the indifference curve and the iso-profit line.

Insurance also faces similar issues, but in a perfectly competitive insurance market, the conclusion is that low-risk clients subsidize high-risk clients in a separating equilibrium. In the theoretical model section, this paper demonstrates that in an oligopolistic credit market at the separating equilibrium, low-risk individuals do not subsidize high-risk individuals, and total social welfare is enhanced. This conclusion is in stark contrast to that in the insurance market (Rothschild and Stiglitz, 1976).

Extending this conclusion further, if there are customers with various risk levels and banks conduct risk-based pricing and set optimal loan contracts for each customer, the utility of high-quality customers will further improve, and banks profitability will increase even more. This will stimulate the borrowing demand of potential high-quality customers. In conclusion, this paper demonstrates through theory and empirical analysis that compared with the pooling equilibrium, the separate equilibrium can improve social welfare. More specifically, it can mitigate the problem of adverse selection, enhance the welfare of low-risk customers, increase bank profitability, expand potential market size.

Machine learning in an expectation-maximisation framework for nowcasting

PS1

July 2
11:00

Paul Wilsens[1], **Katrien Antonio**[2,4] **and Gerda Claeskens**[3]

[1]*KULeuven, Belgium, paul.wilsens@kuleuven.be*
[2]*KULeuven, Belgium, katrien.antonio@kuleuven.be*
[3]*KULeuven, Belgium, gerda.claeskens@kuleuven.be*
[4] *University of Amsterdam, the Netherlands, k.antonio@uva.nl*

Keywords: nowcasting, machine learning, expectation-maximisation algorithm

Information is often only partially observable. In decision making, this may cause under- or overestimation of underlying risk. Leveraging the available information to model the complete information is called nowcasting within the literature. In practical nowcasting applications, partial information is often caused by reporting delays. In this paper, we propose an expectation-maximisation framework that uses machine learning techniques to model both the occurrence as well as the reporting process of events. We allow for the inclusion of information specific to the occurrence and reporting periods as well as information related to the entity for which events occurred. Additionally, we demonstrate how deep learning techniques can be adapted for use in a nowcasting application. With simulation experiments, we show that we can effectively model both the occurrence and reporting of events when dealing with high-dimensional covariate information. In the presence of nonlinear effects, we show that our methodology outperforms existing expectation-maximisation frameworks that rely on generalised linear models.

Modeling multi-state health transitions with a most-recent-event Hawkes process

PS7

July 4
10:30

Jiwon Jung[1], **Kiseop Lee**[1], **and Mengyi Xu**[1,2]

[1]*Department of Statistics, Purdue University, United States*
[2]*Department of Mathematics, Purdue University, United States*

Keywords: self-exciting process, health state transition, semi-Markov process, EM algorithm, functional disability

We present a multi-state health transition model using a most-recent-event Hawkes process. A Hawkes process is a counting process with a stochastic intensity, commonly used to model self-exciting events in which the occurrence of one event increases the likelihood of subsequent events. Unlike the traditional Hawkes process, our model focuses specifically on the most recent transition time and the duration spent in the current state. This modification, based on the nature of our data, preserves the tractability of semi-Markov processes while leveraging the flexibility of the Hawkes process to capture the self-exciting effects of disability transitions. The estimation results suggest that past disability significantly increases the risk of future disability. While this impact diminishes over time, we find that a model with non-monotonic decay provides a better fit for the data. Understanding the dynamics of health transitions, particularly in the context of recurrent disability, allows for more accurate projections of future health trajectories, thereby supporting informed premium pricing for long-term care and related products.

Longevity bond pricing in pension with positive jumps

Yitian Xu[1]

[1]*Central University of Finance and Economics, China, 2024110084@email.cufe.edu.cn*

PS7

July 4
10:30

Keywords: longevity index bond, death jump, multi-factor longevity index, risk-neutral pricing

With global aging, pension deficits are gradually increasing in various countries. Longevity risk (LR) has become a central concern for pension funds and life insurers, as retirees living longer than anticipated can create substantial funding shortfalls. Longevity index bond is a market-based instrument designed to transfer longevity risk to investors in exchange for appropriate returns. When actual longevity improvements exceed expectations, bond payouts to investors are reduced, providing a natural hedge for pension plans against increased liabilities. Conversely, if longevity improvements are lower, investors receive higher returns.

Most of the longevity bonds that have been issued in the market today are of the interest insured longevity bond type. The Survivor Bond, proposed by Blake and Buttows in 2001[1], is this type of longevity bond, where the interest payment on the bond is a continuous function with the survival rate of a specified population as the independent variable. However, in recent years, due to events such as epidemics and environmental disasters, there have been short-term abnormal increases in mortality rates. In addition to the mortality rate dynamic equation, a jump term is often introduced to estimate the probability of tail risk for extreme events through extreme value theory (EVT) to describe short-term shocks as shown in [2]

$$dm(t,x) = \mu(t,x)dt + \sigma(t,x)dW_t + J_t dN_t, \quad J_t \sim \mathsf{Exp}(\eta),$$

$$G_{\xi,\beta}(y) = 1 - \left(1 + \frac{\xi y}{\beta}\right)^{-1/\xi}, \quad P(J_t > u + y \mid J_t > u) = \left(1 + \frac{\xi y}{\beta}\right)^{-1/\xi},$$

where ξ is the tail index. For the impact of extreme events on population mortality, we apply the pricing model of catastrophe bonds to longevity bonds

$$s_{\mathsf{cat}} = \mathbb{E}(\tilde{L}) + \gamma \cdot \mathsf{Var}(\tilde{L}),$$

In order to capture the deficiencies of existing longevity bonds in terms of the long-term trend risk of asymmetric mortality jumps, this paper proposes a pricing framework that incorporates sudden positive jump components and a multi-factor dynamic adjustment mechanism to manage the longevity risk of social pensions.

The study is based on an improved Lee-Carter model that captures the “abrupt positive jump component” affected by the risk of “short-term abnormal increases” in mortality rates due to unexpected events in recent years, compensating for the traditional model’s one-sided focus on “negative jumps” and separating the short-term and long-term fluctuation characteristics of mortality rates. At the same time, an exponential jump diffusion process is introduced to combine multiple factors of socioeconomic indicators and individual mortality rates to construct a multi-factor longevity index.

In terms of pricing methods, we propose a pricing scheme for longevity bonds in incomplete markets based on the CIR interest rate model and risk-neutral pricing measures, analogous to the general pricing model for catastrophe bonds. The breakthrough of this paper lies in the collaborative modeling of “gradual improvement” and “abrupt fluctuations” in longevity risk, which provides a theoretical tool for risk hedging and sustainability management of public pension systems.

Bibliography

[1] Blake, D., Burrows, W. (2001). Survivor bonds: Helping to hedge mortality risk. *Journal of Risk and Insurance*, 68(3), 339–348.

[2] Kou, S. G., Wang, H. (2004). Option pricing under a double exponential jump diffusion model. *Management Science*, 50(9), 1178–1192.

Research on the stock price differences of cross-listed companies – taking China Life A+H+N shares as an example

PS6

July 3
15:30

Lingjia Yan[1], **Jiahao Zhao**[2], **Chang Chen**[3], **and Sujin Zheng**[4]

[1]*Central University of Finance and Economics, China, alina_0408@sina.com*
[2]*Central University of Finance and Economics, China, 1332241469@qq.com*
[3]*Central University of Finance and Economics, China, 18211036882@163.com*
[4]*Central University of Finance and Economics, China, zhengsujin@cufe.edu.cn*

Keywords: stock spread, stock price correlation, EEMD algorithm, ICSS algorithm, event study method

With the deepening of China's economic liberalization, cross-listed companies have become increasingly prevalent. The law of one price suggests that equities of the same corporation trading in different markets should not exhibit significant price discrepancies. However, empirical evidence reveals divergent stock valuations across markets, with Chinese domestic listings often commanding a premium over overseas counterparts—a phenomenon known as the domestic stock premium.

This research examines stock price disparities among cross-listed entities, focusing on China Life Insurance's A-shares, H-shares, and N-shares. Using advanced methodologies like Ensemble Empirical Mode Decomposition (EEMD) and the Iterative Cumulative Sum of Squares (ICSS) algorithm, the study analyzes linkages and disparities in stock valuations across these markets. It identifies structural inflection points and explicates their causes, shedding light on the unique oscillatory patterns of stock prices in cross-listed firms, particularly in the insurance sector. Additionally, the research assesses the impact of pivotal events, such as delisting from the U.S. stock exchange, on equity valuations in diverse markets. The insights aim to provide strategic guidance to investors, regulators, and cross-listed enterprises, enhancing understanding of market segmentation, information dissemination, and policy impacts on stock price dynamics.

Bibliography

[1] Chen Guojin, Wang Jing. Spillover effect analysis of A+H cross-listing of Chinese companies[J]. Nankai Management Review, 2007(04):36-42.

[2] Song Shunlin, Yi Yang, Tan Jinsong. Is the AH share premium reasonable - Market sentiment, individual stock speculation and AH share premium[J]. Nankai Management Review, 2015, 18(02):92-102.

[3] Yuan Xianping, Ke Dagang. Event study method and its application in financial and economic research[J]. Statistical Research, 2006(10):31-35.

[4] Zhu Zheng, He Genqing. Crisis shocks, market time-varying linkages and cross-country risk contagion pathways-An empirical study based on sample data from Chinese and U.S. stock markets[J]. Journal of Central University of Finance and Economics, 2015(05):32-37.

[5] Li Helong, Lin Chuhan, Zhang Weiguo. A contagious study of investor sentiment in Shenzhen and Hong Kong under the background of "Shenzhen-Hong Kong Stock Connect" - Based on SHIBBS-EEMD model[J]. Journal of Systems Management, 2020, 29(06):1056-1064.

[6] Froot, K.A. and Dabora, E.M. How Are Stock Prices Affected by the Location of Trade?, Journal of Financial Economics, Vol. 53, pp. 189-216, 1999.

[7] Barber B M, Lyon J D. Detecting long-run abnormal stock returns: The empirical power and specification of test statistics[J]. Journal of financial economics, 1997, 43(3): 341-372.

[8] Minho Kim, Andrew C. Szakmary and Ike Mathur. Price transmission dynamics between ADRs and their underlying foreign securities?, Journal of Banking and Finance, Vol. 24, PP1359-1382, 2000.

Optimal asset allocation for a household with multi-claim insurance

PS2
July 2
14:00

Shiqi Yan [1], **Jingzhen Liu**[1], **Zhenyu Cui**[2], **Ka Fai Cedric Yiu**[3] **and Yike Wang**[4]

[1]*Central University of Finance and Economics, China*
[2]*Stevens Institute of Technology, United States of America*
[3]*Hong Kong Polytechnic University, Hong Kong*
[4] *Chongqing Technology and Business University, China*

Keywords: multi-claim insurance, optimal consumption, singular control, optimal investment

We examine the optimal consumption, investment, and insurance strategies in a framework where a household purchases multi-claim insurance for the wage earner. Unlike traditional short-term life insurance, this whole-life coverage includes payments not only upon the insured's death but also in the event of illness. Importantly, we allow coverage to increase at any time and by any amount before illness, introducing singular control into the optimization problem. Using dynamic programming, we transform the problem into a two-stage optimization framework divided by the health state of the wage earner, obtaining the Hamilton–Jacobi–Bellman equations. Insurance strategy is determined only in the first period, while consumption and investment should be considered in both periods. For the constant absolute risk aversion utility function (CARA), we derive closed-form solutions for this nested stochastic control problem and demonstrate that the optimal insurance decision is a barrier strategy. Comparing one-claim and multi-claim scenarios, we highlight the distinct effects of multi-claim coverage on financial strategies. Numerical examples are provided to illustrate the practical implications and findings between the two cases.

How does granularity affect motor insurance claim predictions in a telematics setting?

PS5

July 3
13:30

Juan Sebastian Yanez[1] **& Montserrat Guillén**[2]

[1]*University of Barcelona, Spain, yanez.juan_sebastian@ub.edu*
[2]*University of Barcelona, Spain, mguillen@ub.edu*

Keywords: telematics, road accident, rate-making, granularity, Pay-How-You-Drive

Telematics data have tremendously impacted the development of fairer and more precise motor insurance products, such as Pay-How-You-Drive (PHYD) insurance policies. This is because telematics data's accurate and granular nature allows insurers to dynamically estimate accident risk levels based on a client's driving behaviour and risk exposure. However, the collection of this information significantly deviates from traditional motor insurance policies based on non-telematics covariates, which are not observed dynamically as clients drive. This paper aims to bridge the gap between classical non-telematics models and their more modern counterparts by studying various levels of granularity in telematics data sets (e.g., data collected weekly, monthly, or annually). Therefore, it provides insight into the trade-off between more granular and dynamic telematics structures, such as weekly models, and less granular structures that are more akin to classical insurance models. This study benefits from having access to telematics data from a major Spanish insurer, allowing us to investigate driving behaviors and accident patterns among 17,405 policyholders over two years (2017-2018). The dataset includes demographic and telematic variables, providing a comprehensive basis for understanding accident frequency dynamics.

Optimizing portfolios with surrender variable annuities: a deep reinforcement learning approach

PS2

July 2
14:00

Hailiang Yang[1]

[1]*Xi'an Jiaotong-Liverpool University, hailiang.yang@xjtlu.edu.cn*

Keywords: variable annuity, guaranteed minimum death benefit, deep reinforcement learning, surrender, optimal portfolio

This paper investigates a portfolio optimization problem for an investor on asset allocation among risk-free asset, risky asset, and variable annuities with guaranteed minimum death benefits (GMDB) subject to mortality risk and surrender risk. The investor's objective is to maximize the expected utility of the bequest at death or the expected utility of assets at contract maturity. On each trading day before the investor's death, the investor can adjust the allocation between risk-free and risky assets, invest in new surrender GMDB product, or partially or fully surrender existing annuities. This dynamic adjustment creates a high-dimensional state and action space, making traditional optimization methods inadequate. To address this, we utilize the Lee-Carter model to analyze Australian demographic data, predict mortality risk, simulate surrender risk based on market changes, and estimate the fair pricing of GMDBs in the portfolio. Subsequently, we introduce a deep reinforcement learning algorithm within a simulated trading environment that independently models the dynamic behavior of various assets and underlying indices. The algorithm utilizes neural networks to analyze high-dimensional state variables and leverages the interactive capabilities of the agent to flexibly adapt to asset fluctuations, dynamically optimizing investment allocation. Additionally, we prove the global convergence of the algorithm under standard assumptions and validate its effectiveness in managing the complexities of high-dimensional portfolios, particularly in capturing mortality, surrender, and financial risks. Numerical experiments further demonstrate the stability and robustness of the algorithm, showcasing its advantages in complex insurance and financial scenarios. (This is a joint work with Huifang Huang, Zhuo Jin, Pengbo Li and Fuke Wu).

Optimal consumption and investment problem incorporating the housing habits and the household's subjective beliefs

PS2

July 2
14:00

Shang-Yin Yang[1] **and Pei-Ying Chen**[2]

[1]*Tunghai University, Taiwan. R.O.C., shangyin@thu.edu.tw*
[2]*Feng Chia University, Taiwan. R.O.C., pyingchen@fcu.edu.tw*

Keywords: housing habits, life cycle consumption, portfolio choice, subjective beliefs

This study investigates the interplay between housing habits and subjective beliefs in shaping household financial decisions within a stochastic financial market. The findings indicate that households tend to increase their investment in risky assets as a strategy to hedge against mortality risk. Housing habits significantly influence consumption patterns, providing an explanation for the hump-shaped trend observed in perishable consumption and the rising proportion of housing expenditures over time. Furthermore, subjective beliefs play a crucial role in shaping households' expectations regarding labor income, mortality rates, and capital market fluctuations, which, in turn, impact their savings and consumption behaviors. Notably, households with a pessimistic outlook are more likely to exhibit lower savings rates and higher consumption levels compared to their optimistic counterparts. Overall, this study highlights the critical influence of both housing habits and subjective beliefs on household financial decision-making, offering valuable insights for financial planning and risk management strategies.

Statistical learning of trade credit insurance network data with applications to ratemaking and reserving

PS7

July 4
10:30

Woongchae Yoo[1], **Spark C. Tseung**[2], **and Tsz Chai Fung**[3]

[1]*Maurice R. Greenberg School of Risk Science, Georgia State University, USA*
[2]*Department of Statistical Sciences, University of Toronto, Canada*
[3]*Maurice R. Greenberg School of Risk Science, Georgia State University, USA*

Keywords: property and casualty (P&C) insurance, random effects, ratemaking and reserving, second-order degree centrality, social network

Trade credit insurance (TCI) is a specialized line of property and casualty insurance, protecting businesses against financial losses due to buyer's insolvency. Predictive modeling for TCI claims poses formidable challenges due to the data's complexity, yet remains underexplored in the literature. Leveraging six years of detailed TCI data from an Asian TCI insurer, we develop a bivariate, network-augmented Generalized Linear Mixed Model (GLMM) to jointly model claim probability and reporting time gaps. Our model integrates extended-order degree centrality and random effects at the business and policy levels, adjusted for data incompleteness, to capture claim histories, reporting time gaps, and network relationships specific to TCI data. To implement a feasible workaround for the high-dimensional integrations required by individual random effects, we propose a scalable Stochastic Expectation-Maximization (SEM) algorithm. Data analysis using this TCI dataset demonstrates that our model significantly outperforms benchmark models in both model fit and predictive accuracy, highlighting the effectiveness of our approach for improved ratemaking and reserving in TCI. Supplementary materials for this article are available as an online supplement.

Phase-type frailty models: A flexible approach to modeling unobserved heterogeneity in survival analysis

PS7

July 4
10:30

Jorge Yslas[1]

[1]*University of Liverpool, UK, Jorge.Yslas-Altamirano@liverpool.ac.uk*

Keywords: frailty model, heavy tails, parameter estimation, phase-type distributions

Frailty models are essential tools in survival analysis for addressing unobserved heterogeneity and random effects in the data. These models incorporate a random effect, the frailty, which is assumed to impact the hazard rate multiplicatively. In this talk, we introduce a novel class of frailty models in both univariate and multivariate settings, using phase-type distributions as the underlying frailty specification. We investigate the properties of these phase-type frailty models and develop expectation-maximization algorithms for their maximum-likelihood estimation. In particular, we show that the resulting model shares similarities with the Gamma frailty model, has closed-form expressions for its functionals, and can approximate any other frailty model. Through a series of simulated and real-life numerical examples, we demonstrate the effectiveness and versatility of the proposed models in addressing unobserved heterogeneity in survival analysis.

Why insurers price carbon low: An analysis of financed emissions and investment decisions

PS3

July 2
15:40

Haibo Liu[1] **and Zhongyi Yuan**[2]

[1]*Purdue University, USA, haiboliu@purdue.edu*
[2]*The Pennsylvania State University, USA, zuy11@psu.edu*

Keywords: portfolio choice, financed emissions, emission-efficient frontier, expected policy impact, carbon price, carbon-adjusted Sharpe ratio, portfolio decarbonization

A recent research finds that the insurance sector has the lowest median internal carbon price (ICP) across thirteen sectors. In this paper, we rationalize the low ICP through an analysis of insurers' emissions, which are predominately financed emissions. We develop and analytically solve an extended mean-variance model with a constraint on portfolio emissions. Our model identifies an emission-efficient frontier (EEF) for environmentally conscious investors. We utilize the identified EEF to analyze the expected internal carbon policy impact and show that the impact is greatest when the constructed brown fund yields a modest excess return—sufficient for the carbon charge to influence investment decisions, but not so high as to require prohibitively large charges.

Using emissions data from London Stock Exchange Group, we empirically estimate the frontier. According to our model, to maximize the insurer's carbon-adjusted Sharpe ratio, the ICP should not exceed $1.4 per tonne. Meanwhile, the measured carbon policy impact is high, and hence even a low ICP can reduce insurers' financed emissions substantially without compromising investment performance. Our findings provide support for using low ICPs for financed emissions and call into question the practice of benchmarking all ICPs against the range recommended by the Intergovernmental Panel on Climate Change.

The pension dilemma: financial sustainability versus inter-generational equity

PS5
July 3
13:30

Feng Runhuan[1], **Zhang Jingwen**[2], **Zhang Ning**[3] **and Bi Daning**[4]

[1]*Tsinghua University, China, fengrh@sem.tsinghua.edu.cn*
[2]*Hunan University, China, jingwenz@hnu.edu.cn*
[3]*Hunan University, China, zhangning1231@126.com*
[4]*Hunan University, China, daningbi@hnu.edu.cn*

Keywords: inter-generational equality, pay-as-you-go, pensions, sustainability, risk sharing

The global trend of population aging presents profound challenges for societies worldwide, particularly in the context of pension system sustainability. As governments confront the escalating financial pressures on retirement funds, proposed and implemented pension reforms have ignited economic anxiety among younger generations, notably Millennials and Gen Z. A central concern is that the benefits enjoyed by older generations may disproportionately burden future retirees, potentially leading to systemic inequities and governmental shortfalls in meeting the needs of an aging population.

This paper introduces a novel framework of metrics and methodologies designed to evaluate both the sustainability of pension systems and the degree of inter-generational equity across various pension designs. By addressing the following three pivotal questions, the study quantitatively examines the tension between pension system sustainability and inter-generational equity.

(1) What is the cost to inter-generational equity in achieving a net-zero balance for pension systems? By employing a Malthusian population model, we examine the impact of a net-zero balance on inter-generational equity under three demographic scenarios: stable population structures, baby boom dynamics, and increasing life expectancy. Stable populations are further categorized into three types based on size dynamics: stationary (constant size), growing (increasing size), and declining (decreasing size). While stable demographic structures promote inter-generational equity by ensuring equal valuation ratios between lifetime contributions and pension benefits, they do not necessarily guarantee actuarial fairness, which requires individuals' contributions to exactly match their pension entitlements in present value. Actuarial fairness, notably, emerges only under stationary population conditions. As life expectancy increases, particularly for cohorts with initially higher life expectancy, this change positively impacts the pension system by increasing the present value of lifetime benefits relative to contributions for these cohorts. Conversely, baby boomers inherently introduce inter-generational inequities, as the PAYG pension system creates unequal benefits between generations, with some benefiting disproportionately while others face greater burdens.

(2) Does a sustainable pension system inherently require a funding gap to maintain inter-generational parity? We analyze the evolution of funding gaps under different demographic scenarios to preserve inter-generational parity, focusing on stable population structures and baby boom dynamics. This paper shows that a stationary population maintains a closed funding gap. In contrast, a growing population exhibits cumulative funding surpluses that amplify over time, while a shrinking population shows diminishing funding deficits. Baby boom cohorts experience phased gap dynamics: an initial surplus accumulation during workforce entry transitions into structural deficits upon retirement, creating residual imbalances.

(3) How can policymakers strike an optimal balance between sustainability and equity? We propose a unified framework based on an overlapping generations model, focusing on risk-sharing between contributors, pensioners, and the buffer fund, which facilitates risk transfer across different generations. The risk-sharing mechanisms, which involve adjustments to key system variables, are designed to simultaneously enhance both financial sustainability and equity. In this context, we examine the effects of these mechanisms on the system's sustainability and equity, as discussed in the previous two questions. Specifically, we analyze several extreme scenarios to explore their potential implications.

Optimal insurance with two-dimensional adverse selection: risk exposure and probability distortion

PS3

July 2
15:40

Mai Zhang[1] **and Ka Chun Cheung**[2]

[1]*Department of Statistics and Actuarial Science, The University of Hong Kong, Pokfulam Road, Hong Kong, P.R. China, zhangmai@connect.hku.hk*

[2]*Department of Statistics and Actuarial Science, The University of Hong Kong, Pokfulam Road, Hong Kong, P.R. China, kccg@hku.hk*

Keywords: adverse selection, dual utility, stop-loss contracts, numerical methods

This study extends Gershkov et al.'s (2023) framework of optimal insurance under adverse selection by incorporating dual preferences and two-dimensional private information. While Gershkov et al. provide the first complete characterization with single-dimensional types under expected utility, we consider agents with private information about both their risk exposure (θ) and probability distortion (ϕ). Our model replaces the expected utility framework with Yaari's dual theory, where agents distort probabilities through type-dependent functions g_ϕ while maintaining linearity in wealth. Through analysis of incentive compatibility (IC) and individual rationality (IR) constraints in this enhanced setting, we prove that optimal contracts maintain the stop-loss structure but with deductibles $d(\theta, \phi)$ that depend on both dimensions. These deductibles must satisfy: (1) the harmonic condition $\partial g_\phi/\partial\theta \cdot \partial d/\partial\phi = \partial g_\phi/\partial\phi \cdot \partial d/\partial\theta$, and (2) monotonicity in both type dimensions. Using numerical methods, we solve for the profit-maximizing deductibles that balance insurance coverage against informational rents. Our computational results demonstrate how the interaction between risk levels and probability distortion affects optimal contract design, providing new insights for insurance markets where risk and behavioral characteristics are independently distributed.

Bibliography

[1] Gershkov, A., Moldovanu, B., Strack, P., Zhang, M. (2023). Optimal Insurance: Dual Utility, Random Losses, and Adverse Selection. *American Economic Review* 113(10), 2581–2614.

[2] Milgrom, P., Segal, I. (2002). Envelope theorems for arbitrary choice sets. *Econometrica* 70(2), 583–601.

[3] Yaari, M. E. (1987). The dual theory of choice under risk. *Econometrica* 55(1), 95–115.

The impact of wealth shocks on elderly health: Evidence from the China Health and Retirement Longitudinal Study

PS6

July 3
15:30

Hua Zhou[1,2] **and Hua Zhao**[2]

[1]*China Institute for Actuarial Science, Beijing China,*
[2]*School of Insurance, Central University of Finance and Economics, Beijing China, apzhaoh@163.com*

Keywords: wealth shock, elderly, health, housing prices

In recent years, the economic climate has been marked by complexity and volatility, leading to corresponding fluctuations in family wealth. Against the backdrop of an intensifying trend of population aging, the health of the elderly has garnered significant attention. Building upon this context, this paper investigates the influence of wealth shocks on the health of older individuals, a topic of considerable practical importance. Through the construction of a theoretical model, the paper derives the direction of the impact of wealth shocks on the health of the elderly and performs an empirical analysis using data from the China Health and Retirement Longitudinal Study (CHARLS) spanning from 2011 to 2018. The findings indicate that wealth shocks do not significantly affect the self-reported health and mental well-being of the elderly, yet they do exert a significant influence on their objective physical health, a conclusion that is consistent across various robustness tests.Specifically, wealth shocks have a significant impact on conditions such as hypertension, asthma, dyslipidemia, heart disease, and emotional and mental disorders. A mechanism analysis suggests that wealth shocks can impact the objective physical health of the elderly through two primary channels: access to medical care and lifestyle habits. Heterogeneity analysis further reveals that the impact of wealth shocks on the objective physical health of the elderly varies considerably among different genders, age groups, individuals with or without health insurance, and those residing in distinct regions. This study not only enriches the research domain of elderly health but also offers robust policy implications for the development of aging society policies, the provision of medical services, and the standardized operation of the real estate market.

Fine-grained mortality forecasting with deep learning

PS1

July 2
11:00

Huiling Zheng[1], **Hai Wang**[1], **Rui Zhu**[2], **and Jing-Hao Xue**[1]

[1]*University College London, United Kingdom, huiling.zheng.16@ucl.ac.uk, hai.wang.22@ucl.ac.uk, jinghao.xue@ucl.ac.uk*
[2]*Bayes Business School, City, University of London, United Kingdom, rui.zhu@city.ac.uk*

Keywords: fine-grained, mortality forecasting, xgboost, deep learning, multiple populations

Fine-grained mortality forecasting has gained momentum in actuarial research due to its ability to capture localised, short-term fluctuations in death rates. This paper introduces MortFCNet, a deep-learning method that predicts weekly death rates using region-specific weather inputs. Unlike traditional Serfling-based methods and gradient-boosting models that rely on predefined fixed Fourier terms and manual feature engineering, MortFCNet automatically learns patterns from raw time-series data without needing explicitly defined Fourier terms or manual feature engineering. Extensive experiments across over 200 NUTS-3 regions in France, Italy and Switzerland demonstrate that MortFCNet consistently outperforms both a standard Serfling-type baseline and XGBoost in terms of predictive accuracy. Our ablation studies further confirm its ability to uncover complex relationships in the data without feature engineering. Moreover, this work underscores a new perspective of exploring deep learning for advancing fine-grained mortality forecasting.

Bibliography

[1] Robben, J., Antonio, K., & Kleinow, T. (2024). The short-term association between environmental variables and mortality: Evidence from Europe. arXiv preprint arXiv:2405.18020.

[2] Richman, R., & Wüthrich, M. V. (2021). A neural network extension of the Lee–Carter model to multiple populations. *Annals of Actuarial Science*, 15(2), 346–366.

[3] Lee, R. D., & Carter, L. R. (1992). Modeling and forecasting US mortality. *Journal of the American Statistical Association*, 87(419), 659–671.

Dynamic hierarchical graph neural networks for spatiotemporal prediction of flood-related claims

PS4

July 3
10:30

Jing Zou [1] **George Tzougas** [2] **and Ostap Okhrin** [3]

[1]*Technische Universität Dresden; Center for Scalable Data Analytics and Artificial Intelligence (ScaDS.AI), Dresden/Leipzig, Germany, jing.zou@tu-dresden.de*
[2]*Heriot-Watt University, Edinburgh, UK, George.Tzougas@hw.ac.uk*
[3]*Technische Universität Dresden; Center for Scalable Data Analytics and Artificial Intelligence (ScaDS.AI), Dresden/Leipzig, Germany, ostap.okhrin@tu-dresden.de*

Keywords: hierarchical graph neural networks, spatiotemporal modeling, zero-inflated negative binomial regression, subnetworks

The aim of this paper is to develop a dynamic hierarchical Graph Neural Network (GNN) framework for spatiotemporal regression, see, e.g., [1], to predict flood-related insurance claims. Our model utilizes a global graph where nodes—representing postal codes—contain local graph structures that capture policy-level information while addressing imbalances in property distributions over time. Incorporating geographical covariates, building and content characteristics, and vulnerability levels, we also integrate the excessive rainfall index and wind speed index at the postal code level to enhance predictive performance.

For interpretability, we leverage the contextual embedding-based GNN from [2] to visualize pairwise feature interactions by including an interaction network layer at the policy level. To address the high skewness of zeros in the response variable, we also incorporate a Zero-Inflated Negative Binomial (ZINB) module into our GNN framework, drawing inspiration from methods used in highly sparse single-cell RNA-sequencing analysis, see [3] and [4]. Furthermore, we implement a feature selection process using subnetworks to optimize the ZINB parameters for mean and dispersion.

We apply our GNN-ZINB framework to an empirical study using data from Athens, Greece, spanning 257 postal code areas from 2013 to 2022, demonstrating its potential for improving flood insurance design.

Bibliography

[1] Ma, M., Xie, P., Teng, F., Wang, B., Ji, S., Zhang, J., Li, T. (2023). HiSTGNN: Hierarchical spatio-temporal graph neural network for weather forecasting. *Information Sciences* 648, 119580.

[2] Villaizán-Vallelado, M., Salvatori, M., Carro, B., Sanchez-Esguevillas, A. J. (2024). Graph neural network contextual embedding for deep learning on tabular data. *Neural Networks*. 173, 106180.

[3] Risso, D., Perraudeau, F., Gribkova, S., Dudoit, S., Vert, J. P. (2018). A general and flexible method for signal extraction from single-cell RNA-seq data. *Nature Communications*. 9(1), 284.

[4] Gan, Y., Huang, X., Zou, G., Zhou, S., Guan, J. (2022). Deep structural clustering for single-cell RNA-seq data jointly through autoencoder and graph neural network. *Briefings in Bioinformatics*. 23(2), bbac018.

Classification of extreme rainfall events in Switzerland

PS1

July 2
11:00

Herve Zumbach[1], **Hansjoerg Albrecher**[2], **Erwan Koch**[3], **Valerie Chavez-Demoulin**[4]

[1]*HEC Lausanne, Switzerland, herve.zumbach@unil.ch*
[2]*HEC Lausanne, Switzerland, hansjoerg.albrecher@unil.ch*
[3]*University of Lausanne, Switzerland, erwan.koch@unil.ch*
[4]*HEC Lausanne, Switzerland, valerie.chavez@unil.ch*

Keywords: extreme value theory, rainfall, extended generalised pareto distribution, non-stationary process, climate change.

This paper presents a methodology for classifying the extremeness of rainfall events while accounting for their temporal context, specifically the season and year in which they occur—an essential factor in assessing insurance risks associated with heavy precipitation. By incorporating non-stationarity due to seasonal patterns and climate change, our approach effectively identifies quantiles of extreme rainfall events under present climatic conditions. The rainfall distribution is modeled using the Extended Generalized Pareto Distribution (EGPD) [2], with an adaptation of the method proposed by Gubler et al. [1] to accommodate time-varying parameters in the fitting distribution. This analysis enables a distinction between historically extreme events under past climatic conditions and those that are now more frequent under current climatic trends. The methodology is illustrated using Swiss rainfall data, with results interpreted in the context of changing insurability of natural catastrophe (NatCat) losses. This research is conducted in collaboration with H. Albrecher, E. Koch, and V. Chavez-Demoulin.

Bibliography

[1] Gubler, S., Fukutome, S., Scherrer S. C. (2023). On the statistical distribution of temperature and the classification of extreme events considering season and climate change—an application in Switzerland. *Theoretical and Applied Climatology* 153:1273–1291.

[2] Naveau, P., Huser, R., Ribereau, P., Hannart, A. (2016). Modeling jointly low, moderate, and heavy rainfall intensities without a threshold selection. *Water Resources Research* 52, 2753–2769.

Index

Platinum sponsors

LHV

Eesti Liikluskindlustuse Fond
Eesti Kindlustusseltside Liit

Academic partner

ACTEX Learning

Organizers

Eesti Aktuaaride Liit

UNIVERSITY OF TARTU
Institute of Mathematics and Statistics

CONFERENCE EXPERT

visit estonia