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12TH WORLD CONGRESS

FGV EMAp, RIO DE JANEIRO, BRAZIL

8 - 12 JULY

2024

Plenary Speakers:

Francesca Biagini
University of Munich, Germany

Agostino Capponi
Columbia University, USA

Christa Cuchiero
University of Vienna, Austria

Min Dai
The Hong Kong Polytechnic University, China

Pierre Henry-Labordère
Qube Research and Technologies, France

Johannes Muhle-Karbe
Imperial College London, UK

Emanuela Rosazza Gianin
Università degli Studi di Milano-Bicocca, Italy

Peter Tankov
ENSAE, France

Louis Bachelier Lecture:

Michael Ludkovski
University of California, Santa Barbara, USA

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With the paper:
Reconciling Rough Volatility with Jumps (link)

SIG SUSQUEHANNA

Program

Time	Monday	Tuesday	Wednesday	Thursday	Friday
7:30	Registration	Registration	Registration	Registration	Registration
8:30	**Opening Remarks**				
9:00	**Plenary**	**Plenary**	**Plenary**	**Plenary**	**Plenary**
10:00	Coffee Break	Coffee Break	Coffee Break	Coffee Break	Coffee Break
10:30	Parallel Sessions	Parallel Sessions	Parallel Sessions	Parallel Sessions	Parallel Sessions
12:30	**Lunch Break (on-site)**	**Lunch Break (on-site)**		**Lunch Break (on-site)**	**Lunch Break (on-site)**
14:00	Parallel Sessions	Parallel Sessions		Parallel Sessions	**Plenary**
16:00	Coffee Break	Coffee Break		Coffee Break	
16.30	**Plenary**	**Plenary**		**Louis Bachelier Plenary**	
17:30				BFS Assembly (Cultural Center)	
18:30	**Welcome Drinks Poster Session**				
20:00		**Conference Dinner**			

Plenary Talks

All plenary talks will be held at the Cultural Center.

Day (Time)	Speaker	Title	Chair
Monday (9:00 – 10:00)	Francesca Biagini	Deep learning for asset price bubbles' detection	J. Obloj
Monday (16:30 – 17:30)	Min Dai	Recent Advances on Portfolio Choice with Market Frictions	T. Zariphopoulou
Tuesday (9:00 – 10:00)	Agostino Capponi	Mathematics and Economics of Decentralized Exchange Design	Y. Saporito
Tuesday (16:30 – 17:30)	Johannes Muhle–Karbe	Pre-Hedging	J. Zubelli
Wednesday (9:00 – 10:00)	Pierre Henry-Labordere	From Schrodinger bridges to random matrices	H. Buehler
Thursday (9:00 – 10:00)	Christa Cuchiero	Signature methods in finance	C. Reisinger
Thursday (16:30 – 17:30) Louis Bachelier Lecture	Michael Ludkovski	Gaussian Process Models for Quantitative Finance	S. Jaimungal
Friday (9:00 – 10:00)	Peter Tankov	Linear programming approach to mean-field games: theory, numerics and applications in economics and finance	G. Di Nunno
Friday (14:00 – 15:00)	Emanuela Rosazza Gianin	Risk measures: horizon longevity and BSDEs	B. Acciaio

Parallel Sessions - Minisymposia and Thematic Sessions

Talks in minisymposia and thematic sessions are 25 min long with 5 minutes for questions.

Day (Time)	Session	Chair	Auditorium
Monday (10:30 – 12:30)	Option Pricing I	E. Lepinette	306
	Hedging Strategies	J. Armstrong	307
	Interest Rate Modeling	T. Schmidt	308
	Computational Finance I	A. Neufeld	317
	ML for Finance I	J. Zubelli	318
	Recent Advances in Optimal Transport and Applications to Finance	A. Marini	537
	Dynamic Information Acquisition and Adaptive Decision Making (Part I)	C. Reisinger, R. Xu and T. Zariphopoulou	408
	Algorithmic Trading	F. Drissi	409
	Mathematical Advances for environment and energy transition (Part I)	R. Dumitrescu	418
Monday (14:00 – 16:00)	Option Pricing II	A. Andrikopoulos	308
	Financial Economics	H. Xing	318
	Mean-Field Games and related models I	A. Saplaouras	317
	Advances in stochastic control with financial applications	B. Angoshtari	409
	Neural differential methods in Finance	F. Krach	408
	Dynamic Information Acquisition and Adaptive Decision Making (Part II)	C. Reisinger, R. Xu and T. Zariphopoulou	418
	Mathematical advances for environment and energy transition (Part II)	R. Dumitrescu	537

Day (Time)	**Session**	**Chair**	**Auditorium**
Tuesday (10:30 – 12:30)	Volatility Modeling	L. Ballotta	537
	Jump-diffusion and related models I	L. Mercuri	307
	Optimal Investment	S. Desmettre	308
	ML for Finance II	A. Papapantoleon	408
	Market Microstructure I	T. Rheinlander	306
	Systemic Risk I	N. Meimanjan	317
	Blockchain and decentralized finance	S. Sturn	318
	X-OT	J. Wiesel and J. Obloj	418
	Barycenter problems in multi agent markets: Risk sharing, collective arbitrage and collective super-replication	T. Meyer–Brandis	409
Tuesday (14:00 – 16:00)	Jump-diffusion and related models II	A. Bondi	537
	Robust Finance	L. Aquino	317
	Computational Finance II	B. Dupire	318
	Mean Field Games and related models II	A. Hu	409
	Market Microstructure II	A. Danilova	408
	Financial Econometrics I	V. Albani	418
	Systemic Risk II	G. Baker	308
Wednesday (10:30 – 12::30)	Computational Finance III	K. Lu	317
	Financial Econometrics II	J. Schiltz	318
	Insurance mathematics	R. Targino	537
	Stochastic Processes I	M. Souza	308
	Advances in Statistics for Stochastic Processes	C. Amorino	408
	Control, Optimization and Market Microstructure	F. Yu	418
	Distributional robust optimization in mathematical finance	J. Wiesel and J. Obloj	409

Day (Time)	Session	Chair	Auditorium
Thursday (10:30 – 12:30)	Signature-based models	C. Cuchiero	408
	Optimal stopping and stochastic control in Finance	P. Gapeev	318
	Risk Management	D. Zhu	307
	Environmental Finance	N. Rodosthenous	317
	Market Microstructure III	S. Robertson	308
	ML for Finance III	U. Ulrych	537
	Market equilibria and BSDEs in Contract Theory (Part I)	D. Possamaï	418
	Addressing Non-uniqueness in Mean Field Games	Z. Cheng	409
Thursday (14:00 – 16:00)	Mean Field Games and related models III	C. Reisinger	537
	Financial Statistics	D. Konstantinides	308
	Market Microstructure IV	D. Kreher	317
	Stochastic Processes II	U. Schmock	318
	Martingale optimal transport in robust finance	B. Robinson and J. Backhoff-Veraguas	408
	Market equilibria and BSDEs in Contract Theory (Part II)	N. Hernández	418
	Recent advances in market microstructure	E. Neuman	409
Friday (10:30 – 12:30)	Credit Risk	C. Hillairet	537
	Market Microstructure V	S. Campbell	408
	Dynamic Risk Management	E. Mastrogiacomo	308
	Portfolio Selection	J. Vecer	317
	Stochastic Processes III	G. Di Nunno	318
	Recent advances in contract theory	M. Talbi	418
	Recent advances in volatility modeling	F. Bourgey	409

Detailed Conference Program

Monday, July 8th

Plenaries

1 Deep learning for asset price bubbles detection
Francesca Biagini

2 Recent Advances on Portfolio Choice with Market Frictions
Min Dai

Morning Parallel Session – 10:30 to 12:30

Option Pricing I – Room: 306

3 Alternative approach to price European options in general discrete-time models without no-arbitrage condition.
Emmanuel Lepinette

4 NN de-Americanization: A Fast and Efficient Calibration Method for American-Style Options
Peter Pommergård Lind and Jim Gatheral

5 Price equivalence between Parasian options with a moving window and their “fixed window" counterparts
Song-Ping Zhu

6 Bayesian dynamic Pricing under an arbitrary prior
Yuqiong Wang and Erik Ekström

Hedging Strategies – Room: 307

7 Robustness of the Gamma Hedging Strategy
John Armstrong

8 Nonparametric option hedging
Raquel M Gaspar and João Bastos

9 A model for the hedging impact of option market makers
Sebastian Bak Egebjerg and Thomas Kokholm

10 Super-hedging-pricing for vulnerable claims in market models with random horizon
Tahir Choulli and Emmanuel Lepinette

Interest Rate Modeling – Room: 308

11 Reproducing Kernel Based Methods For Modelling The Discount Curve
Andreas Celary, Zehra Eksi-Altay, Damir Filipović and Paul Krühner

12 Implicit Entropic Market Risk-Premium from Interest Rate Derivatives
Juan Carlos Arismendi Zambrano and Rafael Moura Azevedo

13 Endogenous distress contagion in dynamic interbank systems
Andreas Søjmark and Zachary Feinstein

14 Term structure modelling with overnight rates beyond stochastic continuity
Thorsten Schmidt, Claudio Fontana and Zorana Grbac

Computational Finance I – Room: 317

15 Quantum Monte Carlo algorithm for solving Black-Scholes PDEs for high-dimensional option pricing in finance and its proof of overcoming the curse of dimensionality
Ariel Neufeld, Jianjun Chen and Yongming Li

16 Quant Models, Systematic Investments and Risk Management
Franklin De Oliveira Gonçalves and Guilherme Ribeiro

ML for Finance I – Room: 318

Recent Advances in Optimal Transport and Applications to Finance – Room: 537

Dynamic Information Acquisition and Adaptive Decision Making (Part I) – Room: 408

Algorithmic Trading – Room: 409

Mathematical advances for environment and energy transition (Part I) – Room: 418

Afternoon Parallel Session – 14:00 to 16:00

Option Pricing II – Room: 308

Financial Economics – Room: 318

Mean-Field Games and related models I – Room: 317

Advances in stochastic control with financial applications – Room: 409

Neural differential methods in Finance – Room: 408

Dynamic Information Acquisition and Adaptive Decision Making (Part II) – Room: 418

Mathematical advances for environment and energy transition (Part II) – Room: 537

Tuesday, July 9th

Plenaries

Morning Parallel Session – 10:30 to 12:30

Volatility Modeling – Room: 537

Jump-diffusion and related models I – Room: 307

Optimal Investment – Room: 308

ML for Finance II – Room: 408

Market Microstructure I – Room: 306

Systemic Risk I – Room: 317

Blockchain and decentralized finance – Room: 318

X-OT: variants of optimal transport in mathematical finance – Room: 418

Barycenter problems in multi agent markets: Risk sharing, collective arbitrage and collective super-replication – Room: 409

Afternoon Parallel Session – 14:00 to 16:00

Jump-diffusion and related models II – Room: 537

Robust Finance – Room: 317

Computational Finance II – Room: 318

105 From previous tick to pre-averaging: A Spectrum of equidistant transformations for unevenly spaced high-frequency data
Vitali Alexeev, Katja Ignatieva and Jun Chen

106 Calibration risk under parameter probabilistic dependencies and model output effects
Ioannis Kyriakou, Gianluca Fusai and Marina Marena

107 An Order Matching Engine to Trade Multiple Securities Simultaneously
Bruno Dupire

Mean Field Games and related models II – Room: 409

~~108 MF-OMO: an optimization formulation of mean-field games~~
~~*Anran Hu, Xin Guo and Junzi Zhang*~~

109 A Probabilistic Approach to Discounted Infinite Horizon and Invariant Mean Field Games
Kaiwen Zhang, René Carmona and Ludovic Tangpi

110 Continuous time persuasion with filtering and applications to energy transition
Ofelia Bonesini, Luciano Campi, Giorgia Callegaro and René Aïd

111 Bank Liquidity Management and Payout Policy under Peer Pressure
Diogo Duarte, Yuri Fahham Saporito and Ozde Oztekin

Market Microstructure II – Room: 408

112 Order routing and market quality: Who benefits from internalization?
Albina Danilova and Umut Cetin

113 Derivative Pricing with Strategic Competition for Liquidity
Puru Gupta

114 Dynamic Portfolio Choice with Intertemporal Hedging and Transaction Costs
Xiaofei Shi, Johannes Muhle-Karbe and James A. Sefton

115 Stochastic Liquidity as Proxy for Nonlinear Cross Impact
Connor Tracy and Johannes Muhle-Karbe

Financial Econometrics I – Room: 418

~~116 Topological Tail Dependence: Evidence from Forecasting Realized Volatility~~
~~*Hugo Gobato Souto*~~

117 Combining Stochastic Modeling and Artificial Intelligence to Price Electricity Forward Contracts
Vinicius Albani

118 Forecasting Realized Volatility with Spillover Effects: Perspectives from Graph Neural Networks
Chao Zhang, Xingyue Pu, Mihai Cucuringu and Xiaowen Dong

119 Drivers of Bitcoin volatility: A Comprehensive Study with Statistical and Machine Learning Methods
Piotr Fiszeder, Grzegorz Dudek, Witold Orzeszko and Radosaw Pietrzyk

Systemic Risk II – Room: 308

120 Contagious McKeanVlasov problems with common noise: from smooth to singular feedback through hitting times
Aldair Petronilia, Ben Hambly, Christoph Reisinger, Stefan Rigger and Andreas Søjmark

121 From mean field modelling to a forward-looking indicator of systemic risk
Eliana Fausti, Sean Ledger and Andreas Søjmark

122 Two approaches to mean-field systemic risk models with default cascades
Graeme Baker

123 Common Asset Impact on Default Contagion
Osvaldo Paulo Israel Cancado Assuncao

Wednesday, July 10th

Plenary

Morning Parallel Session – 10:30 to 12:30

Computational Finance III – Room: 317

Financial Econometrics II – Room: 318

Insurance mathematics – Room: 537

Stochastic Processes I – Room: 308

Advances in Statistics for Stochastic Processes – Room: 408

Control, Optimization and Market Microstructure – Room: 418

Distributionally robust optimisation in mathematical finance – Room: 409

Thursday, July 11th

Plenaries

Morning Parallel Session – 10:30 to 12:30

Signature-based models – Room: 408

Optimal stopping and stochastic control in Finance – Room: 318

Risk Management – Room: 307

Environmental Finance – Room: 317

Market Microstructure III – Room: 308

ML for Finance III – Room: 537

Market equilibria and BSDEs in Contract Theory (Part I) – Room: 418

177 A new approach to principalagent problems with volatility control
Emma Hubert

178 Randomness and early termination: what makes a game exciting?
Dylan Possamaï

179 Time-inconsistent stochastic control: state dependency
Mateo Rodriguez Polo

Addressing Non-uniqueness in Mean Field Games – Room: 409

180 On the long time behavior of mean field games
Alekos Cecchin

181 MF-OML: Online mean-field reinforcement learning with occupation measures for large population games
Anran Hu

182 Strong solutions to submodular mean field games with common noise under lack of uniqueness
Jodi Dianetti

183 Mean field regrets in discrete time games
Ziteng Cheng

Afternoon Parallel Session – 14:00 to 16:00

Mean Field Games and related models III – Room: 537

184 Simulation of the Calibrated Heston-type Local Stochastic Volatility Model
Maria Olympia Tsianni and Christoph Reisinger

185 Equilibria in incomplete markets an FBSDE approach
Nikolaos Constantinou and Martin Herdegen

186 Extended mean-field games with multi-dimensional singular controls
Robert Denkert and Ulrich Horst

187 Macro-Finance Models: A Mean-field Game Approach
Vu Huy Hoang and Tomoyuki Ichiba

Financial Statistics – Room: 308

188 A new approach in two-dimensional heavy-tailed random variables
Dimitrios Konstantinides and Charalampos Passalidis

189 A Comparison of Neural Networks and Bayesian Approaches for the Heston Model Estimation
Jií Witzany and Milan Ficura

190 Convergence of Heavy-Tailed Hawkes Processes and the Microstructure of Rough Volatility
Zhang Rouyi, Ulrich Horst and Wei Xu

Market Microstructure IV – Room: 317

191 Interacting limit order markets
Dörte Kreher and Cassandra Milbradt

192 A queueing approach to execution probabilities in a limit order book with stochastic order flows
Fenghui Yu

193 The Short-Term Predictability of Returns in Order Book Markets: a Deep Learning Perspective
Lorenzo Lucchese, Mikko Pakkanen and Almut Veraart

194 Stability of order routing systems in fragmented markets
Yonatan Shadmi, Eyal Neuman and Johannes Muhle-Karbe

Stochastic Processes II – Room: 318

Martingale optimal transport in robust finance – Room: 408

Market equilibria and BSDEs in Contract Theory (Part II) – Room: 418

Recent advances in market microstructure – Room: 409

BFS General Assembly – 17:30 – Cultural Center

Friday, July 12th

Plenaries

Morning Parallel Session – 10:30 to 12:30

Credit Risk – Room: 537

Market Microstructure V – Room: 408

Dynamic Risk Management – Room: 308

Portfolio Selection – Room: 317

Stochastic Processes III – Room: 318

Recent advances in contract theory – Room: 418

Recent advances in volatility modeling – Room: 409

Posters

Deep learning for asset price bubbles' detection

Francesca Biagini*

*University of Munich, biagini@math.lmu.de

Keywords:

In this talk we present deep learning techniques to detect financial asset bubbles by using observed call option prices and a model-independent algorithm. Under a given condition on the pricing of call options under asset price bubbles, we are able to provide a theoretical foundation of our approach for positive and continuous stochastic asset price processes. When such a condition is not satisfied, we focus on local volatility models. To this purpose, we give a new necessary and sufficient condition for a process with time-dependent local volatility function to be a strict local martingale.

This talk is based on Biagini, F., Gonon, L., Mazzon, A., Meyer -Brandis, T., Detecting asset price bubbles using deep learning, Preprint University of Munich, 2022.

Recent Advances on Portfolio Choice with Market Frictions

Min Dai*

*The Hong Kong Polytechnic University, minpolyuhk.dai@polyu.edu.hk

Keywords:

In this talk, I will unveil our recent research on continuous-time portfolio choice with market frictions. First, I will show that incorporating transaction costs into mean-variance portfolio choice may result in absurd equilibrium strategies. Second, I will explore the application of reinforcement learning techniques to portfolio choice with transaction costs. Last, I will present a novel portfolio choice model in the presence of capital gains taxes. Throughout the talk, I will highlight several pertinent open questions for further research. This talk is based on some of my recent works jointly with Yuchao Dong, Yanwei Jia, Yipeng Jiang, Hanqing Jin, Yaoting Lei, Hong Liu, and Chen Yang.

Alternative approach to price European options in general discrete-time models without no-arbitrage condition.

Emmanuel Lepinette*

*Ceremade, Paris-Dauphine University, PSL, France, emmanuel.lepinette@ceremade.dauphine.fr

Keywords: Option pricing and hedging; Computational finance

The classical approach to characterize the super-hedging prices of a European style claim does not work as soon as the model is not linear. This is the case when there are transaction costs which are not proportional. We present a new approach which holds for market models with or without friction in discrete time because we do not use the usuel convex duality. Instead, the conditional supremum operator is the key tool that replaces the conditional expectation that naturally appears under the no-arbitrage condition NA. In our approach, we do not need to assume any no-arbitrage condition so that a large class of models may be considered even non linear ones. Moreover, our result based on a dynamic programming principle allows us to deduce a numerical scheme, rather simple to implement.

NN de-Americanization: A Fast and Efficient Calibration Method for American-Style Options

Peter Pommergård Lind* and Jim Gatheral

**Aalborg University*, ppl@business.aau.dk

Keywords: Stochastic volatility and volatility modeling; Machine learning for Finance; Optimal stopping and stochastic control

Neural network (NN) de-Americanization produces fast and accurate pseudo-European option prices from American option market prices, facilitating the calibration of derivative models. The industry approach binomial de-Americanization takes a flat volatility surface as input. In contrast, the NN de-Americanization method takes the detailed shape of the volatility surface as an input; this is critical for the accurate evaluation of the early exercise premium (EEP) when interest rates are not close to zero.

Price equivalence between Parasian options with a moving window and their "fixed window" counterparts

Song-Ping Zhu*

* *University of Wollongong,* spz@uow.edu.au

Keywords: Option pricing and hedging

This paper untangles a price connection between Parasian options with a moving window and their seemly disconnected "fixed window" counterparts through a simple and elegant coordinate transform to the pricing PDE (Partial Differential Equation) system. As a result of our newly discovered quantitative connection between the two, not only are we able to price the former much more efficiently through the latter, we can also provide a better understanding and financial interpretation of the former in their application in finance, particularly corporate finance, as well as potentially for other derivatives of similar "window-sampling" structure such as convertible bonds with the conversion right being defined on a moving window.

Bayesian dynamic Pricing under an arbitrary prior

Yuqiong Wang* and Erik Ekström

*Researcher in Stochastic Control Theory, yuqiong.wang@math.uu.se

Keywords: Optimal stopping and stochastic control

We consider a financial model in which the seller strategically sets prices to sequentially arriving customers to maximize the expected total profit, where the demand function of the potential customers is unknown and has an arbitrary prior distribution. In a Bayesian setting, the problem can be embedded in a Markovian framework. We construct the value function and show that it is convex. Additionally, we present a specific example and further discuss the role of incomplete information in certain "exploration-exploitation" types of problems with discrete-time structures.

Robustness of the Gamma Hedging Strategy

John Armstrong*

**King's College London*, john.armstrong@kcl.ac.uk

Keywords: Machine learning for Finance; Robust finance; Option pricing and hedging

If one knows how option prices will change in response to changes underlying, one can prove using rough path theory that the gamma-hedging strategy will converge surely so long as the underlying process is sufficiently regular. The underlying price process does not need to be generated by any particular probability model. In this sense the gamma-hedging strategy is particularly robust to uncertainty in the behaviour of the underlying. This theory provides an interpretation of the market practice of calibrating a model to prices and gamma hedging. We will discuss these results from from the theoretical of rough-path theory and show that the same strategy emerges if one uses a neural network to identify optimal robust trading strategies.

Nonparametric option hedging

Raquel M Gaspar* and João Bastos

*ISEG, Universidade de Lisboa, rmgaspar@iseg.ulisboa.pt

Keywords: Option pricing and hedging; Machine learning for Finance

We introduce a novel nonparametric methodology for option hedging. Unlike alternative approaches, our method makes no assumptions about the relationship between option prices and underlying explanatory variables. This approach relies on accumulated local effects given by ensembles of decision trees. Although we employ a gradient boosting machine for the ensemble, any method for creating decision tree ensembles can be considered. By simulating synthetic option prices generated via the Black-Scholes model, we observe that our method accurately reproduces the Greeks as predicted by this model. Then, we conduct an empirical study using American call and put options on individual stocks. Our findings reveal deviations from the binomial model when applied to real market prices. In particular, the volatility input has lower impact.

A model for the hedging impact of option market makers

Sebastian Bak Egebjerg* and Thomas Kokholm

*Aarhus University, seeg@econ.au.dk

Keywords: Systemic risk; Option pricing and hedging; Risk management; Market microstructure

We propose a model that captures the directional impact of Option Market Makers (OMM) delta hedging their option inventory. A similar approach is employed in Sornette et al. (2022), where the impact materializes when OMMs update their hedges in reaction to price changes in the underlying security (the Gamma effect). We extend their model and include an impact of new option positions being hedged by the OMM. When the fundamental value of the stock price has constant volatility and drift terms, inclusion of a linear hedging impact implies that the observable stock price features both stochastic volatility and drift terms. We show via simulation that the hedging impact is significant and that the impact of new option positions being hedged is sizable. Focusing on the trading impact implied by the Gamma effect in isolation will underestimate the impact in scenarios where the OMM's option inventory changes in a direction that implies trading in the same direction as the Gamma impact and vice versa. Using a high frequency data set on SPX option trades, we estimate changes to the net option position of OMMs over an extended period and find that the change is a strong predictor of the end-of-day return on SPX futures. A decomposition of the change in the delta position into a change implied by the Gamma effect and a change due to a change in the option inventory reveals that both quantities are strongly significant and with impact in line with the model predictions.

Super-hedging-pricing for vulnerable claims in market models with random horizon

Tahir Choulli* and Emmanuel Lepinette

*Mathematical and Statistical Sciences Dept. University of Alberta, Edmonton, Canada, tchoulli@ualberta.ca

Keywords: Credit risk; Option pricing and hedging; Model risk and uncertainty

We consider the discrete-time setting, and the market model described by the triplet (S, F, T). Herein F is the "public" flow of information which is available to all agents overtime, S is the discounted price process of d-tradable assets, and T is an arbitrary random time whose occurrence might not be observable via F. Thus, we consider the larger flow G which incorporates F and makes T an observable random time. This framework covers the credit risk theory setting where T is the default time of a firm or a client, the life insurance setting where T is the death time of an insured, and the setting of employee stock option valuation. For the stopped model (S^T, G) and for various vulnerable claims, based on this model, we address the super-hedging pricing valuation problem and its intrinsic Immediate-Profit arbitrage (IP hereafter for short). Our first main contribution lies in singling out the impact of change of prior and/or information on conditional essential supremum, which is a vital tool in super-hedging pricing. The second main contribution consists of describing as explicit as possible how the set of super-hedging prices expands under the stochasticity of T and its risks, and we explain how the IP arbitrage for (S^T, G) is triggered. The third main contribution resides in elaborating an explicit and backward pricing formulas for any vulnerable claim on the one hand. On the other hand, we single out and quantify the various informational risks in the prices' dynamics.

Reproducing Kernel Based Methods For Modelling The Discount Curve

Andreas Celary*, Zehra Eksi-Altay, Damir Filipovic, and Paul Krühner

* *Vienna University of Economics and Business*, acelary@wu.ac.at

Keywords: Machine learning for Finance; Yield curve modeling

We consider term structure models from the perspective of the discount framework introduced by Damir Filipovic. In analogy to the Heath-Jarrow-Morton (HJM) setting, we formulate an arbitrage-free dynamic framework for modelling the discount curve. In this proposed setting, we discuss the no-arbitrage conditions that determine the set of admissible discount curves under the assumption of affine finite-dimensional realizations. Following Filipovic et al., we introduce reproducing kernels as a possible regression basis for the corresponding estimation problem and derive a rich class of reproducing kernel Hilbert spaces that are admissible in the HJM framework. To illustrate our approach, we present numerical examples where we estimate the discount curves using real world bond price data.

Implicit Entropic Market Risk-Premium from Interest Rate Derivatives

Juan Carlos Arismendi Zambrano* and Rafael Moura Azevedo

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Keywords: Yield curve modeling; Risk measures; Risk management; Model risk and uncertainty

Implicit in interest rate derivatives are the Arrow–Debreu prices (state price densities, SPDs) that contain fundamental asset pricing information of interest rate markets. To extract such information from interest rate derivatives, we propose a nonparametric method to estimate state prices based on the minimization of the Cressie–Read (Entropic) family function between potential SPDs and the empirical probability measure. An empirical application of the method, in the US interest rates and derivatives market, shows that the entropic based risk-neutral density measure highlight potential risks previous to the 2007/2008 financial crisis, and the potential arbitrage burden during the Quantitative Easing (QE) period.

Endogenous distress contagion in dynamic interbank systems

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Keywords: Systemic risk; Credit risk; Risk management

In this talk, I will introduce an interbank system with stochastic dynamics subject to an endogenous notion of distress contagion that materialises from worries about future solvency contagion within the network. This will entail a forward-backward approach to the equilibrium dynamics, enforced by a suitable mark-to-market valuation adjustment of interbank claims. Distinct from static models, the resulting distress contagion acts as a stochastic volatility term which leads, endogenously, to volatility clustering and a marked downside leverage effect. Moreover, when considering multiple maturities, the model allows us to examine the impact of systemic risk on the full term structure of interbank claims. In particular, we demonstrate how increases in the volatility of a core group of banks can cause an inverted yield curve for the entire banking system.

Term structure modelling with overnight rates beyond stochastic continuity

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Keywords: Yield curve modeling

Overnight rates, such as the SOFR (Secured Overnight Financing Rate) in the US, play a central role in the current reform of interest rate benchmarks. A striking feature of overnight rates is the presence of jumps and spikes occurring at predetermined dates, as a result of monetary policy interventions and liquidity constraints. This corresponds to stochastic discontinuities (i.e., discontinuities occurring at ex-ante known points in time) in the dynamics of overnight rates. In this work, we propose a term structure modelling framework in the presence of overnight rates and characterize absence of arbitrage in a generalised Heath-Jarrow-Morton (HJM) setting. By extending the classical short-rate approach to the case of stochastic discontinuities, we develop a tractable setup driven by affine semimartingales. In this context, we show that simple specifications allow to capture stylized facts of the jump behavior of overnight rates. In a Gaussian setting, we provide explicit valuation formulas for bonds and caplets. Finally, we investigate hedging in the sense of local risk-minimization when the underlying term structures exhibit stochastic discontinuities.

This talk starts from the developments in our paper and will include new results on calibration to data and a performance analysis of the proposed hedging method to existing alternatives

Quantum Monte Carlo algorithm for solving Black-Scholes PDEs for high-dimensional option pricing in finance and its proof of overcoming the curse of dimensionality

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Keywords: Computational finance

In this talk we present a quantum Monte Carlo algorithm to solve high-dimensional Black-Scholes PDEs with correlation for high-dimensional option pricing. The payoff function of the option is of general form and is only required to be continuous and piece-wise affine (CPWA), which covers most of the relevant payoff functions used in finance. We provide a rigorous error analysis and complexity analysis of our algorithm. In particular, we prove that the computational complexity of our algorithm is bounded polynomially in the space dimension d of the PDE and the reciprocal of the prescribed accuracy e and so demonstrate that our quantum Monte Carlo algorithm does not suffer from the curse of dimensionality. This talk is based on joint work with Jianjun Chen and Yongming Li.

Quant Models, Systematic Investments and Risk Management

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Keywords: Algorithmic trading; Risk management; FinTech

Since at least the early 1970s the use of finance models in investment management has been very widespread. Over time, these models formed the basis of so-called "Quant Funds" or algorithm-driven portfolios.

More recently, we have a situation where almost all funds use and implement models, but in the case of the "Systematic Funds", the investment process is completely automated, without human intervention.

In this research we present a framework to best develop systematic funds in a digital bank in São Paulo. Our approach is to integrate the "market signals" algorithms (the returns generators) with the "risk control" algorithms (the monitoring of performance) so that an optimal balance is achieved. Specifically, how to make systematic funds flexible, successful and resilient to market turbulences over time.

Cashflow-driven investment beyond expectations

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Keywords: Asset-liability management, Cashflow-driven investment, Convex stochastic optimization, Defined benefit pensions

This paper presents a computationally tractable optimization model for cashflow-driven investment where the aim is to find asset portfolios whose future payouts cover given liability payments as well as possible. While current industry solutions are largely based on expected future cash flows, we use a stochastic optimization model that seeks portfolios that give the best possible match across time as well as scenarios. Cashflow matching across scenarios is controlled by risk aversion while the timing is controlled by the illiquidity of money markets. When illiquidity increases, the hedging strategy quickly shifts towards portfolios suggested by deterministic models, but significant uncertainty remains. The model can incorporate hundreds of quoted instruments in the construction of optimal hedging strategies. The hedging strategies are able to employ any statistical connections between the liabilities and publicly quoted assets. The model is solved with simple Monte Carlo approximations and off-the-shelf convex optimization software. Besides optimal hedging strategies, we find the least cost of hedging which provides a market-consistent valuation based on the current quotes and the liquidity factors as well as the views and risk preferences of the investor/regulator. The approach is illustrated by the pricing and hedging of defined benefit pension liabilities which depend on uncertain longevity developments and the consumer price index. The hedging strategies are constructed from 128 publicly quoted instruments including index-linked bonds and equities. We find that the optimized hedging strategies achieve lower risk at a lower cost than the strategies obtained by matching expected cashflows. The hedging-based liability valuations are robust with respect to model parameters and the additional risk reduction achieved by optimization does not add much to the overall hedging cost.

Solving Extended Linear Complementarity Problems (XLCP) - Financial and Environmental Implications.

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Keywords: Robust finance; Computational finance

The objective of this work is to establish theoretical and numerical conditions for Solving Extended Linear Complementarity Problems (XLCP), with emphasis on the Horizontal Linear Complementarity Problem (HLCP). Two new strategies for solving complementarity problems are presented, using differentiable and penalized functions, which resulted in a natural formalization for the Linear Horizontal case. The computational results of all suggested strategies are also discussed in depth in this paper. The implication in practice allows solving and optimizing, in an innovative way, the (forestry) problems of the value chain of the industrial wood sector.

A novel Fourier tensor network for solving multi-dimensional expectation problems

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Keywords: Credit risk; Risk management; Computational finance; Machine learning for Finance

Numerous challenges in quantitative finance fundamentally involve solving multi-dimensional expectation problems. Typical examples include the valuation of multi-asset options and quantification of counterparty credit risk at portfolio level. In general, analytical solutions are not available, necessitating the utilization of numerical methods.

In this paper we introduce a novel Fourier tensor network to enhance the supervised learning of the characteristics function (ch.f.) of the combined dynamics of the random variables, with which the targeted expectation can be easily recovered. The ch.f. itself is again a multi-dimensional expectation. We demonstrate that, in several cases, the ch.f. is represented by a network expression consisting of multiple layers of Fourier basis functions and Fourier coefficients.

Our numerical tests show that the Fourier tensor network offers a substantial improvement in computational speed and efficiency, in comparison to the industrial standard Monte Carlo simulation method. Further, various sensitivities of risk metrics and option prices are easily available, thanks to the network representation of Fourier basis functions.

Universal Approximation Property of Random Neural Networks

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Keywords: Machine learning for Finance; Option pricing and hedging

In this talk, we study random neural networks which are single-hidden-layer feedforward neural networks whose weights and biases are randomly initialized. After this random initialization, only the linear readout needs to be trained, which can be performed efficiently, e.g., by the least squares method. By viewing random neural networks as Banach space-valued random variables, we prove a universal approximation theorem within a large class of Bochner spaces. Hereby, the corresponding Banach space can be significantly more general than the space of continuous functions over a compact subset of a Euclidean space, namely, e.g., an L^p-space or a Sobolev space, where the latter includes the approximation of the derivatives. Moreover, we derive approximation rates and an explicit algorithm to learn a deterministic function by a random neural network. In addition, we provide a full error analysis and study when random neural networks overcome the curse of dimensionality in the sense that the training costs scale at most polynomially in the input and output dimension. Furthermore, we show in two numerical examples the empirical advantages of random neural networks compared to fully trained deterministic neural networks. Finally, we apply random neural networks in different forms to the problem of pricing and hedging financial derivatives.

This talk is based on joint work with Ariel Neufeld.

Local Volatility Calibration Using Neural Operators

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Keywords: Stochastic volatility and volatility modeling; Machine learning for Finance; Option pricing and hedging; Computational finance

We develop new techniques for local volatility calibration, based on neural operators. A classical method to achieve this calibration is via implied volatility smoothing, namely fitting an arbitrage-free surface to option quotes and computing local volatility from Dupire's equation. Analogously, our operator deep smoothing approach refines given quotes to high-resolution grids. While implied volatility smoothing conventionally involves an instance-by-instance optimisation routine, our approach uses a single forward pass through a graph neural operator (GNO). This GNO is trained offline and operates coherently on inputs of variable size and spatial distribution, streamlining online calibration. We benchmark our approach on S&P500 data against SSVI. An alternative calibration strategy is to model local volatility and to optimise model parameters based on implied price error. Effective such calibration requires an efficient pricing method. We assess as pricing surrogate a Fourier neural operator (FNO) trained in a Physics-informed fashion through penalisation of deviations from Dupire's equation. The unsupervised training economizes the use of a large synthetic dataset. Combined with our hybrid calibration-optimisation scheme, which allows to fine-tune the FNO online, we achieve robust calibration. Finally, we augment the FNO by a channel predicting the early exercise premium of American options, extending the scope of our method to model-to-market de-Americanisation.

Deep reinforcement learning for stochastic dominance problems with applications to optimal fixed mix strategies.

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Keywords: Reinforcement learning for finance; Machine learning for Finance; Computational finance

In this talk, we present the solution of a dynamic optimization problem combining an optimal constant proportion constraint (fixed-mix policy) with second-order stochastic dominance in a mean-risk problem formulation. The problem is addressed through the implementation of a deep reinforcement learning solution. The methodology employed is based on the recent developments of the convex reinforcement learning approach. In our out-of-sample back-testing results, we demonstrate that contrary to traditional expectations, a fixed-mix policy may turn out very effective over a very short-term investment horizon.

Time-Causal Market Generator

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The generation of synthetic data that mimics real-world observations is important across numerous fields, in particular in finance due to the scarcity of data. While traditional metrics such as Wasserstein distances are prevalent for assessing distribution similarity, financial applications demand stronger metrics like causal or adapted Wasserstein distances, as they provide Lipschitz robustness for pricing, hedging, and utility maximization problems under model uncertainty. Therefore, the generated paths are wished to be close to the data paths under causal or adapted Wasserstein distance. In response, we introduce a novel solution: the time-causal variational autoencoder (TC-VAE) designed specifically for causal robustness. TC-VAE ensures that the causal Wasserstein distance between the data paths and the generated paths is controlled by our loss objective function. Through extensive experimentation on synthetic and market data, we showcase TC-VAE's generative prowess and its generation robustness to stochastic optimization challenges. In essence, TC-VAE represents a promising avenue for synthetic financial data generation with robustness guarantee of stochastic optimization problem. This is joint work with Beatrice Acciaio and Stephan Eckstein.

Calibration of the Bass Local Volatility Model

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Finding martingales that meet specific marginal constraints represents a classical challenge in mathematical finance. Backhoff, Beiglböck, Huesmann, and Källblad have proposed a solution for the two marginal problems based on the Bass construction: the standard stretched Brownian motion. The standard stretched Brownian motion, a continuous, strong Markov Itô diffusion, is the unique-in-law optimizer of the Martingale Benamou-Brenier Problem. Conze and Henry-Larbordère have recently introduced a local volatility model based on this construction, which can be efficiently calibrated through a fixed-point scheme. Our analysis establishes the convergence of the fixed-point scheme, delves into the geometric properties of the associated integral operator, and reveals intriguing connections with the stretched Brownian motion and the renowned Dupire local volatility model. This is a joint work with Beatrice Acciaio and Gudmund Pammer.

The CLM-transformation for weak Martingale Optimal Transport

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The concept of change of numeraire has been a classical tool in mathematical finance for many years. Campi, Laachir and Martini [1] established its applicability to martingale optimal transport. We note that their results seamlessly extend to weak martingale transport. In our work, we apply this to shadow couplings (in the sense of [2]), continuous time martingale transport problems in the framework of Huesmann and Trevisan [3] and in particular to establish the correspondence between stretched Brownian motion with its geometric counterpart introduced by Loeper. Moreover, we reveal that this geometric stretched Brownian motion can be viewed as the metric projection of geometric Brownian motion onto the set of continuous martingales with prescribed marginals with respect to a geometric adapted Wasserstein distance. This is in complete analogy to stretched Brownian motion and adapted Wasserstein distance. This is joint work with Mathias Beiglböck (University of Vienna) and Gudmund Pammer (ETH Zurich).

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Specific relative entropy between continuous martingales and applications

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It is well-known that the relative entropy between continuous martingales is usually infinite. To remedy this shortcoming, Gantert defined the specific relative entropy between continuous martingales as the rate at which the relative entropy explodes, as one samples the martingales involved along a discrete-time grid whose mesh size goes to zero. In this talk, we discuss an explicit formula for the specific relative entropy in terms of the quadratic variation processes of the martingales involved. We then illustrate the power of this concept by showing that it leads to an explicit solution to an open question posed by Aldous: What is the most exciting prediction market?

Decision Making under Costly Sequential Information Acquisition: the Paradigm of Reversible and Irreversible Decisions

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Decision making in modern stochastic systems, including e-commerce platforms, financial markets, and healthcare systems, has evolved into a multifaceted process that involves information acquisition and adaptive information sources. This paper initiates a study on this integrated process, where these elements are not only fundamental but also interact in a complex and dynamically intertwined manner.

We introduce a relatively simple model, which, however, captures the novel elements we consider. Specifically, a decision maker (DM) can choose between an established product A with a known value and a new product B with an unknown value. The DM can observe signals about the unknown value of product B and can also opt to exchange it for product A if B is initially chosen. Mathematically, the model gives rise to a sequential optimal stopping problem with two different informational regimes (before and after buying product B), differentiated by the initial, coarser signal and the subsequent, finer one. We analyze the underlying problems using predominantly viscosity solution techniques, differing from the existing literature on information acquisition which is based on traditional optimal stopping techniques. Additionally, our modeling approach offers a novel framework for developing more complex interactions among decisions, information sources, and information costs through a sequence of nested obstacles.

Risk of transfer learning and its applications in finance

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Transfer learning is an emerging and popular paradigm for utilizing existing knowledge from previous learning tasks to improve the performance of new ones. In this paper, we propose a novel concept of transfer risk and analyze its properties to evaluate transferability of transfer learning. We apply transfer learning techniques and this concept of transfer risk to stock return prediction and portfolio optimization problems. Numerical results demonstrate a strong correlation between transfer risk and overall transfer learning performance, where transfer risk provides a computationally efficient way to identify appropriate source tasks in transfer learning, including cross-continent, cross-sector, and cross-frequency transfer for portfolio optimization.

Information acquisition via a consequentialistic approach under model uncertainty

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In this talk, I will introduce a new approach in stochastic optimization under model uncertainty. It is based on selecting a model by taking into account the effects of erroneous model choices applied to the actual accurate model. Results for the classical Merton paradigm will be presented. This is joint work with Moris Strub (University of Warwick)

A mean field game between informed traders and a broker

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We find closed-form solutions to the stochastic game between a broker and a mean-field of informed traders. In the finite player game, the informed traders observe a common signal and a private signal. The broker, on the other hand, observes the trading speed of each of his clients and provides liquidity to the informed traders. Each player in the game optimises wealth adjusted by inventory penalties. In the mean field version of the game, using a Gâteaux derivative approach, we characterise the solution to the game with a system of forward-backward stochastic differential equations that we solve explicitly. We find that the optimal trading strategy of the broker is linear on his own inventory, on the average inventory among informed traders, and on the common signal or the average trading speed of the informed traders. The Nash equilibrium we find helps informed traders decide how to use private information, and helps brokers decide how much of the order flow they should externalise or internalise when facing a large number of clients.

Price formation and competition in decentralised exchanges

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In decentralised automated market makers, trading is organised in liquidity pools. The liquidity rests in the pool and generates fee revenue from trading activity of liquidity takers until it is withdrawn. We study the microstructure of decentralised markets, where the available reserves dictate the price of liquidity and the dynamics of the exchange rates. First, we show that liquidity providers in decentralised markets incur opportunity costs due to the necessary convexity of the trading function. Next, we propose economic models that describe the equilibrium state of competing decentralised liquidity pools (or competing decentralised pools and centralised exchanges). In particular, we derive the equilibrium fee levels of competing pools when the reserves are fixed, and we derive the equilibrium pool reserves when the fee levels are fixed.

Aggregation of Financial Markets

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We discuss the equivalence between automated market makers (AMMs) in decentralized finance and limit order books (LOBs) of traditional centralized exchanges, as well as its implications for the aggregation of financial markets in algorithmic trading and cross-exchange market making.

Moral hazard, market power and futures market equilibrium

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A risk-averse producer of a commodity can either hedge on a futures market, transfert risk to a subsidiary with a contractual agreement or do both. We develop a model where a producer acts as a monopolist on his commodity market and can hedge on a competitive futures market where liquidity is provided by a market maker. We investigate the effects of these different industrial arrangements on the optimal incentive schemes and on the futures market equilibrium. Joint work with Nizar Touzi (NYU) and Stéphance Villeneuve (TSE).

Control randomisation approach for policy gradient and application to reinforcement learning in optimal switching

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We propose a comprehensive framework for policy gradient methods tailored to continuous time reinforcement learning. This is based on the connection between stochastic control problems and randomised problems, enabling applications across various classes of Markovian continuous time control problems, beyond diffusion models, including e.g. regular, impulse and optimal stopping/switching problems. By utilizing change of measure in the control randomisation technique, we derive a new policy gradient representation for these randomised problems, featuring parametrised intensity policies. We further develop actor-critic algorithms specifically designed to address general Markovian stochastic control issues. Our framework is demonstrated through its application to optimal switching problems, with two numerical case studies in the energy sector focusing on real options.

Optimal trading with propagators and inventory constraints: applications to battery storage and execution

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Motivated by optimal storage management in commodity markets and optimal execution problems with constraints in financial markets, we formulate and solve an optimal trading problem in a general propagator model under linear functional inequality constraints. The optimal control is given explicitly in terms of the corresponding Lagrange multipliers, as a solution to a linear stochastic Fredholm equation. We propose a stochastic version of the Uzawa algorithm to construct the optimal control with general stochastic signals by solving the dual problem formulation via a stochastic projected gradient ascent. We illustrate our theoretical findings for two different applications with an Ornstein Uhlenbeck drift-signal: (i) a battery storage problem with constraints on the charging/discharging velocity and the capacity of the battery and (ii) an optimal execution problem with transient impact, with either a no-short position constraint in a presence of a 'sell' signal or a no-buying constraint in the presence of a 'buy' signal.

Energy efficiency and demand response: a mean-field game approach.

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In this talk, I will present two models developed in the context of energy transition, using as mathematical tools the theory of mean-field games and the principal agent-mean-field game approach. The first model is related to demand response, in which we consider an energy system with a large number of consumers who are linked by a Demand Side Management contract, i.e. they agree to diminish, at random times, their aggregated power consumption by a predefined volume. We provide numerical results which illustrate the impact of such an interaction on the consumption and price levels. The second model focuses on the problem of an energy retailer aiming at designing a new type of contract based on a ranking system for a population of heterogeneous consumers to incentivise them to make energy economies (based on several joint works with C. Alasseur, R. Aïd, E. Bayraktar, L. Campi , Q. Jacquet, P. Tankov, J. Zeng)

Pay for success contracts: Investment valuation in partially complete markets

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Keywords: Option pricing and hedging

Pay-for-success contracts are social and financial innovations in social policy and capital markets, respectively. This paper argues that they exhibit option-like payoffs and implements option-pricing arguments in partially complete markets to assess the value of investing in pay-for-success contracts. Sensitivities vis-à-vis contract specifications are reflected in the valuation formula and help reach investment and social policy decisions.

Robustness of Hilbert space-valued stochastic volatility models

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Keywords: Stochastic volatility and volatility modeling; Commodities and energy finance; Robust finance; Option pricing and hedging; Yield curve modeling; Model risk and uncertainty

We show that Hilbert space-valued stochastic models are robust with respect to perturbation, due to measurement or approximation errors, in the underlying volatility process. Within the class of stochastic volatility modulated Ornstein-Uhlenbeck processes, we quantify the error induced by the volatility in terms of perturbations in the parameters of the volatility process. We moreover study the robustness of the volatility process itself with respect to finite dimensional approximations of the driving compound Poisson process and semigroup generator respectively, when considering operator-valued Barndorff-Nielsen and Shephard stochastic volatility models. We also give results on square root approximations. In all cases we provide explicit bounds for the induced error in terms of the approximation of the underlying parameter. We discuss some applications to robustness of prices of options on forwards and volatility. The presentation is based on a paper which has been accepted for publication in Finance and Stochastics.

From P to Q: Robust Hedging of the Prepayment Option

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Keywords: Option pricing and hedging; Behavioral finance

One of the primary concerns within the fixed-interest rate mortgage domain is "prepayment risk," which is the risk embedded in the right of the mortgage owner to repay the outstanding notional in advance. Because of the magnitude of the underlying market, the development of robust hedging strategies is crucial. A dynamic Delta hedging is proposed, in an incomplete economy, to minimize the prepayment risk. A non-hedgeable risk factor captures the behavioral uncertainty embedded in the mortgage owner's repayment strategy, allowing us to address realistic dynamics where the hypothesis of financially rational behavior is dropped. The hedging strategy is tailored to real-world dynamics (P-dynamics) implied by historical data. The P-dynamics are linked to the pricing framework, developed under an equivalent martingale measure (Q-dynamics), through a suitable, yet non-unique, change of measure, utilizing the tools provided by Girsanov's theorem. A deep learning-based methodology is developed to address the hedging task, which allows the inclusion of features from a realistic framework, such as transaction costs and parsimony in the re-balancing of the hedge. In general, the approach provides a flexible framework for Delta hedging strategies in incomplete economies. Such a framework can be extended and employed in a wide range of realistic applications.

Pricing VIX options under the Heston-Hawkes stochastic volatility model

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Keywords: Option pricing and hedging; Stochastic volatility and volatility modeling

We derive a semi-analytical pricing formula for European VIX call options under the Heston-Hawkes model. This stochastic volatility model is an arbitrage-free model that incorporates the volatility clustering feature by adding a compound Hawkes process to the Heston volatility.

Using the Markov property of the exponential Hawkes an explicit expression of the VIX index is derived as a linear combination of the variance and the Hawkes intensity. We apply qualitative ODE theory to study the existence of some generalized Riccati ODEs. Thereafter, we compute the joint characteristic function of the variance and the Hawkes intensity exploiting the exponential affine structure of the model. Finally, the pricing formula is obtained by applying Fourier techniques.

Does spoofing erode market confidence?

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Keywords: Algorithmic trading; Financial regulation and mechanism design; Market microstructure

In recent years, financial market regulators have increasingly targeted spoofing. In this paper, we analyse a two-period model of strategic interactions between a spoofer and a high frequency trader (HFT) who employs pattern recognition algorithms to predict the incoming order. Detecting this strategy, the spoofer submits a spoofing order to mislead the HFT trader about the incoming order. The HFT protects itself by reducing its market participation. A pure strategy spoofing equilibrium exists and both spoofer and HFT make positive profits. We show that while spoofing delays price discovery in the short run, price dislocation will be so brief as to have few economic efficiency implications. Moreover, spoofing improves market liquidity and market welfare. By studying traders' courtroom testimony and interviews, we find that practices resembling spoofing have existed for centuries. The recent introduction of electronic trading systems has increased the anonymity of trading, thus creating a perfect environment for spoofing to thrive, in turn, increasing regulatory scrutiny. We study recent spoofing courtroom cases and find that the main victims of spoofing are HFTs: they get exploited because spoofers can easily detect and trick their algorithms.

Welfare effects of collective investment for heterogeneous agents

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Keywords: Robust finance

When heterogeneous agents invest in financial markets using the same, collective investment strategy, their individual risk preferences and risk capacities need to be aggregated to come up with a collective strategy. In this paper, we consider this problem for a social planner whose objective is to minimize the maximal certainty-equivalent regret across agents, thus minimizing the regret from being part of the collective. For the financial investment problem, we assume leverage constraints, discrete trading and a restriction to deterministic lifecycle strategies. In order to compute the regret-minimizing investment strategy, we apply a recent technique based on evolutionary dynamics and population games. This gives an efficient algorithm for finding optimal dynamic compromises between hundreds of agents. We then explore the idea of clustering agents into groups so that instead of a single lifecycle there are, say, two or three. We find that already with relatively few groups near optimal welfare can be achieved for all agents. Moreover, in our setting with leverage constraints, CRRA utility and heterogeneous wage trajectories, grouping agents only by their coefficient of risk aversion regardless of their wage trajectories leads to a near-optimal clustering.

Equilibrium Returns in Continuous-Time Markets with Price Impact and Frictions

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Keywords:

We consider an Itô financial market where the assets' returns are derived endogenously through a market clearing condition amongst strategically behaved, risk-averse investors with quadratic preferences and random endowments. Investors act strategically by taking into account the impact that their orders have on the market's drift. Two cases are examined: one for a frictionless market and another for a market with frictions that are modeled via quadratic transaction costs. In the former we derive the unique Nash equilibrium at which investors' demand schedules reveal different hedging needs than the true ones implying, in turn, that the Nash equilibrium in this context deviates from the corresponding competitive one. For the case of frictions while, typically Nash and competitive equilibria differ, we show that the former are invariant with respect to both price impact and frictions under the assumptions of no noise traders and common risk tolerances.

Model Ambiguity versus Model Misspecification in Dynamic Portfolio Choice

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Keywords: Robust finance; Model risk and uncertainty

We study robustness to model ambiguity and misspecification in dynamic portfolio choice. As in Hansen and Sargent (2022) robustness against model ambiguity involves guarding against a worst-case alternative within a set of structured models, while model misspecification considers a wider set of alternatives, including unstructured models. To solve the dynamic consumption and portfolio problem, we use a constraint approach, rather than the multiplier approach of Hansen and Sargent (2001). Our constraint approach has the advantage of preserving homotheticity and tractability, unlike the multiplier approach. We show that the distinction between model ambiguity and model misspecification corresponds to different types of entropy constraints. Investors with relative risk aversion ? >1 endogenously fear return persistence, while risk-tolerant investors ($0 <$? < 1) fear return mean reversion, to confront model misspecification concerns when facing a model with IID returns. The intuition is that risk-averse (risk-tolerant) investors who are keen to hedge (speculate) intertemporally worry about an endogenous worst-case misspecification where returns persist (mean-revert) so that hedging (speculation) is impossible. A log investor is myopic and unaffected by model misspecification, therefore only worrying about model ambiguity among IID models. Our model can explain evidence for dynamic exit from equity markets, for extrapolative return expectations, and for the experience hypothesis.

Stability of backward propagation of chaos

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Keywords: Cooperative and non-cooperative market interactions

It will initially be considered the asymptotic behavior of the solution of a mean-field system of Backward Stochastic Differential Equations with Jumps (BSDEs), as the multitude of the system equations grows to infinity, to independent and identically distributed (IID) solutions of McKean–Vlasov BSDEs. This property is known in the literature as backward propagation of chaos. Afterwards, it will be provided the suitable framework for the stability of the aforementioned property to hold. In other words, assuming a sequence of mean-field systems of BSDEs which propagate chaos, then their solutions, as the multitude of the system equations grows to infinity, approximates an IID sequence of solutions of the limiting McKean–Vlasov BSDE. The generality of the framework allows to incorporate either discrete-time or continuous-time approximating mean-field BSDE systems.

Polynomial and affine McKean-Vlasov stochastic differential equations

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Keywords:

We study a new class of McKean-Vlasov stochastic differential equations (SDEs) applying the theory of time-inhomogeneous polynomial and affine processes. In the polynomial case the drift and volatility coefficients depend on the state variables themselves as well as their (conditional) moments in a way that mimicks the standard polynomial structure. Such McKean-Vlasov SDEs arise for instance in the context of stochastic portfolio theory when interactive particle systems are used to model the capital distribution curves. In the affine case, the drift and volatility may depend on the entire marginal law of the process, opening the door to numerous applications in mathematical finance where the affine characteristics are enhanced by law-dependent factors. Our approach leads to new results on the existence and uniqueness of solutions to McKean-Vlasov SDEs which were, to the best of our knowledge, not obtainable using standard methods. Moreover, we show in the polynomial case that the moments of these McKean-Vlasov SDEs can be computed by non-linear ODEs. As a by-product, this also yields new results on the existence and uniqueness of global solutions to a class of ODEs.

The talk is based on joint work with Christa Cuchiero.

Mean-field equilibrium under model uncertainty

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Keywords: Model risk and uncertainty

In this talk we present a new approach for a mean-field equilibrium under model uncertainty. Our results are inspired by - and can be seen as the distributionally robust analog of - the work of Saldi et al. (SIAM J. Control Optim. 56:6, 4256-4287, 2018). In a discrete time dynamic mean-field game with N agents, the empirical state-distribution of those agents affects their individual rewards and state transition probabilities, which we assume to be uncertain. It is the objective of each agent to choose the optimal Markov policy to maximize their worst-case expected rewards under consideration of the empirical distribution. We show the existence of the mean-field equilibrium in the infinite population limit N to infinity. In analogy to Saldi et al., we aim to demonstrate that an approximate of a Markov-Nash equilibrium can be obtained by using the mean-field equilibrium in the infinite population. This talk is based on joint work with Ariel Neufeld and Kyunghyun Park.

Optimal consumption under loss-averse multiplicative habit-formation preferences

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We consider an individual who invests in a Black-Scholes market and is averse to consuming below a fixed proportion of her current consumption habit, which is defined as the running exponentially weighted average of her past consumption rates. We formulate and solve an infinite horizon stochastic control problem to obtain the individualâ€™s optimal investment and consumption policies, in which the objective is to maximize the expected utility of her lifetime consumption. We use S-shaped multiplicative habit-formation utility functions to capture the individualâ€™s habit-formation and loss-aversion. The utility functions are general and not restricted to a specific class. We provide a thorough analysis of the HJB equation by first reducing it to a non-linear free-boundary problem. We find semi-closed form of the feedback optimal consumption and investment policies, in terms of the solution of the free-boundary problem. If the individualâ€™s wealth-to-habit ratio is below a threshold (expressed in terms of the aforementioned free boundary), then it is optimal to withhold consumption. Above the threshold, the individual optimally consumes at a rate above her habit reference level. We also illustrate properties of the optimal policies through numerical examples. This is joint work with Xiang Yu and Fengyi Yuan.

An approach to the Greeks for indifference pricing

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We consider the problem of sensitivity of the indifference pricing to the dynamics of the underlying assets. In the context of arbitrage-free pricing (AFP), such sensitivities are known as the Greeks. Here, in multidimensional semimartingale settings of incomplete models, we develop the computations of the Greeks and the associated trading strategies for indifference pricing. Unlike the traditional AFP, e.g., in the Black-Scholes model, where the Greeks represent the sensitivity of a linear pricing problem to perturbations of the stock price dynamics, as indifference prices are given via solutions to (non-linear) optimization problems, their sensitivities to perturbations of model parameters, that is the Greeks, are also represented by value functions of (auxiliary quadratic) optimization problems, which we introduce too. The proposed approach also allows for the hedging of nonreplicable contingent claims, in contrast to the Greeks for AFP-based hedging in incomplete markets, where the AFPs form intervals, and their derivatives are not defined in the usual sense. We illustrate the results with positive examples.

Rank-Dependent Predictable Forward Performance Processes

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Predictable forward performance processes (PFPPs) are stochastic optimal control frameworks for an agent who controls a randomly evolving system but can only prescribe the system dynamics for a short period ahead. This is a common scenario in which a controlling agent frequently re-calibrates her model. In this talk, I will introduce a new class of PFPPs based on rank-dependent utility, generalizing existing models that are based on the more restrictive expected utility theory (EUT). Under a conditionally complete market and exogenous probability distortion functions which are updated periodically, I will show that these rank-dependent PFPPs are constructed by repeatedly solving an integral equation which generalizes the integral equation obtained under EUT in the previous studies. I will then discuss a new approach for solving the integral equation via theory of Volterra equations. Finally, I present some numerical examples in the special case of conditionally complete Black-Scholes model. This is joint work with Bahman Angoshtari.

Path-dependent Neural Jump ODEs and their Application to Stochastic Filtering

Jakob Heiss*

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In this talk we study the problem of (online) forecasting general stochastic processes using a path-dependent extension of the Neural Jump ODE (NJ-ODE) framework. Path-dependent NJ-ODEs allow for convergence guarantees in generic, possibly non-Markovian or discontinuous, stochastic processes with incomplete noisy observations, by utilizing the reconstruction properties of the signature transform. These theoretical results are supported by empirical studies. These generalized results allow us to apply the PD-NJ-ODE to stochastic filtering problems, which we will discuss in detail. We also derive theoretical results on which dependence assumptions can be weakened and which ones are necessary. This is joint work with William Andersson, Flroain Krach, Marc Nübel, and Josef Teichmann.

Modelling with signature neural processes

Lingyi Yang*

*University of Oxford,

Permutation-invariant/symmetric functions on collections of paths can be represented as a function of path signatures. We state a Kolmogorov–Arnold like result for signatures and explore using signatures in deep sets as new structures to model neural processes. Finally we demonstrate their performance on applications in finance and compare with neural controlled differential equations.

Forecasting LOBs with Path-Dependent Neural Jump ODEs

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In this talk we study the problem of (online) forecasting general stochastic processes using a path-dependent (PD) extension of the Neural Jump ODE (NJ-ODE) framework. While NJ-ODE was the first framework to establish convergence guarantees for the prediction of irregularly observed time series, these results were limited to data stemming from Itô-diffusions with complete observations, in particular Markov processes, where all coordinates are observed simultaneously. In this work, we generalise these results to generic, possibly non-Markovian or discontinuous, stochastic processes with incomplete observations, by utilising the reconstruction properties of the signature transform. These theoretical results are supported by empirical studies. Applying the PD-NJ-ODE to the midprice forecasting problem in limit order books, once viewed as a regression and once as a classification problem, leads to state-of-the-art results. This is joint work with Marc Nübel and Josef Teichmann.

Neural network pricing models with implications for hedging and risk management

Samuel Cohen*

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Various methods have been proposed for understanding options markets using models based on neural networks. In this talk we will examine how these models interact with classical economic modelling, and how they can be effectively used (or not) in financial problems.

Markov decision processes with observation costs

Christoph Reisinger*

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We consider Markov decision processes where the state of the chain is only given at chosen observation times and of a cost. Optimal strategies involve the optimisation of observation times as well as the subsequent action values. We consider the finite horizon and discounted infinite horizon problems, as well as an extension with parameter uncertainty. By including the time elapsed from observations as part of the augmented Markov system, the value function satisfies a system of quasi-variational inequalities (QVIs). Such a class of QVIs can be seen as an extension to the interconnected obstacle problem. We prove a comparison principle for this class of QVIs, which implies uniqueness of solutions to our proposed problem. Penalty methods are then utilised to obtain arbitrarily accurate solutions. Finally, we perform numerical experiments on three applications which illustrate our framework. This is based on joint work with Jonathan Tam (University of Verona).

Contractive diffusion models and score matching by continuous reinforcement learning

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In this talk, I will link two different topics. The past decade has witnessed the success of generative modeling (e.g. GANs, VAEs,...) in creating high quality samples in a wide variety of data modalities. The first part of this talk is concerned with the recently developed diffusion models, the key idea of which is to reverse a certain stochastic dynamics. I will first take a continuous-time perspective, and examine the performance of different SDE schemes including VE (variance exploding) and VP (variance preserving). The discretization is more subtle, and our idea is to "contract" the reversed dynamics leading to possible new diffusion model designs.

In the second part, I will talk about continuous reinforcement learning. Reinforcement Learning (RL) has been successfully applied to wide-ranging domains in the past decade. Recent years have witnessed a fast growing body of research that has extended the frontiers of continuous RL such as designing model-free methods and algorithms. I will discuss the recently introduced "q-learning" and closely related policy optimization. Finally, I will highlight a natural application of continuous RL to fine-tune the score function in the diffusion models.

Mean-field games of speedy information access with observation costs

Jonathan Tam*

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We investigate mean-field games (MFG) in which agents can actively control their speed of access to information. Specifically, the agents can dynamically decide to obtain observations with reduced delay by accepting higher observation costs. Agents seek to exploit their active information acquisition by making further decisions to influence their state dynamics so as to maximise rewards. In a mean-field equilibrium, each generic agent solves individually a partially observed Markov decision problem in which the way partial observations are obtained is itself subject to dynamic control actions, while no agent can improve unilaterally given the actions of all others. Based on a finite characterisation of belief states, we show how the mean-field game with controlled costly information access can be formulated as an equivalent standard mean-field game on an augmented but finite state space. With sufficient entropy regularisation, a fixed point iteration converges to the unique MFG equilibrium. Moreover, we derive an approximate epsilon-Nash equilibrium for a large but finite population size and small regularisation parameter. We illustrate our (extended) MFG of information access and of controls by an example from epidemiology, where medical testing results can be procured at different speeds and costs. This is based on joint work with Dirk Becherer and Christoph Reisinger.

Coarse correlated equilibria in linear quadratic mean field games and application to an emission abatement game

Luciano Campi*

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Coarse correlated equilibria (CCE) are a good alternative to Nash equilibria (NE), as they arise more naturally as outcomes of learning algorithms and they may exhibit higher payoffs than NE. CCEs include a device which allows players' strategies to be correlated without any cooperation, only through information sent by a mediator. We develop a methodology to concretely compute mean field CCEs in a linear-quadratic mean field game framework. We compare their performance to mean field control solutions and mean field NE (usually named MFG solutions). Our approach is implemented in the mean field version of an emission abatement game between greenhouse gas emitters. In particular, we exhibit a simple and tractable class of mean field CCEs which allows to outperform very significantly the mean field NE payoff and abatement levels, bridging the gap between the mean field NE and the social optimum obtained by mean field control.

A Mean-Field Game Model of Price Formation with Price-Dependent Agent Behavior

Diogo Gomes*

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We propose a mean-field game (MFG) model to study market price formation that takes into account time-dependent preferences. We examine the relation between the price and the demand and present various examples to show the implications of these equations on price formation through supply-demand equilibrium. In some specific cases, we exploit the special structure of our problem to reduce it to initial value problems. We also discuss how the model parameters can be calibrated with statistical data.

Optimal control of storage and intraday price formation in electricity markets

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We study the optimal management of a Pumped Hydroelectric Energy Storage (PHES) facility and the impact of PHES on electricity prices. First, given an arbitrary exogenous price process, we determine the optimal strategy of operating a PHES facility subject to volume and pumping rate constraints. Next, we determine the equilibrium price in the electricity market consisting of PHES facilities, considered as price takers, renewable producers, and conventional producers with a known supply function, subject to an exogenous demand process.

Propagation of carbon taxes in credit portfolio through macroeconomic factors

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We study how the climate transition through a low-carbon economy, implemented by carbon pricing, propagates in a credit portfolio and precisely describe how carbon price dynamics affects credit risk measures such as probability of default, expected and unexpected losses. We adapt a stochastic multisectoral model to take into account the greenhouse gases (GHG) emissions costs of both sectoral firms' production and consumption, as well as sectoral house hold's consumption. GHG emissions costs are the product of carbon prices, provided by the NGFS transition scenarios, and of GHG emissions. For each sector, our model yields the sensitivity of firms' production and households' consumption to carbon price and the rela tionships between sectors. It allows us to analyze the short-term effects of the carbon price as opposed to standard IAM (such as REMIND), which are deterministic and only capture long-term trends. Finally, we use a DCF methodology to compute firms' values which we then combine with a structural credit risk model to describe how the carbon price impacts credit risk measures. We obtain that the carbon price distorts the distribution of the firm's value, increases banking fees charged to clients (materialized by the bank provisions), and reduces banks' profitability (translated by the economic capital). In addition, the randomness we introduce provides extra flexibility to take into account uncertainties on the productivity and on the different transition scenarios. We also compute the sensitivities of the credit risk mea sures with respect to changes in the carbon price, yielding further criteria for a more accurate assessment of climate transition risk in a credit portfolio. This work provides a preliminary methodology to calculate the evolution of credit risk measures of a credit portfolio, starting from a given climate transition scenario described by a carbon price. (joint work with Géraldine Bouveret (Rimm Sustainability), Jean-Francois Chassagneux (Université Paris Cité), Smail Ibbou (BPCE), Antoine Jacquier (Imperial College))

Mathematics and Economics of Decentralized Exchange Design

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Keywords:

We explore liquidity provision in decentralized exchanges (DEXs), a financial technology innovation driven by smart contracts. These platforms currently have a total value locked (TVL) exceeding $15 billion USD, positioning them as the largest service within the decentralized finance (DeFi) ecosystem.

In this talk, we start by outlining the fundamental characteristics of DEXs, comparing and contrasting them with traditional centralized limit order books. We show that the existing infrastructure of DEXs exposes market makers to adverse selection costs by arbitrageurs, potentially resulting in a liquidity freeze. To precisely quantify these costs, we construct a dynamic game-theoretical model that encompasses market makers, traders, and arbitrageurs. The analytical expressions for the subgame perfect Nash equilibrium of the game reveals a key insight: withdrawing liquidity is never incentive compatible for market makers, given that the costs involved outweigh the potential savings from evading arbitrage losses.

We then explore enhancements to DEXs' market design aimed at improving liquidity provision. In the first enhancement, we provide a closed-form characterization of the optimal pricing function for swap transactions, striking a balance between market makers' revenues from investors' trading fees and their losses from arbitrageurs' trades. The second improvement centers on the coexistence of passive and active market makers. Unlike passive market makers who deposit assets into liquidity pools before observing order flows, active market makers monitor order flows prior to execution and inject liquidity accordingly. We demonstrate that in scenarios where order flows are highly responsive to pool depth, active liquidity providers complement passive ones and strengthen their incentive to provide liquidity. We conclude by emphasizing how our research findings can inform the development of the next generation of decentralized exchanges. Additionally, we discuss how tools from financial mathematics and multi-agent games can be utilized to analyze the incentives of liquidity providers, investors, and arbitrageurs within the DeFi ecosystem.

Pre-Hedging

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Keywords:

"Pre-hedging" refers to a dealer's inventory management ahead of and in anticipation of a client's potential request to trade. Proponents of the practice argue that It enables dealers to provide clients with access to more liquidity or a more competitive quote than they otherwise could, but critics assert "it is just a fancy name for front-running".

We study the underlying mechanisms and tradeoffs in a formal model; in particular, we analyse how pre-hedging affects the client's overall execution outcomes. We find that pre-hedging can benefit both dealer and client: improved risk management over an expanded horizon then enables the dealer to charge reduced spreads that more than offset any adverse impact the pre-hedging activity has on the execution price. However, when a dealer pre-hedges too aggressively, this can be detrimental to the client. This result is robust to a setting where competing dealers simultaneously pre-hedge. Any counter-productive pre-hedge activity can be mitigated by introducing timing uncertainty of the potential trade.

(Based on joint work with Roel Oomen and Benjamin Weber. Preprints: `https://papers.ssrn.com/sol3/papers.cfm?abstract_id=4499729andhttps://papers.ssrn.com/sol3/papers.cfm?abstract_id=4796356`)

Time changes, Fourier transforms and the joint calibration to the S&P 500/VIX smiles

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Keywords: Stochastic volatility and volatility modeling; Option pricing and hedging; Computational finance

We develop a model based on time changed Lévy processes and study its ability of reproducing the joint S&P500/VIX implied volatility smiles and the VIX futures prices - a problem known in the literature as the 'joint calibration problem'. The model admits semi-analytical characteristic functions for the key quantities, and therefore efficient Fourier based pricing schemes can be deployed. We focus on a specification of the proposed general setting which uses purely discontinuous processes. Results from the application to market data show satisfactory performances in solving the joint calibration problem, and therefore demonstrate that the class of affine processes can provide a workable fit.

Consistent Joint Modeling of SPX Options, VIX Options, and VIX Futures

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Keywords:

This paper introduces a highly efficient methodology for jointly modeling VIX-based derivatives. The VIX index serves as a measure of the 30-day expected volatility of the S&P 500 index, widely recognized as a key instrument for monitoring and trading volatility in financial markets. The joint modeling of VIX-based derivatives presents a distinctive challenge within the realm of mathematical finance literature. We explore a variant of the traditional two-factor Bergomi model and empirically validate its capability to simultaneously calibrate to the term structure of SPX options, VIX options, and VIX futures. Pricing of these derivatives is conducted utilizing a quantization method. Our findings reveal a robust joint fit to the term structure of the derivatives, underscoring the efficacy of the proposed approach.

Reconciling rough volatility with jumps

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Keywords:

We reconcile rough volatility models and jump models using a class of reversionary Heston models with fast mean reversions and large vol-of-vols. Starting from hyper-rough Heston models with a Hurst index H $(-1/2,1/2)$, we derive a Markovian approximating class of one dimensional reversionary Heston-type models. Such proxies encode a trade-off between an exploding vol-of-vol and a fast mean-reversion speed controlled by a reversionary time-scale >0 and an unconstrained parameter H R. Sending to 0 yields convergence of the reversionary Heston model towards different explicit asymptotic regimes based on the value of the parameter H. In particular, for H $-1/2$, the reversionary Heston model converges to a class of Lévy jump processes of Normal Inverse Gaussian type. Numerical illustrations show that the reversionary Heston model is capable of generating at-the-money skews similar to the ones generated by rough, hyper-rough and jump models.

Life as a Quant at Susquehanna

Jesse Freeman*

**Susquehanna*

I will discuss the retail wholesaling space for equities and will speak about my work as a quant at Susquehanna.

A local jump compound CARMA(p,q)-Hawkes process.

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Keywords: Option pricing and hedging; Computational finance

Recently, a new self-exciting point process with a continuous-time autoregressive moving average intensity process, named CARMA(p,q)-Hawkes model, has been introduced. The model generalizes the well-known Hawkes process by substituting the Ornstein-Uhlenbeck intensity with a CARMA(p,q) model where the associated state process is driven by the counting process itself. The new model maintains the same level of tractability of the Hawkes (e.g., Infinitesimal generator, backward and forward Kolmogorov equation, joint characteristic function and so on). Its main advantage is the ability to reproduce more complex time-dependence structures observed in market data.

Starting from this model, we introduce a Compound CARMA(p,q)-Hawkes with a random jump size independent of the counting and of the intensity processes. This result can be used for a new option pricing model, due to the log-affine structure of the characteristic function of the underlying log-price driven by a pure jump compound CARMA(p,q)-Hawkes.

We scale the newly introduced process with a measurable function of time and left-limit of the price itself. Exploiting the Markov structure of the new model, we derive the forward Kolmogorov equation that leads us to a Dupire-like formula. The proposed model is directly calibrated on the implied volatility surface. The (path-dependent) contingent claim evaluation uses numerical procedures already available in the literature for local volatility models.

Empirical Analysis of Crude Oil Dynamics Using Affine vs. Non-affine Jump-Diffusion Models

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Keywords: Stochastic volatility and volatility modeling; Commodities and energy finance; Option pricing and hedging

This paper investigates the dynamics of the United States oil (USO) exchange-traded fund (ETF). Daily USO returns are modelled using stochastic volatility (SV) frameworks derived from three different model classes: an SV model with contemporaneous jumps in returns and volatility (SVCJ); an SV model with jumps in returns only (SVJ); and a pure SV model without jumps. Six affine and non-affine models are considered within each model class that depend on the specification of the drift and the diffusion terms in the variance process, resulting in a total of 18 models that are estimated using the particle Markov Chain Monte Carlo (PMCMC) approach. Model comparison is carried out through Deviance Information Criteria, Bayes factors, probability plots and deviation measures capturing the difference between the estimated volatility and the Oil Volatility Index (OVX), i.e., a volatility index associated with USO. We document that adding jumps to the return and volatility process allows us to better capture USO dynamics, compared to the pure SV models, while SVCJ models outperform SVJ models. Across all the models considered, the SVCJ-PLY-0.5 model with polynomial drift and square root diffusion is ranked first based on the DIC statistics and is also preferred by the Bayes factor when compared against its SVJ or SV counterparts. Furthermore, we present the valuation of options written on USO with the affine and non-affine stochastic volatility jump-diffusion models.

Pricing VIX derivatives under a regime-switching Jump Log Ornstein-Uhlenbeck process with stochastic volatility plus rough stochastic jump intensity

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Keywords: Option pricing and hedging; Stochastic volatility and volatility modeling

This paper studies the prices of VIX futures and VIX options when dynamics of VIX directly modeled as a regime-switching Jump Log Ornstein-Uhlenbeck process with stochastic volatility plus rough stochastic jump intensity. Under this framework, the mean level of Log Ornstein-Uhlenbeck process depends on states of the economy modeled by a continuous-time Markov chain and variance follows the CIR process. There is a jump in VIX process whose intensity follows a rough CIR process. The joint characteristic function of the model is derived via solving a system of fractional Riccati equations. The semi-analytical prices of VIX futures and VIX options are obtained via inverse Fourier transform. In addition, numerical examples are given.

Equilibrium Investment with Random Risk Aversion

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Keywords: Robust finance; Model risk and uncertainty

We solve the problem of an investor who maximizes utility but faces random preferences. We propose a problem formulation based on expected certainty equivalents. We tackle the time-consistency issues arising from that formulation by applying the equilibrium theory approach. To this end, we provide the proper definitions and prove a rigorous verification theorem. We complete the calculations for the cases of power and exponential utility. For power utility, we illustrate in a numerical example, that the equilibrium stock proportion is independent of wealth, but decreasing in time, which we also supplement by a theoretical discussion. For exponential utility, the usual constant absolute risk aversion is replaced by its expectation. The talk is based on [1].

[1] S. Desmettre, M. Steffensen, Equilibrium Investment with Random Risk Aversion, Mathematical Finance, 2023, 33:946975, https://doi.org/10.1111/mafi.12394

Strategic investment and subsidy within an asymmetric duopoly under uncertainty

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Keywords: Optimal stopping and stochastic control

This paper examines the impact of the subsidy on strategic investment and social welfare within an asymmetric duopoly scenario. In this context, two heterogeneous firms possess varying maximum capacities, marginal costs, and investment costs. Within this market, firms make optimal choices regarding whether to assume a leading or following role, as well as the optimal production quantity. Furthermore, firms can choose to be active or inactive post-investment. Our findings indicate that it is never advantageous for the government to subsidize a firm with a new technology that requires higher investment costs, despite having a lower marginal cost, leading to its leadership in the market. Instead, it is more prudent to allow the older technology to make the initial investment. The subsidy is determined in such a way that the new technology opts to be a follower.

Optimal Investment Time under Moral Hazard

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Keywords: Optimal stopping and stochastic control

This paper studies the relationship contract between an investor (principal) and a financial advisor (agent). The agent searches for investment opportunities, recommends the investment timing, and takes costly unobservable actions that increase the likelihood of finding good investment opportunities. The principal incentivizes the agent by conditioning the scheduled payments on the current and past values of investment opportunities. Formally, time is continuous and the value of the potential investment follows a Brownian motion with drift controlled by the agent's actions. The principal and agent share the same discount rate and are risk-neutral, but the principal faces a limited liability constraint that restricts payments to be nonnegative. The optimal contract can be characterized by the solution of a partial differential equation. The first and the second best investment decisions follow a cutoff rule, i.e. they will invest in the project whenever its value surpasses a threshold. Our novel result is that as long as the agent's continuation value is positive, the second-best stopping rule will be the same as the first-best one, entailing the exact same threshold. Whenever the continuation value reaches zero, it becomes impossible to incentivize the agent and they are retired.

Strategic Investment under Uncertainty with First- and Second-mover Advantages

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Keywords: Optimal stopping and stochastic control

We analyze firm entry in a duopoly real-option game. The interaction between first- and second-mover advantages gives rise to a unique Markov subgame-perfect symmetric equilibrium, featuring state-contingent pure and mixed strategies in multiple endogenously-determined regions. In addition to the standard option-value-of-waiting region, a second waiting region arises because of the second-mover advantage. For sufficiently high market demand, waiting preserves the second-mover advantage but forgoes profits. Two disconnected mixed-strategy regions where firms enter probabilistically surface. In one such region, Leader earns monopoly rents while Follower optimally waits. Finally, when the first-mover advantage dominates the second-mover advantage, firms enter using pure strategies.

Deep gradient flow methods for option pricing in (rough) diffusion models

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Keywords: Option pricing and hedging; Computational finance; Machine learning for Finance

We develop a novel deep learning approach for pricing European options written on assets that follow (rough) diffusion dynamics. The option pricing problem is formulated as a partial differential equation, which is approximated via a new implicit-explicit gradient flow time-stepping approach, involving approximation by deep, residual-type Artificial Neural Networks (ANNs) for each time step. In particular, we split the PDE operator in a symmetric gradient flow with known energy functional and an asymmetric part in which we substitute the neural network of the previous time step, so that we can treat it explicitly. We compare our method with the related Deep Galerkin Method (DGM) and with deriving the conditional characteristic function of the stock price which leads to the option price with the COS method. In the lifted Heston model with twenty volatility processes, the curse of dimensionality makes deriving the characteristic function too slow, while our method remains fast and accurate.

Convergence of the Deep BSDE method for general coupled FBSDEs and applications in stochastic optimal control

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Keywords: Machine learning for Finance; Computational finance; Optimal stopping and stochastic control

In this talk, I present our recent results that generalize the convergence of the well-known Deep BSDE method of Han et al., 2018. Previously, it was shown in Han and Long, 2020 that the Deep BSDE method admits to a posteriori convergence bound which can be measured in terms of the value of the loss functional at terminal time. However, this result has been given for FBSDEs where the solution pair of the backward equation only couples into the forward diffusion via the Y process, rendering it inapplicable in stochastic optimal control applications. In our work, we extend these convergence results to a more general coupling framework, allowing the Z process to enter the forward dynamics. This enables us to treat a broader class of FBSDEs, including ones which stem from stochastic optimal control problems with control dependent diffusion coefficients. In particular, if time allows, we demonstrate our findings by numerical experiments from our accompanying paper on equations related to portfolio allocation and utility maximization, where the corresponding FBSDE is derived through the stochastic maximum principle.

Convergence of Deep Gradient Flow Methods for Option Pricing

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Keywords: Option pricing and hedging; Machine learning for Finance

In this research, we consider the convergence of neural network algorithms for option pricing partial differential equations (PDE). More specifically, we consider a Deep Gradient Flow method, where the PDE is solved by discretizing it in time and writing it as the solution of minimizing a variational problem. A neural network approximation is then trained to solve this minimization using stochastic gradient descent. This method reduces the training time compared to for instance the Deep Galerkin Method. We prove two things. First, as the number of nodes of the network goes to infinity that there exists a neural network converging to the solution of the PDE. This proof consists of three parts: 1) convergence of the time stepping; 2) equivalence of the discretized PDE and the minimization of the variational formulation and 3) convergence of the neural network approximation to the solution of the minimization problem by using a version of the universal approximation theorem. Second, as the training time goes to infinity that stochastic gradient descent will converge to the neural network that solves the PDE.

Nonparametric determinants of market liquidity

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Keywords: Machine learning for Finance; Computational finance

We investigate the determinants of equity market liquidity and transaction costs using explainable AI techniques applied to nonparametric models comprising ensembles of decision trees. We find that these models exhibit superior accuracy when compared to traditional parametric linear models. Furthermore, they uncover nonlinear dependencies on market liquidity that linear models fail to capture. For instance, our findings indicate that in highly active markets, liquidity tends to increase, while it remains relatively stable within specific volume ranges. Broker efficiency, trade market impact, and price volatility emerge as crucial predictors of liquidity. Periods characterized by increased uncertainty and/or weak economic activity are found to be associated with lower liquidity.

Contagion in high-frequency (il)liquidity networks

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Keywords: Risk measures; Systemic risk; Market microstructure

Financial market liquidity is a complex phenomenon, and so is its measurement. Market liquidity has various, and often interrelated, aspects such as transaction costs, breadth, depth, price impact and so on, and no single liquidity indicator accounts for all of those. The task of measuring liquidity is further complicated by the interconnectedness of financial markets which could lead to propagation of illiquidity across (not necessarily related) assets (for instance due to funding constraints) thereby amplifying the initial shock. We propose a new liquidity measure that accounts for that cross-asset amplification of shocks to liquidity: centrality measure that is based on the theories of copula and networks to capture the heavy-tailedness property of the considered variables and the network effects. In a directed network we further differentiate between amplification based on outgoing and on incoming links. The former indicates contagiousness of a given asset in terms of its impact on the liquidity in the rest of the network. The latter reflects its vulnerability to the liquidity shocks to other assets. The introduced liquidity measures can be used as indicators of systemic importance of individual assets in the network and as early warning signal of large-scale liquidity dry-ups.

Uncovering Market Disorder and Liquidity Trends Detection

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Keywords: Optimal stopping and stochastic control; Market microstructure; Algorithmic trading

The primary objective of this paper is to conceive and develop a new methodology to detect notable changes in liquidity within an order-driven market. We study a market liquidity model that allows us to dynamically quantify the level of liquidity of a traded asset using its limit order book data. The proposed metric holds the potential for enhancing the aggressiveness of optimal execution algorithms, minimizing market impact and transaction costs, and serving as a reliable indicator of market liquidity for market makers. As part of our approach, we employ Marked Hawkes processes to model trades-through which constitute our liquidity proxy. Subsequently, our focus lies in accurately identifying the moment when a significant increase or decrease in its intensity takes place. We consider the minimax quickest detection problem of unobservable changes in the intensity of a doubly-stochastic Poisson process. The goal is to develop a stopping rule that minimizes the robust Lorden criterion, measured in terms of the number of events until detection, for both worst-case delay and false alarm constraint. We prove our procedure's optimality in the case of a Cox process with simultaneous jumps while considering a finite time horizon. Finally, this novel approach is empirically validated through real market data analysis.

Deep Hedging in Illiquid Markets

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Keywords: Option pricing and hedging; Reinforcement learning for finance; FinTech

Iliquid markets pose a major economical challenge, since a large investor might impact the price process by herself. We use nonlinear stochastic integration by Carmona & Nualart to model the market value process [1]. Moreover, we perform numerical results by deep learning algorithms [2], [3].

[1] Financial markets with a large trader. With T. Blümmel. Annals of Applied Probability Vol 27, No 6 (2017), 3735–3786

[2] Importance sampling for option pricing with feedforward neural networks. With A. Arandjelovic, P. V. Shevchenko. arXiv:2112.14247 (2022). Accepted for publication in Finance and Stochastics.

[3] A comparative study of the neural network models for the stock market data classification - a multicriteria optimization approach. With Dragana and Nina Radojicic. Accepted for publication in Expert Systems With Applications,

A mixed-integer programming approach in computation of systemic risk measures

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Keywords: Systemic risk; Risk measures

Systemic risk is concerned with the instability of a financial system whose members are interdependent in the sense that the failure of a few institutions may trigger a chain of defaults throughout the system. Several systemic risk measures have been proposed in the literature that are used to determine capital requirements for the members subject to joint risk considerations. We addressed the problem of computing systemic risk measures for systems with sophisticated clearing mechanisms. In particular, we considered an extension of the Rogers–Veraart network model where the operating cash flows are unrestricted in sign. We proposed a mixed-integer programming problem that can be used to compute clearing vectors in this model. Because of the binary variables in this problem, the corresponding (set-valued) systemic risk measure fails to have convex values in general. We associated nonconvex vector optimization problems with the systemic risk measure and provided theoretical results related to the weighted-sum and Pascoletti–Serafini scalarizations of this problem. In addition, we tested the proposed formulations on computational examples and performed sensitivity analyses with respect to some model-specific and structural parameters.

The Memoryless Property in a Mean-Field Systemic Risk Model with Defaults

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Keywords: Systemic risk; Optimal stopping and stochastic control

In this talk, we discuss a mean-field model of a banking system with defaults and government interventions. The banks are represented by their capital buffer which is modelled as a diffusion process on the real line. Whenever the capital buffer becomes negative, the bank has a positive default intensity and a default occurs once the cumulative intensity exceeds an exponential clock. Defaults feed back into the remaining system by lowering the capital buffer of other banks. This contagion can lead to systemic events, where a large number of banks default at once. A government intervenes in the system through capital injections with the goal of limiting the contagion. We show that the optimal level of capital provided by the government only depends on the current level of the capital buffer and not on the accumulated default intensity. This result is relevant for numerical simulations of the model as it reduces the effective dimension of the control problem. Proving it leads us to the study of a novel type of nonlocal semilinear BSPDE.

Post-Trade Netting and Contagion

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Keywords: Systemic risk

We analyse how post-trade netting in over-the-counter derivatives markets affects systemic risk. In particular, we focus on portfolio rebalancing and portfolio compression, which are two post-trade services using multilateral netting techniques. First, we provide a mathematical characterisation of portfolio rebalancing. We show how it can be used as a general representation for post-trade netting mechanisms and relate it to portfolio compression. Then, we analyse the effects of portfolio rebalancing on the financial system from a network perspective by considering contagion arising from only partial repayments in networks of variation margin payments. We provide sufficient conditions for portfolio rebalancing to reduce systemic risk. We show using examples that portfolio rebalancing can be harmful. Finally, we investigate the implications of post-trade netting when financial institutions strategically react to liquidity stress by delaying their payments. In this setting, we show that netting that preserves counterparty relationships always reduces systemic risk, whereas netting that does not preserve counterparty relationships can be harmful to the system.

Chain or Channel? Channel Optimization with Heterogeneous Payments

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Keywords: Blockchain and decentralized finance

Payment-channel networks (PCNs) such as the Lightning Network enable off-chain payments secured by the channels' balances as alternatives to on-chain transactions. This paper solves the optimal channel management problem for two agents who pay IID amounts to each other at IID times. Agents optimally choose the channel's size and whether to make each payment on-chain or on-channel, depending on their current balance. With unidirectional payment flows, payments below some endogenous chain amount happen on-channel while others on-chain. When the balance reaches the reset level, the channel is closed and replaced by a new one. Symmetric bidirectional flows lead to a similar policy, with distinct chain thresholds and reset levels for both directions. The paper establishes the existence and optimality conditions for optimal policies and the convergence of an algorithm to obtain optimal policies, given the distribution and frequency of payments.

The Distribution Builder - A tool for financial decision making in the FinTech era

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Keywords: Behavioral finance; Optimal stopping and stochastic control

The era of FinTech heralds personalized financial decision making through tools such as robo-advising. Alas, the input of personal preferences needed to personalize decision making is difficult and existing methods lack robustness. Sharpe, Goldstein, Blythe and Johnson introduced with the distribution builder a powerful tool to directly solicit user preferences on the outcomes of investments that can be used as base from decision making. In this presentation we explain how the methodology of the distribution builder can be leveraged successfully from the original setting - portfolio optimization in complete markets - to a wide array of other situations: consumption, incomplete markets and the timing of asset sales. This talk is based on joint work with Carole Bernard, Peter Carr, Mauricio Elizalde Mejia, Sixian Jin and Benjamin Rajotte.

Centralizing effects of exclusive order flow under Ethereum's proposer-builder separation

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Keywords: Blockchain and decentralized finance

Maximum Extractable Value (MEV) introduced economies of scale in block validation on the Ethereum blockchain. Proposer-builder separation (PBS) is a blockchain feature designed to reduce the centralizing effect of MEV by separating the roles of block building and block validation. Under PBS, validators propose blocks to the network, but delegate block building to a market of specialized builders. We consider a game-theoretic model of block building under PBS where strategic order flow providers adopt a payment-for-order-flow (PFOF) model to allocate exclusive order flow to builders, who subsequently engage in a competition for the right to build a block auctioned off by validators. Our results show that the builder market is prone to centralization, with small advantages in block building ability translating into a large share of blocks built. We show that order flow acquisition lead to a vicious cycle where large builders get larger. Furthermore, such centralization may spill over to the set of validators through vertical integration, defeating the purpose of introducing PBS. We argue that larger order flow providers (e.g., wallets and dApps rather than individual users) are preferable in order to curb builder centralization and preserve supply chain modularity. We also discuss protocol changes that mitigate the negative externalities of exclusive order flow under PBS.

Quadratically Regularized Optimal Transport

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We consider the regularized optimal transport problem where couplings are penalized by the squared norm. In contrast to entropic regularization, this penalty is empirically known to produce sparse solutions. We present a theoretical guarantee for sparsity as well as quantitative results on the convergence to unregularized optimal transport. Based on joint work with Alberto Gonzalez-Sanz.

Empirical martingale projections via the smoothed adapted Wasserstein distance

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Given a collection of multidimensional pairs (Xi,Yi):1 i n, we study the problem of projecting the associated suitably smoothed empirical measure onto the space of martingale couplings (i.e. distributions satisfying [Y|X]=X) using the adapted Wasserstein distance. We call the resulting distance the smoothed empirical martingale projection distance (SE-MPD), for which we obtain an explicit characterization. We also show that the space of martingale couplings remains invariant under the smoothing operation. We study the asymptotic limit of the SE-MPD, which converges at a parametric rate as the sample size increases if the pairs are either i.i.d. or satisfy appropriate mixing assumptions. Additional finite-sample results are also investigated. Using these results, we introduce a novel consistent martingale coupling hypothesis test, which we apply to test the existence of arbitrage opportunities in recently introduced neural network-based generative models for asset pricing calibration. (Joint work with J. Blanchet, M. Larsson, J. Park, E. Zhang, Z. Zhang)

Martingale Benamou-Brenier: arithmetic and geometric Bass martingales

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Optimal transport (OT) proves to be a powerful tool for non-parametric calibration: it allows us to take a favourite (non-calibrated) model and project it onto the space of all calibrated (martingale) models. The dual side of the problem leads to an HJB equation and a numerical algorithm to solve the projection. However, in general, this process is costly and leads to spiky vol surfaces. We are interested in special cases where the projection can be obtained semi-analytically. This leads us to the martingale equivalent of the seminal fluid-dynamics interpretation of the optimal transport (OT) problem developed by Benamou and Brenier. Specifically, given marginals, we look for the martingale which is the closest to a given archetypical model. If our archetype is the arithmetic Brownian motion, this gives the stretched Brownian motion (or the Bass martingale), studied previously by Backhoff-Veraguas, Beiglbock, Huesmann and Kallblad (and many others). Here we consider the financially more pertinent case of Black-Scholes (geometric BM) reference and show it can also be solved explicitly. In both cases, fast numerical algorithms are available. Based on joint works with Julio Backhoff, Benjamin Joseph and Gregoire Leoper.

An Approximation Theory for Metric Space-Valued Functions: From Rough Path Theory to Adapted Optimal Transport

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Keywords: Machine learning for Finance

We build universal approximators of continuous maps between arbitrary Polish metric spaces X and Y using universal approximators between Euclidean spaces as building blocks. Earlier theoretically founded deep learning models assume that the output space Y is a topological vector space. We overcome this limitation by "randomization": our approximators output discrete probability measures over Y. When X and Y are Polish, we prove that our models can approximate any Hölder-like map between X and Y, quantitatively.

As applications in finance, we construct 1) deep learning models which can approximate the solution operators to rough differential equations between certain Carnot groups and 2) kernels of stochastic processes with respect to various (adapted) Wasserstein distances.

This talk is based on: - Kratsios, Anastasis, et al. "An Approximation Theory for Metric Space-Valued Functions." ArXiV: 2304.12231 - (2023). - Acciaio, Beatrice, Anastasis Kratsios, and Gudmund Pammer. "Designing universal causal deep learning models: The geometric (Hyper) transformer." Mathematical Finance (2023). - Kratsios, Anastasis, Zamanlooy, Behnoosh, et al. "Universal Approximation Under Constraints is Possible with Transformers." International Conference on Learning Representations. 2021.

Collective Arbitrage

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We extend the classical Arbitrage Pricing Theory to a setting where N agents are investing in their respective security markets and additionally are allowed to cooperate through a zero-sum risk exchange mechanism, where no money is injected or taken out of the overall system. Cooperation and the multi-dimensional aspect are the new key features of our setting. In the case of only one agent, the collective theory reduces to the classical Arbitrage Pricing Theory. Within this framework, we introduce the novel notion of Collective Arbitrage. We study the connection between collective and classical arbitrage in our market, and provide various collective versions of the First Fundamental Theorem of Asset Pricing.

Collective super replication and collective risk measures

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We extend the classical notion of super-replication of contingent claims to a scenario where N agents invest in stochastic security markets while also engaging in zero-sum risk exchange mechanisms. In these exchanges, no money is injected or withdrawn from the overall system. The novel concept we introduce, Collective Super-replication, is closely tied to Collective Arbitrage, where agents not only invest in their respective markets but also cooperate to improve their positions by leveraging risk exchanges. When computing the Collective Super-replication price for a given vector of contingent claims, one for each agent in the system, allowing additional exchanges among the agents reduces the overall cost compared to classical individual super-replication. The positive difference between the aggregation (sum) of individual superhedging prices and the Collective Super-replication price represents the value of cooperation. We describe the main properties of the Collective Super-replication functional and its dual representation, which is based on the collective version of the First Fundamental Theorem of Asset Pricing. We discuss the fairness of the cost allocation associated with the Collective Super-replication procedure and provide explicit numerical examples showcasing its features and advantages. Finally, we explain how these collective features can be associated with a broader class of risk measurement or cost assessment procedures beyond the superhedging framework. This leads to the notion of Collective Risk Measures, which generalize the idea of risk sharing and inf-convolution of risk measures.

On stability of law-invariant risk measures and EOT problems

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In this paper we introduce and study the properties of a Wasserstein-type distance between Borel laws on Polish spaces. The construction is fairly general, going well beyond the Lebesgue case. We then apply the distance in a natural way for assessing stability properties of law-invariant convex risk measures defined on general rearrangement-invariant spaces of random variables, including Orlicz spaces as a prominent example. Particular focus is given to the entropic risk measures, for which explicit bounds are derived. Finally, we apply our results in order to prove stability of an Optimal Transport problem with entropic penalties.

Constrained Barycentre of Models with Deep Learning

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When models are trained on data alone, they may not accurately reflect a modeller's view, an expert's judgement, or user inputs. Moreover, on many occasions experts may disagree and thus their models, potentially trained on different datasets, need to be combined. To amalgamate the conflicting nature of expert's views, we propose a modified Barycentre approach. Specifically, each expert proposes an n-dimensional Ito process and the combined meta model is created by penalising each experts' model using a weighted relative entropy. The weights may, e.g., be proportional to an expert's historical performance. We prove existence and uniqueness of the meta model, derive its dynamics, and we develop two deep learning algorithms to estimate the barycentre of models using simulations. Furthermore, we allow the meta model to satisfy certain types of expectation constraints - e.g., specifying the amount of time the process lies within a given region.

Affine Volterra processes with jumps

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Keywords: Option pricing and hedging; Stochastic volatility and volatility modeling

The theory of affine processes has been recently extended to continuous stochastic Volterra equations. These so-called affine Volterra processes overcome modeling shortcomings of affine processes by incorporating path-dependent features and trajectories with regularity different from the paths of Brownian motion. More specifically, singular kernels yield rough affine processes. This work extends the theory by considering affine stochastic Volterra equations with jumps. Such an extension is not straightforward because the jump structure and possible singularities of the kernel may induce explosions of the trajectories. This study also provides exponential affine formulas for the conditional Fourier-Laplace transform of marked Hawkes processes.

Semi-static variance-optimal hedging with self-exciting jumps

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Keywords: Option pricing and hedging; Commodities and energy finance

The aim of this work is to study a hedging problem in an incomplete market model in which the underlying log-asset price is driven by a diffusion process with self-exciting jumps of Hawkes type. We aim at hedging a variance swap (target claim) at time $T > 0$, using a basket of European options (contingent claims). We investigate a semi-static variance-optimal hedging strategy, combining dynamic (i.e., continuously rebalanced) and static (i.e., buy-and-hold) positions to minimize residual error variance at T. The semi-static strategy has already been computed in literature for different models of S. The purpose of our work is to solve the hedging problem for an unexplored model featuring self-exciting jumps of Hawkes type. The key aspect of our work is the generality of our framework, both from the perspective of the hedging and the model investigated. Moreover, research into models with self-exciting jumps is significant as it has been observed that prices in the financial market (e.g. commodity markets) exhibit spikes having clustered behavior. In our work, we establish and analyze our model, studying its properties as an affine semimartingale. We characterize its Laplace transform to rewrite contingent claims using a Fourier transform representation. We finally obtain a semi-explicit expression for the hedging strategy. A possible further development might regard the problem of optimal selection of static hedging assets and potential applications in energy markets.

Jump risk premia in the presence of clustered jumps

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Keywords: Risk measures; Risk management; Option pricing and hedging; Blockchain and decentralized finance

The emergence of the cryptocurrency market, known for its frequent jumps, provides a favourable environment for the study of jump premia. This paper presents a novel option pricing model that incorporates clusters of jumps using a bivariate Hawkes process with exponential decay memory kernels.

The jump premia derived based on the model reflect investors' responses, emerging as relative adjustments in the pricing of options in addition to the effects from prices and jump intensities changes. This is achieved by our model being able to accounts for changes in options prices stemming from both movements in the underlying price and variations in intensities, i.e. the option prices have already priced in the effects of the future jumps and their follow up impacts to the option prices.

In parallel, we design an estimation procedure that estimates both the objective and the risk-neutral measures. Our model proficiently captures both the jumps arrival times in the BTC price and the BTC Implied Volatility smiles. The resulting objective and risk-neutral measures are absolutely continuous with each other.

Our findings reveal that the jump premia: (i) provides insights into how the BTC options market reacted to major events, such as the COVID-19 outbreak and the FTX scandal; (ii) posses significant predictive power for delta-hedged option returns; and (iii) are indicators in explaining the cost-of-carry implied from BTC futures prices.

Quants at G-Research

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We are a leading quantitative research and technology company based in London. Day to day we use a variety of quantitative techniques to predict financial markets from large data sets worldwide. Mathematics, statistics, machine learning, natural language processing and deep learning is what our business is built on. Our culture is academic and highly intellectual. We will explain our background, what our quants do, what our quant background looks like, current AI research applications to finance and our on going outreach, recruitment and grants programme.

ALM Through Distributionally Robust Optimization

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Keywords: Insurance mathematics

We consider a second pillar defined benefit (DB) occupational pension fund (PF) asset-liability management (ALM) problem from the perspective of a PF manager delegated to pay benefits to the employees – the PF members – by a company – the sponsor – who is also funding the pension plans. The pension fund collects the contributions from the sponsor and pays the benefits to the passive members. We do not consider the possibility to cover the fund through an insurance company (which in certain systems is compulsory). The PF manager objective is to determine an investment strategy that allows the fund to cover its liabilities while minimizing the cost of funding, given by the contributions payed by the sponsor and the deficit between liabilities and total asset value at the end of the time horizon. We take into account uncertainty over members' lifetime and assets returns. In particular the LeeCarter model is considered for the survival probabilities and the Nelson/Siegel one for the yield curve. The ALM problem is formulated in constant monetary values to immunize the impact of inflation. To solve the problem we propose a distributionally robust stochastic optimization (DRSO) approach and analyze how the choice of metric affects the worst-case distribution and the out-of-sample performance of the solution.

Robust multi-objective stochastic control

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Keywords: Model risk and uncertainty

Model uncertainty is relevant for various dynamic optimization problems within the field of financial mathematics. There has been a significant body of work dedicated to the study of uncertain stochastic control problem within the literature.

While model uncertainty and robust optimization are relatively well understood for standard control problems with a single (scalar) objective, this is much less the case for problems with multiple objectives. In recent years, several (dynamic) problems of financial mathematics have been approached through methods of multi-objective and set optimization. Set-valued Bellman's principle, a version of the well known Bellman's principle for problems with multiple or set-valued objectives, has been derived across different problems.

In this work we explore the robust approach to model uncertainty for multi-objective stochastic control problems. Robust multi-objective optimization has been explored in the static but not in the dynamic setting. We are particularly interested in the application of dynamic programming and the impact model uncertainty has on the set-valued Bellman's principle. We show how the set-valued Bellman's principle is replaced by certain set relations under robustness and present assumptions under which equality can be obtained. These results are the first step to extending dynamic programming also to multi-objective problems in the context of model uncertainty.

Reference-dependent asset pricing with a stochastic consumption-dividend ratio

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Keywords: Behavioral finance

We study a discrete-time consumption-based capital asset pricing model under expectations-based reference-dependent preferences. Namely, we consider an endowment economy populated by a representative agent who derives utility from current consumption and from gains and losses in consumption with respect to a forward-looking, random reference point. First, we consider a general model in which the agent's preferences include both contemporaneous gain-loss utility, that is, utility from the difference between current consumption and previously held expectations about current consumption, and prospective gain-loss utility, that is, utility from the difference between intertemporal beliefs about future consumption. A semi-closed form solution for equilibrium asset prices is derived for this case. We then specialize to a model in which the agent derives contemporaneous gain-loss utility only, obtaining equilibrium asset prices in closed form. Numerical experiments show that, with plausible values of risk aversion and loss aversion, our models generate equity premia that match empirical estimates. Further, the models are consistent with some well-known empirical facts, namely procyclical variation in the price-dividend ratio and countercyclical variation in the conditional expected equity premium and in the conditional volatility of the equity premium. Finally, we find that including prospective gain-loss utility is necessary to predict reasonable values of the price-dividend ratio.

Robust asymptotic insurance-finance arbitrage

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Keywords: Insurance mathematics; Model risk and uncertainty; Robust finance

In most cases, insurance contracts are linked to the financial markets, such as through interest rates or equity-linked insurance products. To motivate an evaluation rule in these hybrid markets, [1] introduced the notion of insurance-finance arbitrage. In this talk we extend their setting by incorporating model uncertainty. To this end, we allow statistical uncertainty in the underlying dynamics to be represented by a set of priors P. Within this framework we introduce the notion of robust asymptotic insurance-finance arbitrage and characterize the absence of such strategies in terms of the concept of QP-evaluations. This is a nonlinear two-step evaluation which guarantees no robust asymptotic insurance-finance arbitrage. Moreover, the QP-evaluation dominates all two-step evaluations, as long as we agree on the set of priors P. This shows that those two-step evaluations do not allow for robust asymptotic insurance-finance arbitrages. Furthermore, we illustrate how the QP-evaluation can be employed for the pricing of hybrid insurance products. The talk is based on [2].

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K-nearest neighbor resampling for limit order books

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Keywords: Algorithmic trading; Generative Models in Finance; Reinforcement learning for finance; Financial data science; Machine learning for Finance

Limit order books (LOBs) are the prevalent execution mechanism for a wide variety of financial assets. As such, large amounts of data are available. However, this data is observational in nature and does not directly allow for the counterfactual analysis necessary for either the evaluation or learning of execution or market making strategies. We propose to use K-nearest neighbor resampling, a novel off-policy evaluation technique, for simulating LOBs. These simulations allow us to interact with the LOB environment, enabling us to evaluate and learn trading strategies. In contrast to other recent methods for simulating LOBs, the advantage of our reinforcement learning-based approach lies in its relative simplicity (i.e. no optimization) and statistical guarantees. In particular, we provide statistical consistency results for estimating strategy performance for a generic stochastic control problem from historical data containing realized episodes of a decision process generated under a different strategy. We apply this algorithm in the context of money market futures, a highly liquid asset, essential for risk management of short-term interest rate exposures, yield curve arbitrage and price discovery.

From previous tick to pre-averaging: A Spectrum of equidistant transformations for unevenly spaced high-frequency data

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Keywords: Model risk and uncertainty; Stochastic volatility and volatility modeling; Computational finance; Risk management; Financial data science

We propose a novel sampling scheme, based on the exponential moving average (EMA), to convert tick-by-tick data into equidistant series. Our proposed scheme bridges the gap between the two popular methods: previous tick and pre-averaging, in essence producing a spectrum of schemes that spans these two extremes. By varying a smoothing parameter, the scheme can focus on the latest observations (to reflect the most up-to-date information) or favour more pronounced averaging (to reduce microstructure noise). To illustrate the benefits of our scheme, we use the computation of realised variance (RV) and its convergence to the integrated variance (IV). Simulation study and empirical analysis demonstrate that at ultra-high sampling frequencies (10s, 20s and 30s), the EMA scheme collapses to the pre-averaging. In contrast, for lower frequencies (30-min or lower), it results in the previous tick sampling scheme. However, for frequencies ranging from 1-min to 10-min, the EMA sampling scheme is recommended to achieve reliable RV estimates.

Calibration risk under parameter probabilistic dependencies and model output effects

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Keywords: Risk management; Option pricing and hedging; Model risk and uncertainty

We propose a novel regression-based framework for modelling the calibration risk associated with asset price models. The models are traditionally calibrated to liquid contract quotes by minimizing an error functional. Calibration risk relates to the uncertainty in the model parameter estimates (probabilistic inputs), which is transferred to other contracts (model outputs) on the same underlying. We present a systematic way of detecting and improving the calibration risk and a lucid probabilistic approach to modelling this, considering parameter dependencies, and its effect to ultimate outputs. We study the output's global sensitivity to them and the implications for a given position's profitability.

An Order Matching Engine to Trade Multiple Securities Simultaneously

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Keywords: Financial regulation and mechanism design

Exchanges have a function of facilitating trades buy allowing for buyers and sellers of a security to meet and trade. However many strategies require the trade of not only one security but simultaneous execution of several legs, involving several securities. Examples include pair trading, equity portfolios, multi–maturities Futures strategies and options combinations. We call these multi-legs trades bundles. Not executing the various legs at the same time creates a risk of adverse price movement before the full completion. It can be eliminated by crossing the spreads and posting market orders but it incurs cost. We present a mechanism that allows for market participants to post one-sided orders on arbitrary bundles and then the matching engine computes (case of buy order) the cheapest super-replication of the posted bundle by a portfolio of other already posted bundles. So the features of the algorithm is that 1) it does not match security by security but rather a bundle with a collection of other bundles and 2) it can be a "super-match" in the sense that the super-replication may give the additional benefit of a positive residual. We detail the algorithm and apply this methodology to show how it can in certain cases improve the price of option combinations. This approach has an economic value as it allows for more trades to occur at mutually desirable prices.

MF-OMO: an optimization formulation of mean-field games

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Keywords:

this paper proposes a new mathematical paradigm to analyze discrete-time mean-field games. It is shown that finding Nash equilibrium solutions for a general class of discrete-time mean-field games is equivalent to solving an optimization problem with bounded variables and simple convex constraints, called MF-OMO. This equivalence framework enables finding multiple (and possibly all) Nash equilibrium solutions of mean-field games by standard algorithms. For instance, projected gradient descent is shown to be capable of retrieving all possible Nash equilibrium solutions when there are finitely many of them, with proper initializations. Moreover, analyzing mean-field games with linear rewards and mean-field independent dynamics is reduced to solving a finite number of linear programs, hence solvable in finite time. This framework does not rely on the contractive and the monotone assumptions and the uniqueness of the Nash equilibrium.

A Probabilistic Approach to Discounted Infinite Horizon and Invariant Mean Field Games

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Keywords: Optimal stopping and stochastic control

We study discounted infinite horizon mean field games by extending the probabilistic weak formulation of the game as introduced in [1]. By adapting the assumptions from the finite horizon game, we prove existence and uniqueness of solutions for the extended infinite horizon game. The key idea is to construct local versions of the previously considered stable topologies. Further, we analyze how sequences of finite horizon games approximate the infinite horizon one. Under a weakened Lasry-Lions monotonicity condition, we can quantify the convergence rate of solutions for the finite horizon games to the one for the infinite horizon game using a novel stability result for mean field games. Lastly, applying our newfound results allows us to solve the invariant mean field game as well. This is a joint work with René Carmona and Ludovic Tangpi.

[1] Carmona, René, and Daniel Lacker. "A PROBABILISTIC WEAK FORMULATION OF MEAN FIELD GAMES AND APPLICATIONS." The Annals of Applied Probability 25, no. 3 (2015): 1189–1231. http://www.jstor.org/stable/24520471.

Continuous time persuasion with filtering and applications to energy transition

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Keywords: Optimal stopping and stochastic control; Commodities and energy finance

We investigate a game between a sender and receiver (the agents). While the sender has access to a stochastic process X, which is called, borrowing the terminology from information theory and stochastic filtering theory, the (unobservable) signal process, the receiver only knows the process M, that is the message the sender is providing to him. In this setting, each player aims at solving a stochastic control problem with an ergodic criterion. The resulting formulation is a (stochastic) Stackelberg game with asymmetric information. We solve this first case exploiting tools from linear filtering. The existing literature on this topic is quite limited, offering various opportunities for further research and exploration. Our ongoing work includes an extension involving two senders and a large population of receivers, leading to a two-layer game structure. Initially, we seek to establish an equilibrium for the receivers using mean field game techniques. Subsequently, we integrate this solution into the senders' objectives, leading to the resolution of a Nash equilibrium in the two-player game between the senders. This formalisation naturally lends itself to different practical applications such as signalling for electricity demand-response and carbon footprint reduction.

Bank Liquidity Management and Payout Policy under Peer Pressure

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Keywords:

We present a theoretical model that examines the effects of peer pressure on the trade-off that bank managers face when deciding whether to accumulate reserves or to pay shareholders. We show that under high peer pressure, banks reduce payouts and increase cash reserves, which reduces the probability of default and improves financial stability. Using data from the Federal Reserve's Y-9C report from 1987-2020, we document that a 1% increase in peer pressure is associated with a 1.97% increase in the average cash reserve in the banking industry and a 19.54% decrease in dividend payout ratio, thereby leading to improved bank risk profiles.

Order routing and market quality: Who benefits from internalization?

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Keywords: Cooperative and non-cooperative market interactions; Market microstructure; Financial regulation and mechanism design

Does retail order internalization benefit (via price improvement) or harm (via reduced liquidity) retail traders? To answer this question, we compare two market designs that differ in their mode of liquidity provision: In the setting capturing retail order internalization, liquidity is provided by market makers (wholesalers) competing for the retail order flow in a Bertrand fashion. Instead, in the open exchange setting, price-taking competitive agents act as liquidity providers. We discover that, when liquidity providers are risk averse, routing of marketable orders to wholesalers is preferred by *all* retail traders: informed, uninformed, and noise. Furthermore, most measures of liquidity are unaffected by the market design.

Derivative Pricing with Strategic Competition for Liquidity

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Keywords: Option pricing and hedging; Cooperative and non-cooperative market interactions; Optimal stopping and stochastic control

We examine utility based prices and hedging strategies for derivative securities in an extended version of the canonical Black–Scholes option pricing model, in which risk preferences of investors are represented by exponential utility function and market incompleteness is generated on account of non–Walrasian trading by large investors whose trading influences the drift of the underlying asset price, motivated by the example of burgeoning crypto derivatives market. We analyze the resulting non–zero sum singular stochastic differential game to obtain an investor specific, manipulation free, nonlinear pricing rule which can be characterized following certainty equivalent principle as the nonlinear expectation of the derivative security payoff under a pricing measure associated with the Markov–Nash equilibrium price drift. We show that the unique manipulation free price coincides with the canonical Black-Scholes price and that the pricing functional is convex which implies that the bid price of a derivative security claim exceeds its replication costs which in turn dominate the ask price of the derivative, implying consistency with no–arbitrage pricing.

Dynamic Portfolio Choice with Intertemporal Hedging and Transaction Costs

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Keywords: Option pricing and hedging; Market microstructure

When returns are partially predictable and trading is costly, CARA investors track a target portfolio at a constant trading speed. The target portfolio is optimal for a frictionless market, where asset returns are scaled back to account for trading costs and volatilities are adjusted to proxy execution risk. The trading speed solves an optimal execution problem, which describes how the legacy portfolio inherited from past trading is tilted towards the target portfolio in an optimal manner. Unlike for period-by-period mean-variance preferences, the target portfolio and trading speed are linked through a coupled system of Riccati equations, which describe how intertemporal hedging against changing investment opportunities (Merton, 1971) interacts with the principle that one should "aim in front of the target" when trading is costly (Garleanu and Pedersen, 2013). We illustrate the practical implications of these results for the model of Koijen et al. (2009), where return predictions are based on a short-term momentum and and a long-term value signal.

Stochastic Liquidity as Proxy for Nonlinear Cross Impact

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Keywords: Algorithmic trading; Optimal stopping and stochastic control; Market microstructure

We study multi-asset propagator models, that describe how the price impact of individual orders decays over time. As in the single-asset case, the model fit can be improved by using suitable concave rather than linear price impact functions. Such models are not themselves analytically tractable, but can be approximated effectively by tractable linear models in which stochasticity of the impact level acts as a reduced-form proxy for concavity. We illustrate the relevance of cross impact and the effectiveness of the approximation using price and trade data from the LOBSTER database.

Topological Tail Dependence: Evidence from Forecasting Realized Volatility

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Keywords: Stochastic volatility and volatility modeling; Robust finance; Risk measures; Risk management; Financial data science; Computational finance; Machine learning for Finance

This study introduces the Topological Tail Dependence Theory, bridging Persistent Homology (PH) in mathematics with financial stock market theory. It proposes a novel algorithm for measuring topological market changes and their incorporation into forecasting realized volatility (RV) models, enhancing forecast accuracy during turbulent periods. The theory posits that Wasserstein Distances (WD) or Ln norms, derived from PH, effectively predict financial turbulence by capturing complex stock correlations. This research empirically tests the theory using three model families—linear (HAR, HARX), nonlinear (HARST), and neural network (NBEATSx)—across major stock indices (S&P 500, DJIA, RUT, FTSE, GDAXI, STOXX) from January 2000 to March 2022. Robustness tests include different training/testing data splits and geographical diversification. Evaluation metrics include RMSE, MAE, Quasi-likelihood (QLIKE), along with Diebold-Mariano and Model Confidence Set tests. Results demonstrate significant positive relationships between WD and future RV, particularly in nonlinear and neural network models, validating the theory's prediction of improved RV forecasts during crises, such as the 2020 turmoil. The findings suggest the potential of PH information in enhancing RV forecast models, particularly in nonlinear and neural network contexts, endorsing further exploration of Topological Tail Dependence Theory in financial market analysis.

Combining Stochastic Modeling and Artificial Intelligence to Price Electricity Forward Contracts

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Keywords: Commodities and energy finance; Computational finance

Sophisticated stochastic models have been at the core of quantitative modeling since, at least, the seminal work of Merton, Black, and Scholes. More recently, artificial intelligence has emerged as an appealing alternative to the now classical approach in many areas of Quantitative Finance, such as derivative pricing and price forecasting. However, the combination of stochastic modeling and artificial intelligence seems to provide interesting tools that aggregate features from these two worlds. We propose a univariate model that combines a stochastic model and an artificial neural network (ANN) to describe the dynamics of electricity forward prices. The stochastic component, with time-dependent parameters, is used to incorporate well-known features of electricity markets, such as mean reversion and jumps. The ANN is used to model more appropriately the intricate dependence of forward prices on reservoir levels, incorporating, for example, seasonality. We also propose to use ANNs in combination with principal component analysis to improve forecasts.

Forecasting Realized Volatility with Spillover Effects: Perspectives from Graph Neural Networks

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Keywords: Risk measures; Machine learning for Finance; Systemic risk; FinTech Econometrics; Financial data science; Risk management

We present a novel nonparametric methodology for modeling and forecasting multivariate realized volatilities using customized graph neural networks to incorporate spillover effects across stocks. The proposed model offers the benefits of incorporating spillover effects from multi-hop neighbors, capturing nonlinear relationships, and flexible training with different loss functions. The empirical findings suggest that incorporating spillover effects from multi-hop neighbors alone does not yield a clear advantage in terms of predictive accuracy. Furthermore, modeling nonlinear spillover effects enhances the forecasting accuracy of realized volatilities, particularly for short-term horizons of up to one week. More importantly, our results consistently indicate that training with the Quasi-Likelihood loss leads to substantial improvements in model performance compared to the commonly used mean squared error, primarily due to its superior handling of heteroskedasticity. A comprehensive series of empirical evaluations in alternative settings confirm the robustness of our results.

Drivers of Bitcoin volatility: A Comprehensive Study with Statistical and Machine Learning Methods

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Keywords: Stochastic volatility and volatility modeling; Computational finance; Machine learning for Finance; Model risk and uncertainty

Since the release of Bitcoin in 2009, the development of cryptocurrencies has been impressive. The cryptocurrency market has evolved into one of the world's biggest financial innovation and is now more than 1.5 trillion USD market. Each year, hundreds of new altcoins appear, and their current number is already more than 20,000. Cryptocurrencies still attract considerable attention from investors, regulatory authorities, financial journalists and researchers. One of great challenges which need to be addressed before electronic currencies can become mainstream is how to manage the huge volatility of cryptocurrencies. In the paper Dudek, Fiszeder, Kobus, Orzeszko (Forecasting cryptocurrencies volatility using statistical and machine learning methods: A comparative study, Applied Soft Computing, 2024, 151, 111132) we tried to find the best forecasting methods of cryptocurrencies volatility. In this article we go one step further and attempt to explain volatility of Bitcoin by analyzing a wide range of factors: stock indices, fiat currencies rates, commodities, bonds, volatility indices, economic policy uncertainty, geopolitical risks, attention and sentiment measures and coin-specific factors. We apply both statistical methods like the heterogeneous autoregressive model, Bayesian model averaging and machine learning like LASSO and random forest. We determine which variables explain Bitcoin's volatility to the greatest extent.

Contagious McKean–Vlasov problems with common noise: from smooth to singular feedback through hitting times

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Keywords: Systemic risk

We propose a new method to construct solutions to McKean–Vlasov equations that originate from the mean-field limit of a particle system with positive feedback. Interacting diffusions on the positive half-line with an absorbing boundary can be used as a simplified model for contagion in large financial networks or portfolios with defaultable entities. Each particle has a drift, an independent Brownian motion, and a contagion term. The contagion is an impulse felt by all entities in the system when an entity defaults, that is, takes a non-positive value. Due to the instantaneous nature of the contagion, cascades of defaults can occur. Hence, the mean-field limit lives in the space of cadlag functions. In our work, we look at smoothed approximations to the limiting equation where the contagion is mollified with a kernel. Due to the kernel smoothing the feedback, these approximations do not jump. By employing a sequence of kernels that converge towards the Dirac delta, we can construct solutions to the limiting McKean–Vlasov equation with more general drift and diffusion coefficients than those that have been established in the literature. Lastly, provided with suitable regularity on the contagion, we have obtained a rate of convergence before the first jump time of the smoothed equation to the limiting equation.

From mean field modelling to a forward-looking indicator of systemic risk

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Keywords: Risk measures; Systemic risk; Credit risk

In recent years, several works have studied a class of mean field models for contagion in large financial systems linked to the so-called supercooled Stefan problem. While we now have a good mathematical understanding of these models, their practical relevance remains unexplored. As regards large financial portfolios, 2023 marked the 20 year anniversary of the iTraxx and CDX credit default swap indices with the traded volumes reaching record heights. Relying on time series for the tranche spreads of these indices, this talk will explore the use of the aforementioned mean field models as a natural way of developing an economically meaningful systemic risk indicator that is forward-looking, based on the implied levels of contagion priced in by the market.

Two approaches to mean-field systemic risk models with default cascades

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Keywords: Systemic risk

We consider a class of models for systemic risk where the assets of firms interact through the hitting times of a default level. In the mean-field limit, we obtain a free boundary problem for a representative firm, and the boundary can exhibit singularities where a marcoscopic proportion of firms default simultaneously. We study two notions of solution for this problem: minimal solutions which arise as the fixed point of a monotone operator, and physical solutions which are obtained as large-system limits satisfying an energy conservation rule. We show that physical solutions can be used to make sense of the mean-field problem when the interaction term is non-monotonic, where the default of some firms may be beneficial to others. And for the monotonic case, we prove that physical solutions are well-posed if and only if minimal solutions are well-posed.

Common Asset Impact on Default Contagion

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Keywords: Risk management; Systemic risk

In this work we present a simulation study to show that a shock in a common asset can be very impactful to default contagion, and we extend some analytic concepts to this scenario with common assets. We use an inhomogeneous random graph to represent the banking network, and, based on the possible exposures between banks, we dene a minimum amount of capital each bank must hold in order to make the system stable to a shock that aects only a few banks. Then, we consider the case when a shock hits all banks at the same time, making them weaker and some of them initially in default. We analyze the nal fraction of banks in default and compare it with other cases when the shock hits only a small proportion of banks. We show that a common shock can cause severe damage to the system. Key words: Default Contagion, Common Assets, Inhomogeneous Random Graph, Banking Network.

From Schrodinger bridges to random matrices

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Keywords: TBA

TBA

The Stochastic Block Ornstein Uhlenbeck Process

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Keywords: Blockchain and decentralized finance; Machine learning for Finance; FinTech Econometrics; FinTech

In this paper, we introduce the Stochastic Block Ornstein-Uhlenbeck (SBOU) process, a novel model wherein the drift matrix of the multivariate Ornstein-Uhlenbeck Process exhibits a graphical structure. This structure partitions the time series into latent groups, enhancing spillover effects among series within the same group. Our contributions are twofold:

First, we establish the consistency of a broad class of estimators - including the maximum likelihood, Lasso, and Slope estimators - as both time and the dimensions of the observed SBOU process approach infinity. We adapt our approach to a discrete-time framework using a combination of Riemann-sum and thresholding techniques. This tailored approach ensures that the estimators based on discrete-time observations mirrors the performance of their continuous-time counterpart.

Second, we address the critical question of latent group detection within this framework. We propose an algorithm that leverages the eigenvectors of the estimated drift matrix for group detection. We demonstrate that our algorithm consistently identifies groups when cross-sectional and time-series dimensions are sufficiently large.

We then apply our algorithm to cryptocurrencies, shedding light on group dynamics in a market with little understood price behaviours.

A Novel Approach to Queue-Reactive Models: The Importance of Order Sizes

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Keywords: Reinforcement learning for finance; Market microstructure

In this study, we delve into the application and extension of the queue-reactive model for the simulation of limit order books. Our approach emphasizes the importance of order sizes, in conjunction with their type and arrival rate, by integrating the current state of the order book to determine, not only the intensity of order arrivals and their type, but also their sizes. These extensions generate simulated markets that are in line with numerous stylized facts of the market. Our empirical calibration, using futures on German bonds, reveals that the extended queue-reactive model significantly improves the description of order flow properties and the shape of queue istributions. Moreover, our findings demonstrate that the extended model produces simulated markets with a volatility comparable to historical real data, utilizing only endogenous information from the limit order book. This research underscores the potential of the queue-reactive model and its extensions in accurately simulating market dynamics and providing valuable insights into the complex nature of limit order book modeling.

Monte Carlo Simulation for Trading Under a Lévy-Driven Mean-Reverting Framework

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Keywords: Computational finance

We present a Monte Carlo framework for pairs trading on mean-reverting spreads modeled by Lévy-driven Ornstein-Uhlenbeck processes. Specifically, we focus on using a variance gamma driving process, an infinite activity pure jump process to allow for more flexible models of the price spread than is available in the classical model. However, this generalization comes at the cost of not having analytic formulas, so we apply Monte Carlo methods to determine optimal trading levels, and develop a variance reduction technique using control variates. Within this framework, we numerically examine how the optimal trading strategies are affected by the parameters of the model. In addition, we extend our method to bivariate spreads modeled using a weak variance alpha-gamma driving process, and explore the effect of correlation on these trades.

Efficient simulation of the SABR model

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Keywords: Option pricing and hedging; Computational finance

We propose efficient and reliable simulation schemes for pricing options under the stochastic-alpha-beta-rho (SABR) model. Firstly, we derive a new CEV approximation formula that satisfies the martingale condition, an important property that precludes arbitrage. Secondly, we adopt the displaced Poisson-mixture Gamma distribution for the exact simulation of the underlying CEV process in the simulation of the terminal forward price conditional on integrated variance and terminal variance. Thirdly, we use the (shifted) lognormal approximation of the integrated variance based on analytic formulas of the first and second-order moments or simple trapezoidal rule to compute the integrated variance. Numerical results demonstrate all these methods are fast and accurate. These enhanced procedures avoid the tedious Fourier/Laplace inversion algorithm in integrated variance calculations and non-efficient inverse transform in the forward price calculations in various popular simulation schemes, thus ensuring improved efficiency and reliability.

Functional weak convergence of financial gains for tick-by-tick models

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Keywords:

Continuous time financial models driven by Lévy processes may be seen as scaling limits of some underlying tick-by-tick dynamics. This was recently analysed by Jacod and Aït-Sahalia, who define models to be compatible with such dynamics if there is convergence in Skorokhod's M1 topology. Starting from continuous-time random walks as examples for tick-by-tick processes, Jacquier and Toricelli develop a powerful option pricing theory based on time-changed tempered stable Lévy processes. In this talk, we will explore the stability of the corresponding financial gains, across general classes of adapted trading strategies, as the tick-by-tick models converge to their scaling limit. As part of this, we will encounter both positive and negative results for the J1 and M1 topologies.

Finite Mixture Models for an underlying Beta distribution with an application to COVID-19 data

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Keywords: FinTech Econometrics

We introduce an extension of Nagin's finite mixture model to underlying Beta distributions and present our R package trajeR which allows to calibrate the model. Then, we test the model and illustrate some of the possibilities of trajeR by means of an example with simulated data. In a second part of the paper, we use this model to analyze COVID-19 related data during the first part of the pandemic. We identify a classification of the world into five groups of countries with respect to the evolution of the contamination rate and show that the median population age is the main predictor of group membership. We do however not see any sign of efficiency of the sanitary measures taken by the different countries against the propagation of the virus.

On the Matrix-Valued Gamma Distribution in Multivariate Poisson Mixture Models

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Keywords: Insurance mathematics; Credit risk

In the collective model of actuarial science, it is popular to assume that the claim number has a Poisson distribution with a random intensity following a gamma distribution (which results in a negative binomial distribution allowing for overdispersion). The multivariate Poisson distribution enables an extension to a multi-business-line model with joint defaults, which can be particularly useful for credit risk modelling. The vector of random Poisson intensities including their dependence structure can be modelled in terms of a matrix-valued gamma distribution, which is a generalization of the Wishart distribution. We discuss and derive properties of the involved distributions, including their degenerate variants. Particular emphasis is given to the probability-generating functions and the range of dependency structures, both among the Poisson intensities and the modeled default numbers, that can be effectively represented within this framework.

Roll-Over Risk: New Evidence from an Emerging Market

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Keywords:

The objective of this study is to examine the existence of roll-over risk in South Africa, an emerging market. Building on the work of Alfeus, Grasselli, and Schlogl (2020), we model "roll-over risk" as the determinant of the spread between a term structure based on Overnight Index Swaps (OIS) and a term structure based on interest rate swaps (IRS) referencing rates of a longer tenor (specifically, the three-month Johannesburg Interbank Agreed Rate - JIBAR). In this context, where there is no active OIS market but an OIS discount curve is essential for pricing collateralized derivatives transactions, we utilize SAFEX overnight, JIBAR, and JIBAR–based IRS data to infer the OIS discount factor dynamics consistent with the estimated roll–over risk dynamics. Our model calibration employs a term structure model with deterministic jumps when specifying the stochastic dynamics for the model variables.

Mortality Forecasting of Small Pension Fund Population with Gaussian Processes in a Sub Population Framework

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Keywords: Insurance mathematics; Risk management

In order to assess the financial condition of a pension fund, one needs to take into account the mortality forecast so the longevity risk is considered in a consistent way on future cash flows. Usually, the forecast of mortality rates is performed with national or country population data. Even in the presence of basis risk when applying it for pension funds sub-populations (selected populations), for most of the countries this may not be a meaningful problem. However, for countries with relevant social inequalities and a heterogeneous population, national mortality rates may be quite different and more severe than the ones observed in selected sub-populations. In this paper, we use Gaussian processes in a spatial covariance framework applied to sub-population frameworks such that reference populations are used. The applications are performed with a time series of a Brazilian small pension fund population along with the annual country mortality table and also with the use of a public non-periodic insurance industry mortality table. Our aim is to coherently forecast longevity scenarios for the pension fund population. The GP models were implemented in Stan in a Bayesian approach in R statistical package.

Towards a Measurement of Cyber Pandemic Risk

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Keywords: Risk management; Risk measures; Systemic risk

Systemic cyber risks like the 2017 WannaCry and NotPetya incidents pose a major threat to societies, governments, and businesses worldwide. For regulatory institutions, preventing cyber pandemics is thus a top-priority issue. Moreover, dealing with systemic accumulation risks is also challenging for insurance companies since risk pooling does not apply to these incidents.

In this talk, we discuss a novel class of risk measures for the management of systemic risk in networks. In contrast to most existing approaches, our measures target the topological network structure in order to control the propagation risk of a contagious threats. While the main discussion is tailored to the management of systemic cyber risks in digital networks, we also draw parallels to similar risk management frameworks for other types of complex systems.

Collectivized pensions in the presence of systematic longevity risk

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Keywords:

We establish and study a benchmark mathematical model for collectivised pension funds, otherwise known as collective defined contribution (CDC) schemes. CDC schemes offer an alternative to traditional defined benefit (DB) and defined contribution (DC) schemes, whereby risk factors are shared between members of the scheme, hence shifting risk away from employers (as in DB schemes) and individuals (as in DC schemes). We model continuous time collective funds with the aim of; (a) defining the optimal strategy for running them in the presence of different risk factors, and (b) defining what the benefits of pooling these risk factors are. Examples of relevant risk factors are income uncertainty, interest-rate and credit risk, as well as systematic longevity risk. The latter is believed to be one of the biggest challenges facing CDC. We therefore assess the impact of longevity risk on a collective fund, and how individuals can protect against this risk by exchanging mutual insurance contracts. We determine the equilibrium price of these contracts and the benefits they may bring. With these foundations laid, we begin to quantify the effects of the other risk factors stated above.

Actuarial Learning for Loss Modeling of Brazilian Soybean Crops

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Keywords: Insurance mathematics; Machine learning for Finance; Environmental Finance and climate risk; Risk management

In Brazil, the agricultural sector plays a fundamental role, accounting for approximately 25% of the national GDP. Within this sector, soybean cultivation stands out as the most significant, with a total production equivalent to the combined production of all Organisation for Economic Co-operation and Development (OECD) nations. Nevertheless, soybean production is subject to considerable climatic vulnerabilities that not only affect the yield but also have a considerable impact on the formulation of crop insurance pricing. The consequences of drought and excessive rainfall in Brazil's South and Central-West regions severely affected the crop yield of 2021/2022, leading to a substantial rise in the loss ratio of insurer's portfolios. In this paper, we utilize actuarial learning models to predict losses in soybean crops, taking into account weather covariates, specifically rainfall, and temperature. Both generalized linear models and random forest have been benchmarked to assess their predictive performance. We also compare the charged premium with the estimated premium by using standard insurance modeling techniques. Additionally, we carry out simulated stress tests to highlight the significance of weather-related variables in evaluating total losses during extreme events. The implications of these results are significant for (re)insurance pricing, risk management, and solvency. They also bear substantial importance for formulating effective agricultural public policies.

Pathwise stability analysis: Euler schemes and log-optimal portfolios

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Keywords:

Rough path theory provides a pathwise approach to stochastic integration and differential equations. In particular, over the past two decades, the theory contributed many novel insights to questions arising in applied mathematics ranging from numerical schemes to robust finance. In this talk, we identify a property of right-continuous paths that is satisfied by almost all sample paths of all classical probabilistic models in mathematical finance and that ensures the existence of the rough integral as a limit of Riemann sums. Remarkably, this leads to a natural rough path based framework for robust finance as well as for the numerical analysis of stochastic differential equations. As applications we discuss the pathwise stability of log-optimal portfolio theory in volatility models, and the pathwise convergence of the first order Euler scheme for stochastic differential equations.

A comparison principle for Hamilton-Jacobi-Bellman-Isaacs equations based on couplings of differential operators

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Keywords: Model risk and uncertainty; Optimal stopping and stochastic control

In this talk, we present a comparison principle for viscosity solutions to abstract Hamilton-Jacobi-Bellman and Isaacs equations, which is based on the notion of a coupling for integro-differential operators. Examples that are covered by our setup include nonlinear first and second order partial differential equations as well as nonlocal equations such as partial integro-differential equations. In a first step, we introduce the notion of a coupling for operators defined on spaces of continuous functions, discuss the relation to optimal transport and couplings of probability measures, and illustrate the concept of a coupling for generators of Brownian motions and pure jump processes. In a second step, we provide some intuition on the use of couplings in the proof of the comparison principle and apply the abstract results to problems appearing in the context of stochastic optimal control and robust finance. The talk is based on joint work with Serena Della Corte, Richard Kraaij and Max Nendel.

Itô's formula for non-anticipative functionals of càdlàg rough paths

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Keywords: Option pricing and hedging

Relying on the approximation properties of the signature of càdlàg rough paths, we derive a (rough) functional Itô's formula for non-anticipative path functionals via a density approach. Our results lead to a functional extension of the classical Itô's formula for rough paths which furthermore coincides with the functional change of variable formula formulated by Cont and Fournie (2010), whenever the relative notions of integration coincide. As a byproduct, we show that sufficiently regular non-anticipative path functionals admit a functional Taylor expansion, leading to a far-reaching extension of the recently established results of Dupire and Tissot-Daguette (2022). This talk is based on ongoing joint work with Christa Cuchiero and Xin Guo.

Learning to reflect – On data driven approaches to stochastic control

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Even though theoretical solutions to stochastic optimal control problems are well understood in many scenarios, their practicability suffers from the assumption of known dynamics of the underlying stochastic process. This raises the statistical challenge of developing purely data-driven strategies. In this talk we focus on singular control problems for diffusions and demonstrate how such data-driven strategies with explicit sublinear regret bounds can be constructed by employing nonparametric statistical techniques.

The talk is based on joint work with Sören Christensen, Asbjørn Holk Thomsen and Claudia Strauch

On a projection least squares estimator for jump diffusion processes

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The study of statistical properties within diffusion models has gained importance due to their widespread application in finance. Models incorporating both diffusion and jumps have been developed to better capture the dynamics of asset prices, exchange rates, and volatility. The objective of this joint work with N. Marie is to estimate the drift function in a stochastic differential equation (SDE) driven by a jump diffusion process. We consider a least squares projection estimator derived from independent copies of the solution process observed over a fixed time interval. This approach differs from previous works on the subject, which proposed estimators computed from one path solution of the SDE, either over long time periods or at high frequency over a fixed time interval. During this talk, I will introduce the estimation procedure, the resulting risk bound, and an oracle inequality for the associated adaptive estimator.

On nonparametric estimation of the interaction function in particle system models

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This talk delves into a challenging problem of nonparametric estimation for the interaction function within diffusion-type particle system models. We introduce two estimation methods based upon an empirical risk minimization. Our study encompasses an analysis of the stochastic and approximation errors associated with both procedures, along with an examination of certain minimax lower bounds. In particular, for the first method we show that there is a natural metric under which the corresponding estimation error of the interaction function converges to zero with parametric rate which is minimax optimal. This result is rather surprising given the complexity of the underlying estimation problem and rather large class of interaction functions for which the above parametric rate holds. The talk is based on the joint work with D. Belomestny and S.-Y. Zhou.

Optimum thresholding using conditional mean squared error in the presence of infinite activity jumps

Cecilia Mancini*

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We consider a univariate semimartingale model for (the logarithm of) an asset price, containing infinite activity jumps. The nonparametric threshold estimator $\hat{IV}_n$ of the integrated variance $IV := \int_0^T \sigma_s^2 ds$ proposed in Mancini (2009) is constructed using observations on a discrete time grid, and precisely it sums up the squared increments of the process when they are below a threshold, which depends on the observation time step and, sometimes, model parameters or latent variables, that need to be estimated. All the threshold functions satisfying given conditions allow asymptotically consistent estimates of IV , however the finite sample properties of $\hat{IV}_n$ can depend on the specific choice of the threshold. We aim here at optimally selecting the threshold by minimizing the conditional mean squared error. This criterion allows to reach a threshold which is optimal not in mean but for the specific jumps paths at hand.

A parsimonious characterization of the optimum is established, which turns out to be asymptotically pro- portional to the Lévy 's modulus of continuity of the underlying Brownian motion. This work extends results found in Figueroa-Lopez and Mancini (2019), where the jumps were assumed to be of finite activity.

Is it easier to learn robust optimal investment strategies?

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Even though robust optimal trading appears to be a more involved mathematical problem, approximating its solutions by machine learning technology can benefit from several mathematical insights. We highlight on several instances of this phenomenon, some with a proper mathematical justification, others only with empirical evidence. (joint work with Florian Krach and Hanna Wutte).

Optimal Linear Strategies under Concave Price Impact

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"We study an investor with mean-variance preferences who has access to a noisy predictive signal of future price returns and whose trades generate price impact that is concave in the order size. In the case of linear price impact, it is well documented that the optimal strategy can be solved explicitly, and it is in linear feedback form. When the predictive signal is Gaussian, we are able to establish explicit formulas for the performance of these strategies in the more general setting with nonlinear impact. This leads to a simple and efficient parametric optimization problem when restricting to strategies of this form. In the general concave impact setting the strategies are no longer globally optimal but our numerical experiments for the power law impact case show that they perform nearly optimally in a range of realistic market regimes"

Reinforcement Learning for Trade Execution in a Simulated Market

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We consider the trade execution problem in a simulated limit order book. We allow the agent to have full flexibility in her order placement and provide it with complete information of the order book and the state of its own orders. Since the control problem is not suitable to be solved with classical stochastic control techniques, we train an agent with deep reinforcement. The reinforcement learning agent is compared to multiple benchmarks and in multiple market settings, with the results indicating superior performance with respect to various metrics.

Segmented Trading Markets

A. Max Reppen*

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We study competition and endogenous fragmentation among heterogeneous trading venues that differ in technology (fast vs. slow), where traders can dynamically choose which venue to trade in. We show that technological improvements increase trading speed, but may also heighten differentiation, which reduces competition, leads to higher trading fees, and potentially reduces trading volume and welfare. Improvements in the slower venue led to increased trading speed, decreased differentiation, and thus increased trading volume and welfare. Conversely, the effect of improvements in the faster venue is generally ambiguous and depends on the extent of traders' patience, the frequency of their preference shocks, and the competition between venue owners. We further study the effect of technological improvement in one of the venues when both initially have the same trading speed. We find that if the trading speeds are initially slow enough, the technological improvement will increase trading volume and trader welfare. Conversely, if the trading speeds are initially fast, the increase in trading fees outweighs the speed advantage that comes with technological improvement, leading to decreased trading volume and trader welfare.

Sensitivity of causal distributionally robust optimization

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In this talk, we study the distributionally robust optimization (DRO) in a dynamic context. We consider a general penalized DRO problem with a causal transport-type penalization. We derive the sensitivity of the causal DRO with respect to the level of the uncertainty of the model. Moreover, we investigate the case where a martingale constraint is imposed on the underlying model. As an application, this leads to a non-parametric Greek to path-dependent options. If time permits, I will also talk about passing to the continuous-time limit under two different scaling regimes.

Sensitivity of robust optimization problems under drift and volatility uncertainty

Ariel Neufeld*

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In this talk we examine optimization problems in which an investor has the opportunity to trade in d stocks with the goal of maximizing her worst-case cost of cumulative gains and losses. Here, worst-case refers to taking into account all possible drift and volatility processes for the stocks that fall within a -neighborhood of predefined fixed baseline processes. Although solving the worst-case problem for a fixed > 0 is known to be very challenging in general, we show that it can be approximated as $\to 0$ by the baseline problem (computed using the baseline processes) in the following sense: Firstly, the value of the worst-case problem is equal to the value of the baseline problem plus times a correction term. This correction term can be computed explicitly and quantifies how sensitive a given optimization problem is to model uncertainty. Moreover, approximately optimal trading strategies for the worst-case problem can be obtained using optimal strategies from the corresponding baseline problem. This talk is based on joint work with Daniel Bartl and Kyunghyun Park

First order Martingale model risk hedging

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This joint work with Nizar Touzi is concerned with the study of sensitivity of functional of measure under the martingale constraint. Following the work of [1] and [2], we study sensitivity analysis under classical Wasserstein distance and adapted Wasserstein distance.In each cases, we propose a new approach of the problem, allowing us to consider more general functional on the Wasserstein space. The counter-part will be to ask regularity of the functional. This approach also allows us to obtain order two estimates for the adapted Wasserstein metric in the martingale case. In the unconstrained case we obtained higher order expansions for both the classical and adapted Wasserstein metric. [1] : Daniel Bartl and Johannes Wiesel. Sensitivity of multiperiod optimization problems in adapted Wasserstein distance [2] : Daniel Bartl, Drapeau Samuel, Oblöj Jan, Wiesel Johannes. Sensitivity analysis of Wasserstein distributionally robust optimization problems

Nonconcave Robust Utility Maximization under Projective Determinacy

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Keywords: Model risk and uncertainty; Robust finance

We study a robust utility maximization problem in a general discrete-time frictionless market. The investor is assumed to have a random nondecreasing utility function on the whole real-line, which may or may not be finite, concave or continuous. She also faces model ambiguity on her beliefs about the market, which is modeled through a set of priors. We prove, using only primal methods, the existence of an optimal investment strategy when the utility function is also upper-semicontinuous. For that, we assume the set-theoretical axiom of Projective Determinacy (PD) and consider projectively measurable prices process and priors whose graphs are projective sets. Our other assumptions are stated on a prior-by-prior basis and correspond to generally accepted assumptions in the literature on markets without ambiguity.

Signature methods in finance

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Keywords:

Signature methods represent a non-parametric way for extracting characteristic features from time series data which is essential in machine learning tasks, dynamic stochastic modeling, mathematical finance and risk assessment. Indeed, signature based approaches allow for data-driven and thus more robust model selection mechanisms, while first principles like no arbitrage can still be easily guaranteed.

One focus of this talk lies on the use of signature as universal linear regression basis of certain continuous paths functionals for financial applications. In these applications key quantities that have to be computed efficiently are the expected signature or the characteristic function of the signature of some underlying stochastic process. Surprisingly this can be achieved for generic classes of (jump-)diffusions, called signature-SDEs (with possibly path dependent characteristics), via techniques from affine and polynomial processes. More precisely, we show how the signature process of these diffusions can be embedded in the framework of affine and polynomial processes and how the infinite dimensional Feynman Kac PDE can be reduced to an infinite dimensional ODE either of Riccati or linear type.

In terms of concrete applications we present several recent contributions ranging from signature based asset price models for joint VIX and SPX calibration, over control problems in stochastic portfolio theory to functional Taylor expansions of path-dependent options.

The talk is based on several joint works with Guido Gazzani, Xin Guo, Janka Möller, Francesca Primavera, Sara-Svaluto Ferro and Josef Teichmann.

Gaussian Process Models for Quantitative Finance

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Keywords:

The talk is structured as an overview and a brief tutorial on Gaussian Process (GP) models which offer a flexible probabilistic framework for functional approximation and interpolation. The first half will survey GP training, kernel selection, and observation noise modeling. The second half will highlight several applications of GPs in quantitative finance, including (i) statistical learning and uncertainty quantification of derivative contract sensitivities using GP gradients; (ii) GP surrogates for value- and policy-approximation within the Regression Monte Carlo framework for stochastic control problems; (iii) uncertainty quantification and probabilistic curve-fitting for forward curves and implied volatility surfaces.

Signature-based Time Series Wasserstein GAN

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Keywords: Generative Models in Finance; Machine learning for Finance

Recently, generative AI has gained widespread attention in various business areas, primarily for its text generation capabilities. However, synthetic data generation is an emerging technology that can significantly improve model accuracy and robustness and enable data sharing while ensuring data privacy constraints for various data classes. We are interested in designing a generative model for time series data to approximate the distribution of an underlying stochastic process given sample time series data, to later generate new data variations of the learned distribution. While classical time series generative models usually rely on strong assumptions regarding the nature of time series, data-driven approaches are often computationally infeasible due its dimension of the target space. To overcome these challenges, we propose a purely data-driven market generating model for (financial) time series data, that integrates the mathematical principle of path signatures with Wasserstein generative adversarial networks (GANs) architectures. Path signatures originate from rough path theory and are sequences of iterated integrals fully characterizing the data streams. They provide a powerful way for encoding time series models. We validate the performance of our proposed model on both synthetic and real-world data, across several performance evaluation metrics, showcasing its potential and effectiveness in financial time series analysis.

Joint calibration to SPX and VIX options with signature-based models

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Keywords: Stochastic volatility and volatility modeling; Option pricing and hedging; Computational finance

We consider a stochastic volatility model where the dynamics of the volatility are described by linear functions of the (time extended) signature of a primary underlying process, which is supposed to be some multidimensional continuous semimartingale. Under the additional assumption that this primary process is of polynomial type, we obtain closed form expressions for the VIX squared, exploiting the fact that the truncated signature of a polynomial process is again a polynomial process. Adding to such a primary process the Brownian motion driving the stock price, allows then to express both the log-price and the VIX squared as linear functions of the signature of the corresponding augmented process. This feature can then be efficiently used for pricing and calibration purposes. Indeed, as the signature samples can be easily precomputed, the calibration task can be split into an offline sampling and a standard optimization. We also propose a Fourier pricing approach for both VIX and SPX options exploiting that the signature of the augmented primary semimartingale is an infinite dimensional affine process. For both the SPX and VIX options we obtain highly accurate calibration results, showing that this model class allows to solve the joint calibration problem without adding jumps or rough volatility.

Signature stochastic volatility models: pricing and hedging with Fourier

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Keywords: Stochastic volatility and volatility modeling; Option pricing and hedging

In this talk we will present some of our work on a stochastic volatility model where the volatility is driven by a linear function of the signature of a (time extended) Brownian motion. Our main motivation is to improve the pricing and hedging method of [1, 3]. Their theory has the main advantage of being completely model-free and adapted to path dependent payoffs, but at the cost of being much less tractable and to not realistically converge in practice to good approximations for non-smooth payoffs, e.g. European/Asian calls/puts. Our aim is to show that we can improve their results by restricting to a class of Sig-SDE models (inspired by [2] but with an additional correlation between the Brownians). We do so by using Fourier techniques: provided that some infinite-dimensional Riccati equation admits a solution, we can derive the joint characteristic function of the log-price and integrated variance which allows us to price and (quadratically) hedge certain European and path-dependent options using Fourier inversion techniques.

This is a joint work with Eduardo Abi Jaber.

Advancing Optimal Stochastic Control with Signatures

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Keywords: Machine learning for Finance; Optimal stopping and stochastic control

The role of signatures in solving non-Markovian control problems has been increasingly recognized, particularly in areas of mathematical finance, such as optimal execution, portfolio optimization, and the valuation of American options. In this work, we study a general class of differential equations driven by stochastic rough paths, where the control impacts the system's drift. In the theoretical aspect, we demonstrate that optimal controls can be approximated using linear and deep signature functionals. This includes a refined lifting result for progressively measurable processes into continuous path-functionals, in addition to implementing a robust stability result for rough differential equations from Diehl et al., 2017. Building on these theoretical insights, we have developed a practical numerical methodology based on Monte-Carlo sampling and deep learning techniques. We demonstrate the efficiency of this methodology through numerical examples, including the optimal tracking of fractional Brownian motion, for which we provide exact theoretical benchmarks.

Optimal stopping of Gauss-Markov bridges with applications to American options

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Keywords: Optimal stopping and stochastic control; Option pricing and hedging

We solve the non-discounted, finite-horizon optimal stopping problem of a Gauss–Markov bridge by using a time-space transformation approach. The associated optimal stopping boundary is proved to be Lipschitz continuous on any closed interval that excludes the horizon, and it is characterized by the unique solution of an integral equation. A Picard iteration algorithm is discussed and implemented to exemplify the numerical computation and geometry of the optimal stopping boundary for some illustrative cases. We comment on the application to the optimal exercise of American options, and conduct a real-data study for the Brownian bridge case.

Perpetual American Options in a Two-Dimensional Black-Merton-Scholes Model

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Keywords: Insurance mathematics; Option pricing and hedging; Optimal stopping and stochastic control

We study optimal stopping problems for two-dimensional geometric Brownian motions driven by constantly correlated standard Brownian motions on an infinite time interval. These problems are related to the pricing of perpetual American options such as basket options (with an additive payoff structure) and traffic-light options (with a multiplicative payoff structure) in a two-dimensional Black-Merton-Scholes model. We find closed formulas for the value functions expressed in terms of the optimal stopping boundaries which in turn are shown to be unique solutions to the appropriate nonlinear Fredholm integral equations. A key argument in the existence proof is played by a pointwise maximisation of the expressions obtained by the change-of-measure arguments. This provides tight bounds on the optimal stopping boundaries describing its asymptotic behaviour for marginal coordinate values.

Pricing American Barrier Options with Transaction Costs

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Keywords: Option pricing and hedging

When transaction costs in trading underlying stocks are considered, far more modelling effort is needed for pricing options, as a unique fair price between the holder and writer no longer exists. This complexity is heightened for American and exotic features, and in this talk, we shall discuss the challenges in pricing American down-and-out call options with transaction costs. We will also examine the impact of transaction costs on option pricing, particularly on how they affect the optimal exercise boundary.

Non-Concave Utility Maximization with Transaction Costs

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Keywords: Optimal stopping and stochastic control

This paper studies a finite-horizon portfolio selection problem with non-concave terminal utility and proportional transaction costs. The commonly used concavification principle for terminal value is no longer valid here, and we establish a proper theoretical characterization of this problem. We first give the asymptotic terminal behavior of the value function, which implies any transaction close to maturity only provides a marginal contribution to the utility. After that, the theoretical foundation is established in terms of a novel definition of the viscosity solution incorporating our asymptotic terminal condition. Via numerical analyses, we find that the introduction of transaction costs into non-concave utility maximization problems can prevent the portfolio from unbounded leverage and make a large short position in stock optimal despite a positive risk premium and symmetric transaction costs.

The explicit solution to a risk-sensitive ergodic singular stochastic control problem

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Keywords: Optimal stopping and stochastic control

We consider a two-sided singular stochastic control problem with a risk-sensitive ergodic criterion. In particular, we consider a stochastic system whose uncontrolled dynamics are modelled by a linear diffusion. The control that can be applied to this system is modelled by an additive finite variation process. The objective of the control problem is to minimise a risk-sensitive long-term average criterion that penalises deviations of the controlled process from a nominal point as well as the expenditure of control effort. Such a problem has been motivated by applications in target tracking and in portfolio selection with transaction costs. We derive the complete solution to the problem under general assumptions by relating a suitable Sturm-Liouville problem with the free-boundary problem associated with the control problem's Hamilton-Jacobi-Bellman equation. In the limit as the risk-sensitivity parameter tends to zero, we recover the solution to the risk neutral case. Furthermore, we show that the optimal long-term average cost converges to the upper value of a deterministic zero sum differential game in the totally risk- sensitive limit. The talk is based on joint work with Mihail Zervos.

Simulating Sensitivities of Risk Measures in the Presence of Sample Path Discontinuity

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Keywords: Risk measures

We study the problem of estimating the sensitivities of two popular risk measures, namely, Value-at-Risk and conditional Value-at-Risk, for a stochastic performance measure with discontinuous sample paths. These sensitivities may play a pivotal role in a range of applications in operations research, such as optimizing financial portfolios of exotic options and improving system performances of complex stochastic activity networks. In this work, we show that the presence of the sample path discontinuity contributes an additional term to the sensitivity of its continuous counterpart, and derive a closed-form expression for this additional term. We further propose efficient simulation estimators for the sensitivities. Efficiency of the proposed estimators are demonstrated via numerical examples.

Factor Risk Budgeting and Beyond

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Keywords: Risk measures; Computational finance; Risk management

Portfolio optimization methods have evolved significantly since Markowitz introduced the mean-variance framework in 1952. While the theoretical appeal of this approach is undeniable, its practical implementation poses important challenges, primarily revolving around the intricate task of estimating expected returns. As a result, practitioners and scholars have explored alternative methods that prioritize risk management and diversification. One such approach is Risk Budgeting, where portfolio risk is allocated among assets according to predefined risk budgets. The effectiveness of Risk Budgeting in achieving true diversification can, however, be questioned, given that asset returns are often influenced by a small number of risk factors. From this perspective, one question arises: is it possible to allocate risk at the factor level using the Risk Budgeting approach? This paper introduces a comprehensive framework to address this question by introducing risk measures directly associated with risk factor exposures and demonstrating the desirable mathematical properties of these risk measures, making them suitable for optimization. Then, we propose a novel framework to find the portfolio that effectively balances the risk contributions from both assets and factors. Leveraging standard stochastic algorithms, our framework enables the use of a wide range of risk measures.

Calibration to market-implied risk measures

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Keywords: Option pricing and hedging; Risk measures; Machine learning for Finance; Computational finance

In incomplete market models the interval of arbitrage-free prices for a contingent claim is typically very wide and different prices may correspond to hedging strategies with radically different risk profiles. The classical approach to calibration, however, consists in estimating a single martingale measure for the underlying asset by matching the observed mid prices of some calibration instruments (typically a selection of ATM call/put options) and using the resulting measure as a linear pricing rule for pricing new contingent claims. This approach does not explicitly take into account market-implied risk preferences and, when used to price exotic or bespoke contingent claims, it may yield prices that are far from realistic market valuations and hedging positions that can only be liquidated at a loss. In this work we present an alternative approach to model calibration, in which we directly estimate the market-implied risk measure that corresponds to the observed bid and ask prices of the calibration instruments. This approach is related to the literature on good deal bounds and is based on machine learning techniques, which combine deep hedging under convex risk measures with a gradient-based algorithm from adversarial machine learning. We present empirical results on synthetic and real datasets and investigate the stability of the market-implied risk measures in time.

Optimal entry and exit problems under climate scenario uncertainty, ambiguity aversion and learning

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Keywords: Model risk and uncertainty; Environmental Finance and climate risk

We take the point of view of investors who have to decide when to enter into a green energy project or dismiss a fossil fuel infrastructure.

Profits and costs are functions of the values of risk factors, such as the prices of coal, electricity and carbon emission allowances, whose probability distribution heavily depends on the future climate scenario.

We assume that agents can acquire information about the scenario only partially and progressively, by observing the evolution of the risk factors values. The fact that the scenario is not known introduces model uncertainty: we identify every scenario with a different probability measure and consider the smooth model of decision-making under ambiguity aversion of Klibanoff et al. (2005). We investigate the resulting maxmin problem and show that it admits a solution under given conditions.

We then consider representative climate scenarios from the Network for Greening the Financial System database and numerically analyze the problems of selling a coal-fired power plant without Carbon Capture and Storage (CCS) and entering into a biomass power plant with CCS.

Uncertainty over uncertainty in environmental policy adoption: Bayesian learning of unpredictable socioeconomic costs

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Keywords: Optimal stopping and stochastic control; Environmental Finance and climate risk

In this talk, we propose a model where the traditional uncertainty in the socioeconomic impact of pollution (e.g. due to the current state of technological developments, etc.) is expanded by an additional layer of uncertainty in the future trend of environmental damage costs. This is incorporated in a real-options-like model, in which a decision maker aims at adopting a costly reduction in the current emissions rate, when the cost trend is an unobservable random variable. The decision maker can learn and form a posterior dynamic belief for the true value of this unknown trend by keeping track of the actual evolution of costs in time. The resulting decision maker's timing problem is formulated as a three-dimensional optimal stopping problem, and addressed via probabilistic free-boundary methods and state-space transformations. We completely characterise the solution by showing that the optimal timing for implementing the emissions reduction policy is when the learning process has become "decisive" enough. We manage to obtain the optimal policy as the unique solution to a nonlinear integral equation, a result that allows for numerical illustrations and comparative statics, which lead to interesting results on the value of waiting. This is joint work with Matteo Basei and Giorgio Ferrari.

On the impact of tax uncertainty on investment into carbon abatement technologies

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Keywords: Environmental Finance and climate risk; Commodities and energy finance; Model risk and uncertainty

We study the problem of a profit maximizing electricity producer who decides on investments in technologies for abatement of CO2 emissions based on the carbon tax policy in force. We compare two tax scenarios: in the first scenario, taxes are deterministic; in the second scenario we allow for exogenous deviations from the deterministic setting which arrive at exponential times. The investment in the technology is irreversible and subject to transaction cost so that the producer faces a stochastic control problem. We characterize the value function as unique viscosity solution of this problem and we give conditions for the existence of classical solutions. Using numerical methods we show that in in the random tax scenario the company is typically less willing to invest in abatement technologies than in the scenario where taxes are credible and fixed. This complements earlier results from the real options literature. In the last part we tackle the same problem from the viewpoint of an uncertainty averse investor using differential games and the Bellman Isaacs equation. Interestingly, in this setup uncertainty about taxes might lead to higher investments.

Greenium Climate News Anomalies

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Keywords: Environmental Finance and climate risk

Do Green (low carbon intensity) securities outperform Brown (high carbon intensity) securities during higher intensity/scrutiny on climate change-related news?

In this paper, we propose to answer this question by providing an extension to the Man Institute research paper, "The Climate News Anomaly: Is the Stock Market Efficient in Pricing Climate Change Risks?," which was inspired by the Pastor, et al. paper on Green versus Brown factors based on the MSCI Environmental Score . We revisit this research and advance it by: • Analyzing the so-called Greenium Anomaly across all regions, beyond the U.S. context alone. • Providing a more comprehensive and exogenous definition of Brown and Green stocks using the Environment fields available via Bloomberg and utilizing Bloomberg Query Language (BQL) and BQuant Enterprise. • Proposing a more elaborate Climate News Index based not only on Volume, but also on Sentiment and premium specific tagging methodology to extract Climate Change and Energy Transition-related news for all of the Bloomberg and third-party partners' news sources, which are available in the Tier 1 News Package in BQuant Enterprise for Global News. • Analyzing an intraday event study around Climate News Index events (when the Index goes beyond/above a certain threshold) with more granularity, and providing an empirical distribution of Brown and Green stock intraday return distributions after such events using our BQuant Enterprise Intraday Market Data API.

The value of information flows in the stock market

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Keywords: Market microstructure

Stock market traders in possession of private information about fundamental values reveal that information to the rest of the market in the process of bidding: if the information is positive they bid up the price, and if it is negative they lower it. New information constantly develops and is brought to the market in this way, and because it influences prices, it ultimately influences the allocation of investments by firms.

Using a new approach, we estimate the flow of this information, its price (different from the stock price), and thus its total value, for each stock, and then sum up this value across all stocks, obtaining an estimate of the total value of the dynamic flow of information in the stock market as a whole. This requires digesting the records of tens of thousands of stock orders (including cancelled orders, not just executed trades) to construct the dynamic limit order book and estimate the information flow and value from its structure.

Our results support the notion that the cross-correlation of price impact across stocks is consistent with the CAPM: there is a single systematic component of price impact, and this is driven by the volatility of the systematic component of the stock market. This result suggests that by separating the underlying information into two components, systematic and idiosyncratic, informed traders distinguish between productive assets that have a systematic impact on the economy and those that can be diversified.

Price formation under asymmetry of information - a mean-field approach

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Keywords:

In financial markets, quantifying the information possessed by an agent trading an asset is a crucial task, especially when there is no homogeneity between the amount of information that can be accessed by every player. Our purpose is to study the behaviour of an equilibrium price p determined by the market clearing condition (i.e. the match between the demand and the supply) between rational financial agents who observe different amounts of information. We focus on a market in which one asset is traded by N less informed agents and one major agent. We show that, under the observation of the equilibrium price process p, the less informed players bridge the gap in terms of the amount of available information. However, the equation for the price process in the game with N+1 agents is not tractable. Thus, we prove the existence of a mean-field solution to the equation for the price process p when N goes to infinity. To construct the solution, we apply techniques related to the existence of weak mean-field game equilibria and based on the discretization of the common source of stochasticity shared by every agent. Finally, we show that the construction of the price process in the mean-field limit guarantees a weak form of the market clearing condition for the game with N+1 players.

Rational Expectations Equilibrium with Optimal Information Acquisition

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Keywords: Optimal stopping and stochastic control; Market microstructure

In this talk, we establish equilibrium in the presence of heterogenous information. In particular, there is an insider who receives a private signal, as well as uninformed agents with no private signal, and noise traders with price-inelastic demand. The novelty of the current work is that we allow the insider to decide (optimally) when to acquire the private signal. This endogenizes the entry time and stands in contrast to the existing literature which assumes the signal is received at the beginning of the period. Allowing for optimal entry also enables us to study what happens before the insider enters with private information, and how the possibility for future information acquisition affects current asset prices. Results are valid in continuous time, and when the private signal is a noisy version of the assets' terminal payoff, which itself is the terminal value of a diffusion. Additionally, the quality of the signal depends on the entry time. We will first present results when the diffusion is an Ornstein-Uhlenbeck process and agents have exponential preferences. Time permitting, we will extend to general diffusions and general uninformed agent preferences. This is joint work with Jerome Detemple and Nikos Vingos, both of Boston University.

On the Perils of Overfitting

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Keywords: Algorithmic trading; Risk management

A key problem in systematic investing is the selection of strategies to allocate capital to. In particular, estimating strategies' out-of-sample (i.e. live trading) performance is notoriously difficult, with many researchers resorting to using vague heuristics, such as simply halving the historical in-sample Sharpe ratio. In a linear prediction model, we formally quantify how much overfitting historical data can lead to over-optimism in the backtest performance. In particular, we estimate how much in-sample estimated performance should be haircut to more accurately predict out-of-sample performance, accounting for overfitting and uncertainty in the estimation of model parameters and the moments of the returns of the trading strategy. We find these estimates are in line with observed in vs out-of-sample performance differences for a set of quantitative strategies. This complements existing works in this domain which focus on the multiple testing problem in quantitative finance (e.g. de Prado, Bailey, Harvey, etc.), and specifically on how much one can overfit historical data in a linear model in even a single test, rather than the selection bias which can occur during a search of multiple potential strategies.

Asymmetric Violations of the Spanning Hypothesis

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Keywords: Machine learning for Finance; Yield curve modeling

We document that the Spanning Hypothesis, which is implied by most macro-finance term structure models, is violated asymmetrically along the U.S. yield curve. After controlling for information in bond prices, we find that macroeconomic variables help predict short-maturity bond returns with statistical and economic significance, while the evidence for long-maturity bonds is much weaker. To understand this pattern, we provide a new decomposition of bond excess returns in terms of innovations of short-, medium- and long-run factors of the yield curve. We show that, in fact, macro data only contains unspanned predictive information about the short-run factor. This extra predictability varies over time and is stronger when inflation is high.

Adaptive Collaborative Filtering with Personalized Time Decay Functions for Financial Product Recommendation

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Keywords: Financial data science; Machine learning for Finance

Classical recommender systems often assume that historical data are stationary and fail to account for the dynamic nature of user preferences, limiting their ability to provide reliable recommendations in time-sensitive settings. This assumption is particularly problematic in finance, where financial products exhibit continuous changes in valuations, leading to frequent shifts in client interests. These evolving interests, summarized in the past client-product interactions, see their utility fade over time with a degree that might differ from one client to another. To address this challenge, we propose a time-dependent collaborative filtering algorithm that can adaptively discount distant client-product interactions using personalized decay functions. Our approach is designed to handle the non-stationarity of financial data and produce reliable recommendations by modeling the dynamic collaborative signals between clients and products. We evaluate our method using a proprietary dataset from BNP Paribas and demonstrate significant improvements over state-of-the-art benchmarks from relevant literature. Our findings emphasize the importance of incorporating time explicitly in the model to enhance the accuracy of financial product recommendation.

Smart Kernel Factors

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Keywords: Risk management; Financial data science; Machine learning for Finance; Computational finance

Factor models are widely employed in finance to capture the relationship between asset returns and underlying, often latent, factors. These models are typically linear and assume a linear relationship between the factors and asset returns. However, in many cases, the underlying relationship between the factors and asset returns may not be linear, leading to potential misspecification and inaccurate predictions and inference. In this paper, we enhance factor models by introducing non-linearity through low-rank kernel functions, which provide a more flexible representation of the complex, non-linear relationships between factors and asset returns. To achieve this, we select a reproducing kernel Hilbert space with the associated reproducing kernel as a hypothesis space for modeling the factors (i.e., factor portfolios) and their corresponding factor loadings. By incorporating low-rank kernel functions, our approach captures the complex and non-linear interactions between factors and asset returns, improving the accuracy and predictive power of factor models in asset pricing. The proposed framework addresses the limitations of linear models, contributing to an enhanced understanding of financial market dynamics and highlighting the role of machine learning in advancing quantitative methodologies in finance.

A new approach to principal–agent problems with volatility control

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The recent work by Cvitanić, Possamaï, and Touzi (2018) [1] presents a general approach for continuous-time principal-agent problems, through dynamic programming and so-called second order backward stochastic differential equations (2BSDEs). In this paper, we provide an alternative formulation of the principal-agent problem, which can be solved using more straightforward techniques, simply relying on the theory of BSDEs. This reformulation is strongly inspired by an important remark in [1], namely that if the principal observes the output process X in continuous-time, she can compute its quadratic variation pathwise. While in [1] this information is used in the contract, our reformulation consist in assuming that the principal could directly control this process, in a 'first-best' fashion. The resolution approach for this alternative problem actually follows the line of the so-called 'Sannikov's trick' in the literature on continuous-time principal-agent problems, as originally introduced by Sannikov (2008) [2]. We then show that the solution to this 'first-best' formulation is identical to the solution of the original problem. More precisely, using the contract's form introduced in [1] as penalisation contracts, we highlight that this 'first-best' scenario can be achieved even if the principal cannot directly control the quadratic variation. Nevertheless, we do not have to rely on the theory of 2BSDEs to prove that such contracts are optimal, as their optimality is ensured by showing that the 'first-best' scenario is achieved. We believe that this more straightforward approach to solve general continuous-time principal-agent problems with volatility control will facilitate the dissemination of these problems across many fields, and its extension to more intricate principal-agent problems, for example with many (or even a continuum of) agents, or to more general, non-necessarily continuous, output processes.

Randomness and early termination: what makes a game exciting?

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In this talk, we revisit an open problem posed by Aldous on the max-entropy win-probability martingale: given two players of equal strength, such that the win-probability is a martingale diffusion, which of these processes has maximum entropy and hence gives the most excitement for the spectators? From a stochastic control perspective, the corresponding value function can be characterised by a nonlinear parabolic PDE, for which we show existence and uniqueness of classical solutions. We establish key qualitative properties of the solution including concavity, monotonicity, and convergence to a steady state. Moreover, we construct convergent numerical approximations, which allow us to highlight the behaviour of the win-probability process in the present case where the match may end early, in contrast to recent work by Backhoff-Veraguas and Beiglböck where the match always runs the full length.

Time-inconsistent stochastic control: state dependency

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We address the challenge of time-inconsistent stochastic control within a continuous-time framework. The focus lies in uncovering a probabilistic representation in the form of a system of backward stochastic differential equations (BSDEs) that encapsulate the equilibrium value function in the case where the present state affecting the target functional triggers the inconsistency. Furthermore, we present applications that illustrate this theory using classical examples from the stochastic control literature.

On the long time behavior of mean field games

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We study uniqueness and the long time behavior of mean field games and of controlled McKean-Vlasov dynamics with a non-degenerate idiosyncratic noise, without assuming convexity, nor monotonicity, of the cost coefficients. Instead, we consider a drift component which is strongly decreasing, but just outside a ball. Using coupling by reflection arguments, we show that, if this drift is strong enough, the mean field game has a unique solution, while otherwise solutions are not unique, and establish uniform in time estimates for the Lipschitz constant of the optimal feedback control, as a function of the measure. Thus we show existence and uniqueness of the turnpike, i.e. the stationary measure which solves the ergodic problem, and establish exponential convergence of the optimal trajectories to such equilibrium, as the time horizon grows.

Based on joint work with Giovanni Conforti (Padova), Alain Durmus, and Katharina Eichinger (Ecole Polytechnique Paris).

MF-OML: Online mean-field reinforcement learning with occupation measures for large population games

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Reinforcement learning for multi-agent games has attracted lots of attention recently. However, given the challenge of solving Nash equilibria for large population games, existing works with guaranteed polynomial complexities either aim at solving (coarse) correlated equilibria, or require access to simulators, or rely on certain assumptions that are hard to verify. In this talk, we propose a novel algorithm MF-OML (Mean-Field Occupation-Measure Learning), the first sample-efficient online mean-field reinforcement learning (RL) algorithm for computing approximate Nash equilibria (NEs) of large population sequential symmetric games. When evaluated by the cumulative errors to the set of Nash equilibia, the algorithm is shown to achieve a high probability regret bound of $\tilde{O}(M^{3/4}+N^{-1/2}M)$ for games with strong Lasry-Lions monotonicity condition, and a regret bound of $\tilde{O}(M^{11/12}+N^{-1/6}M)$ for games with only Lasry-Lions monotonicty condition, where M is the total number of episodes and N is the number of agents of the game. As a by-product, we also obtain the first tractable globally convergent computational algorithm for computing approximate Nash equilibira of monotone mean-field games.

Strong solutions to submodular mean field games with common noise under lack of uniqueness

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We study multidimensional mean field games with common noise and the related system of McKean-Vlasov forward-backward stochastic differential equations deriving from the stochastic maximum principle. We first propose some structural conditions which are related to the submodularity of the underlying mean field game and are a sort of opposite version of the well known Lasry-Lions monotonicity. By reformulating the representative player minimization problem via the stochastic maximum principle, the submodularity conditions allows to prove comparison principles for the forward-backward system, which correspond to the monotonicity of the best reply map. Building on this property, existence of strong solutions is shown via Tarski's fixed point theorem, both for the mean field game and for the related McKean-Vlasov forward backward system. In both cases, the set of solutions enjoys a lattice structure with minimal and maximal solutions which can be approximated by the simple iteration of the best response map and by the Fictitious Play algorithm. Numerical experiments illustrate the presence of multiple equilibria.

Mean field regrets in discrete time games

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We use mean field games (MFGs) to investigate approximations of N-player games with uniformly symmetrically continuous heterogeneous closed-loop actions. Centered around the notion of regret, we conduct non-asymptotic analysis on the approximation capability of MFGs from the perspective of state-action distributions without requiring the uniqueness of equilibria. Under suitable assumptions, we first show that scenarios in the N-player games with large N and small average regrets can be well approximated by approximate solutions of MFGs with relatively small regrets. We then show that δ-mean field equilibria can be used to construct ε-equilibria in N-player games. If time permits, we will discuss the incorporation of risk aversion into MFGs.

This is based on a joint work with Sebastian Jaimungal (UToronto).

Simulation of the Calibrated Heston-type Local Stochastic Volatility Model

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Keywords: Computational finance; Optimal stopping and stochastic control

In this work, we study the convergence of an Euler–Maruyama particle scheme that arises from the simulation of the calibrated Heston-type local stochastic volatility model. This is a McKean–Vlasov equation with irregular coefficients. To approximate the conditional expectation term appearing in the original calibrated dynamics, we apply a particle method that leads to a regularised equation. Under certain assumptions, we prove a strong propagation of chaos result for the convergence of the particle system to the regularised equation. Adding a condition on the Feller ratio, we also prove the strong convergence of the Euler–Maruyama scheme applied to the particle system with a rate of 1/2 (up to a logarithmic factor) in the step size. Finally, we implement the particle method for different values of the Feller ratio to illustrate the convergence of the discretisation scheme and the propagation of chaos in practice.

Equilibria in incomplete markets – an FBSDE approach

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Keywords:

Starting with a complete-market specification, we study equilibrium asset pricing over infinite time horizon in an incomplete market, where the incompleteness stems from an extra source of randomness for the dividend stream. We consider two heterogeneous agents with either CARA or CRRA preferences. In both cases, the equilibrium condition leads to a system of strongly-coupled Forward-Backward Stochastic Differential Equations (FBSDEs). This talk is based on joint work in progress with Martin Herdegen.

Extended mean-field games with multi-dimensional singular controls

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Keywords: Optimal stopping and stochastic control; Cooperative and non-cooperative market interactions

We consider a class of extended mean-field games (MFG) involving multi-dimensional singular controls where the impact of the singular control both on the state-process and the reward functional is not necessarily linear but instead depending on the current state and control. Our key idea is linking singular controls to parametrisations which carry the missing information on how jumps of the singular control are executed. By first considering the bounded velocity case and then proving an approximation result, we show the existence of Nash equilibria to the MFG in the general singular control case.

Macro-Finance Models: A Mean-field Game Approach

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Keywords: Cooperative and non-cooperative market interactions; Systemic risk; Risk management; Machine learning for Finance

Following the financial crisis in 2008, an increasing body of research has emerged, focusing on the vital roles of financial intermediaries and financial friction when analyzing the reaction of the economy during booms and busts with heterogeneity. We develop a new framework using tools from mean-field games to examine this subject by studying the interactions between and within groups of heterogeneous agents. Two groups in our models, namely the expert and the household, have a mean-field interaction through the capital with common noise and are bound by financial constraints. Such constraints prevent the allocation of funds to sectors with insufficient capital and slow down the optimal sharing of risks before they occur. This explains the capital misallocation and expert's asset fire sale when big shocks hit the economy as well as the "paradox of volatility". Moreover, due to mean-field interaction, our model can capture the phenomenon of slow economic recovery in practice, which contrasts with the rapid recoveries predicted by classical representative agent models in macro-finance literature. As a further contribution, we propose a universal approach for solving the general heterogeneous agent models (mean-field or not) based on rough path signature. Our signature-based method offers comparable accuracy to the existing machine learning approaches used in macro-finance literature while requiring less computational resources.

A new approach in two-dimensional heavy-tailed random variables

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Keywords: Insurance mathematics; Risk management; Model risk and uncertainty

We consider a new approach in the definition of two-dimesional heavy-tailed distributions. Namely, we introduce the classes of two-dimesional long-tailed, of two-dimesional dominatedly varying and of two-dimesional consistently varying distributions. Next, we define the closure property with respect to two-dimesional convolution and to two-dimesional max-sum equivalence in order to study if they are satisfied by these classes. Further we examine the joint behavior of two random sums, under generalized tail asymptotic independence. Afterward we study the closedness under scalar product and two dimensional product convolution and by these results we extented our main result in the case of joint randomly weighted sums. We conclude with an application where we establish the asymptotic expression of the ruin probability in a two-dimesional discrete-time risk model.

A Comparison of Neural Networks and Bayesian Approaches for the Heston Model Estimation

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Keywords: Option pricing and hedging; Stochastic volatility and volatility modeling; Machine learning for Finance; Computational finance

The main goal of this paper is to compare the classical Markov Chain Monte Carlo (MCMC) Bayesian estimation method with a universal Neural Network (NN) approach to estimate unknown parameters of the Heston stochastic volatility model given a series of observable asset returns. The main idea of the NN approach is to generate a large training synthetic dataset with sampled parameter vectors and the return series conditional on the Heston model. The NN can then be trained reverting the input and output, i.e. setting the return series, or rather a set of derived generalized moments as the input features and the parameters as the target. Once the NN has been trained, the estimation of parameters given observed return series becomes very efficient compared to the MCMC algorithm. Our empirical study implements the MCMC estimation algorithm and demonstrates that the trained NN provides more precise and substantially faster estimations of the Heston model parameters. We discuss some other advantages and disadvantages of the two methods, and hypothesize that the universal NN approach can in general give better results compared to the classical statistical estimation methods for a wide class of models.

Hawkes-based microstructure of rough volatility model with sharp rise

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Keywords: Stochastic volatility and volatility modeling; Market microstructure

We consider the microstructure of a stochastic volatility model incorporating both market and limit orders. In our model, the volatility is driven by self-exciting arrivals of market orders as well as self-exciting arrivals of limit orders, which are modeled by Hawkes processes. The impact of market order on future order arrivals is captured by a Hawkes kernel with power law decay, and is hence persistent. The impact of limit orders on future order arrivals is temporary, yet possibly long-lived. After suitable scaling the volatility process converges to a fractional Heston model driven by an additional Poisson random measure. The random measure generates occasional spikes in the volatility process. The spikes resemble the clustering of small jumps in the volatility process that has been frequently observed in the financial economics literature. Our results are based on novel uniqueness results for stochastic Volterra equations driven by a Poisson random measure and non-linear fractional Volterra equations.

Interacting limit order markets

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Keywords: Market microstructure

In this talk, we study the high-frequency limit of two interacting limit order markets, in which transactions between market participants from different venues are limited, as it is e.g. the case in the European intraday electricity market SIDC. Our market model can be conveniently described by a regime-switching process alternating between active and inactive regimes, in which cross-trading is possible respectively prohibited. Starting from a reduced-form representation of the two coupled limit order books, we derive a scaling limit approximation of the microscopic model, assuming that the size of an individual order converges to zero while the order arrival rate tends to infinity. If cross-trading is allowed, the limiting dynamics are as follows: the queue size processes at the top of the two limit order books follow a four-dimensional semimartingale reflecting Brownian motion in the positive orthant with oblique reflection at the axes. Each time two queues simultaneously hit zero, the process is reinitialized. Moreover, the cross-traded volume can be explicitly described as a linear combination of local times and is hence of finite variation. The analytic tractability of the limiting dynamics allows us to compute key quantities of interest like the duration until the next price change and to study the effect of the market coupling on price stability.

A queueing approach to execution probabilities in a limit order book with stochastic order flows

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Keywords:

We are interested in computing the execution probabilities of limit orders placed at different price levels, which plays a crucial role in optimizing executions. We consider using a tractable stochastic model to capture the dynamics of the order book, treating it as a queueing system. This model is state-dependent, and it also incorporates the stylized factors to enhance its representation of real-world intricacies. Based on this stochastic model, we then derive semi-analytical expressions to compute execution probabilities of orders posted at the best ask/bid price, and also for the orders placed one price level below before the opposite best quote moves. The expressions can be further generalized for orders posted even deeper in the order book although the probabilities are usually very small in this case. Detailed numerical methods are also provided so that all the computations can be done explicitly and efficiently. Finally, we conduct the numerical experiments with order book data from the FX spot market.

The Short-Term Predictability of Returns in Order Book Markets: a Deep Learning Perspective

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Keywords: Algorithmic trading; Market microstructure; Machine learning for Finance

In this talk, we conduct a systematic large-scale analysis of order book-driven predictability in high-frequency returns by leveraging deep learning techniques. First, we introduce a new and robust representation of the order book, the volume representation. Next, we carry out an extensive empirical experiment to address various questions regarding predictability. We investigate if and how far ahead there is predictability, the importance of a robust data representation, the advantages of multi-horizon modeling, and the presence of universal trading patterns. We use model confidence sets, which provide a formalized statistical inference framework particularly well suited to answer these questions. Our findings show that at high frequencies predictability in mid-price returns is not just present, but ubiquitous. The performance of the deep learning models is strongly dependent on the choice of order book representation, and in this respect, the volume representation appears to have multiple practical advantages.

Stability of order routing systems in fragmented markets

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Keywords: Market microstructure

We study an order routing system with multiple limit order book exchanges proposed by Maglaras et al. (2021). In this model traders of different types choose where to place their limit orders according to a trade-off between expected execution time and trading fees, and place their market orders by prioritizing exchanges with more liquidity. We rigorously prove the convergence to the fluid limit of this queueing routing system and characterise it as a system of coupled ODEs. Then we prove stability results for the equilibrium state of the system for any number of exchanges using Lyapunov theory, verifying the conjectures of Maglaras et al. (2021).

Martingale bridges with restricted support

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Keywords: Optimal transport; Robust finance

In the study of martingale Schrödinger bridge models, as discussed by Henry-Labordere [arXiv:1904.04554], a common assumption is the non-emptiness of the set of martingale measures that satisfy specific marginal constraints on their initial and final distributions. We investigate the existence of such martingale bridges in the discrete-time setting by restricting their support to a prescribed set of paths. It turns out that the conventional convex ordering requirement on marginal distributions is insufficient for their existence. Consequently, we reformulate Strassen's theorem departing from the concave envelope formulation, to one that aligns with the geometry of the underlying set of paths. This version allows to derive duality results in view of robust utility maximization with either fixed initial or terminal distributions. Additionally, we also explore continuous-time stochastic volatility models where we only consider equivalent measure changes affecting the drift of the volatility in spirit of Henry-Labordere [arXiv:1904.04554]. This is joint work with Christa Cuchiero.

Non-decreasing martingale couplings

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Keywords: Robust finance; Optimal transport

The traditional optimal transport problem (OT) consists in minimizing the expected cost $\mathbb{E}[c(X_1, X_2)]$ by considering the joint distribution (μ, ν) where the marginal distributions of the random variables $X_1 \sim \mu$ and $X_2 \sim \nu$ are fixed. Motivated by financial applications, martingale optimal transport is considered adding an additional martingale constraint $\mathbb{E}[X_2|X_1] = X_1$ on top of the OT problem. Hobson and Neuberger first studied the problem with a specific cost function $c(x, y) = -|yx|$, Juillet and Beiglbock proved the uniqueness of the associated optimizer π^{HN} when μ is continuous. For $c(x, y) = |y - x|^\rho$, we observe numerically that the π^{HN} is still a maximizer for $\rho \in (0, 2)$ and a minimizer for $\rho > 2$. We investigate the theoretical validity of this numerical observation and give rather restrictive sufficient conditions for the property to hold. We also exhibit couples (μ, ν) such that it does not hold. π^{HN} is known to satisfy some monotonicity property which we call non-decreasing. We check that the non-decreasing property is preserved for maximizers when $\rho \in (0, 1]$. In general, there exist distinct non-decreasing martingale couplings, and we find some decomposition of ν which is in one-to-one correspondence with couplings in a non-decreasing sense.

Equivalent Conditions for the Stochastic Exponential to be a Uniformly Integrable Martingale

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Keywords: Option pricing and hedging

Let M be a real-valued continuous local martingale starting at the origin. Novikov's condition and Kazamaki's condition are well-known sufficient conditions such that the stochastic exponential of M is a uniformly integrable martingale. Hence it can be used as a density process for a change to an absolutely continuous probability measure, which is useful for arbitrage-free option pricing. Inspired by work of J. Ruf (2013) and B. Chikvinidze (2020), we present a list of conditions, which are all equivalent to the stochastic exponential of M being a uniformly integrable martingale. One of these equivalent conditions looks like a suitable process-level combination of the conditions of Novikov and Kazamaki. The proof is suitable for class room presentations.

Occupied Processes: Going with the Flow

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Keywords: Option pricing and hedging; Stochastic volatility and volatility modeling

An Itô calculus is developed for functionals of the "time" spent by a path at arbitrary levels. We recover a Markovian setting by lifting a process with its flow of occupation measures, and call the resulting pair the occupied process. While the occupation measure erases the chronology of the path, the framework still includes many relevant problems in financial mathematics. We extend Itô's and Feynman-Kac's formula after introducing the occupation derivative, a projection of the linear derivative popularized in mean field games. Through Feynman-Kac, a large class of path-dependent PDEs are conveniently recast as parabolic problems where the occupation measure plays the role of time. We finally discuss applications to exotic options and path-dependent volatility. Reference: arxiv:2311.07936

Improved model-free bounds for multi-asset options using option-implied information and deep learning

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We consider the computation of model-free bounds for multi-asset options in a setting that combines dependence uncertainty with additional information on the dependence structure. More specifically, we consider the setting where the marginal distributions are known and partial information, in the form of known prices for multiasset options, is also available in the market. We provide a fundamental theorem of asset pricing in this setting, as well as a superhedging duality that allows to transform the maximization problem over probability measures in a more tractable minimization problem over trading strategies. The latter is solved using a penalization approach combined with a deep learning approximation using artificial neural networks. The numerical method is fast and the computational time scales linearly with respect to the number of traded assets. We finally examine the significance of various pieces of additional information. Empirical evidence suggests that "relevant" information, i.e. prices of derivatives with the same payoff structure as the target payoff, are more useful that other information, and should be prioritized in view of the trade-off between accuracy and computational efficiency.

Computation of Robust Option Prices via Structured Martingale Optimal Transport

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During the last decade there has been a rapid development of methods for computationally addressing optimal transport problems; motivated by applications within robust finance, effort has also been made to generalise some of these techniques to problems equipped with an additional martingale constraint. Computationally solving multi-marginal martingale optimal transport problems remains a challenging task though, particularly for problems formulated with a large number of marginals. In this talk we will present an efficient framework for solving a class of such problems computationally. Our method combines the celebrated entropic regularisation with the exploitation of certain structures inherent in the problem, enabling fast computation of the optimal dual variables. We will also provide some examples that demonstrates the utility of our method in terms of computing model-independent bounds on the fair price of some exotic options. The talk is based on joint work with Sigrid Kallblad and Johan Karlsson.

Numerics of Martingale Optimal Transport with Causality Constraints

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Martingale optimal transport (MOT) often yields broad price bounds for options, constraining their practical applicability. In this study, we extend MOT by incorporating causality constraints among assets, which is inspired by the non-anticipativity condition of stochastic processes. However, this introduces a computationally challenging bilinear program. To tackle this issue, we propose McCormick relaxations to ease the bicausal formulation. The primal attainment and strong duality of McCormick MOT are established under standard assumptions. McCormick MOT demonstrates the capability to narrow price bounds, and the degree of improvement depends on the type of exotic payoffs.

Risk measures based on weak optimal transport

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We study convex risk measures with weak optimal transport penalties. In a first step, we show that these risk measures allow for an explicit representation via a nonlinear transform of the loss function. In a second step, we discuss computational aspects related to the nonlinear transform as well as approximations of the risk measures using, for example, neural networks. Our setup comprises a variety of examples, such as classical optimal transport penalties, parametric families of models, divergence risk measures, uncertainty on path spaces, moment constraints, and martingale constraints. In a last step, we show how to use the theoretical results for the numerical computation of worst-case losses in an insurance context and no-arbitrage prices of European contingent claims after quoted maturities in a model-free setting. The talk is based on joint work with Michael Kupper and Max Nendel.

Reflections on BSDEs

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We consider backward stochastic differential equations (BSDEs) and reflected BSDEs in a generality that allows for a unified study of certain discrete-time and continuous-time control problems with random time horizons. We provide well-posedness results for BSDEs and reflected BSDEs with optional obstacle processes, given appropriately weighted square-integrable data, and touch upon the corresponding second-order BSDEs. This is based on joint work with Dylan Possamaï.

Dynamic programming approach for continuous-time Stackelberg games

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We propose a general approach to reformulating any continuous-time stochastic Stackelberg differential game under closed-loop strategies as a single-level optimisation problem with target constraints. More We first show that, by considering the second-order—backward stochastic differential equation associated with the continuation utility of the follower as a controlled state variable for the leader, the latter's unconventional optimisation problem can be reformulated as a more standard stochastic control problem with stochastic target constraints. Thereafter, the optimal strategies, as well as the corre sponding value of the Stackelberg equilibrium, can be characterised through the solution of a well-specified system of Hamilton–Jacobi–Bellman equations.

Golden parachutes under the threat of accidents

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Based on recent work by Possamaï and Touzi, we consider an extension of Sannikov's principal-agent problem by letting the agent control the instantaneous growth rate of the project's value, and the likelihood of accidents occurring. In order to compensate for these costly actions, the principal offers a continuous stream of payments throughout the entire duration of a contract, which concludes at a random time, potentially resulting in a lump-sum payment. We examine the consequences stemming from the introduction of accidents, modelled by a compound Poisson process that negatively impacts the project's value. Furthermore, we investigate whether certain economic scenarios are still characterized by a golden parachute as in Sannikov's model. A golden parachute refers to a situation where the agent stops working and subsequently receives compensation, which may be either a lump-sum payment leading to termination of the contract or a continuous stream of payments, thereby corresponding to a pension. This is based on joint work with Dylan Possamaï.

Equilibrium in Functional Stochastic Games with Mean-Field Interaction

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We consider a general class of finite-player stochastic games with mean-field interaction, in which the linear-quadratic cost functional includes linear operators acting on controls in L2. We propose a novel approach for deriving the Nash equilibrium of the game explicitly in terms of operator resolvents, by reducing the associated first order conditions to a system of stochastic Fredholm equations of the second kind and deriving their closed form solution. Furthermore, by proving stability results for the system of stochastic Fredholm equations we derive the convergence of the equilibrium of the N-player game to the corresponding mean-field equilibrium. As a by-product we also derive an epsilon-Nash equilibrium for the mean-field game, which is valuable in this setting as we show that the conditions for existence of an equilibrium in the mean-field limit are less restrictive than in the finite-player game. Finally we apply our general framework to solve various examples, such as stochastic Volterra linear-quadratic games, models of systemic risk and advertising with delay, and optimal liquidation games with transient price impact. Based on joint work with Eyal Neuman and Moritz Voss.

Auction market design and regulation policies

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We model the interaction between an investor executing trades at low frequency and a high-frequency trader as a multiperiod stochastic Stackelberg game. The high-frequency trader exploits price information more frequently and is subject to periodic inventory constraints. We are able to explicitly compute the equilibrium strategies, in two steps. We first derive the optimal strategy of the high-frequency trader given any strategy adopted by the investor. Then, we solve the problem of the investor given the optimal strategy of the high-frequency trader, in terms of the resolvent of a Fredholm integral equation. Our results show that the high-frequency trader adopts a predatory strategy whenever the value of the trading signal is high, and follows a cooperative strategy otherwise. We also show that there is a net gain in performance for the investor from taking into account the order flow of the high-frequency trader. A U-shaped intraday pattern in trading volume is shown to arise endogenously as a result of the strategic behavior of the agents. This is a joint work with Rama Cont and Alessandro Micheli.

Offline learning for propagator models

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We consider an offline learning problem for an agent who first estimates an unknown price impact kernel from a static dataset, and then designs strategies to liquidate a risky asset while creating transient price impact. We propose a novel approach for a nonparametric estimation of the propagator from a dataset containing correlated price trajectories, trading signals and metaorders. We quantify the accuracy of the estimated propagator using a metric which depends explicitly on the dataset. We show that a trader who tries to minimise her execution costs by using a greedy strategy purely based on the estimated propagator will encounter suboptimality due to spurious correlation between the trading strategy and the estimator. By adopting an offline reinforcement learning approach, we introduce a pessimistic loss functional taking the uncertainty of the estimated propagator into account, with an optimiser which eliminates the spurious correlation, and derive an asymptotically optimal bound on the execution costs even without precise information on the true propagator. Numerical experiments are included to demonstrate the effectiveness of the proposed propagator estimator and the pessimistic trading strategy.

Fast and Slow Optimal Trading with Exogenous Information

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We consider an offline learning problem for an agent who first estimates an unknown price impact kernel from a static dataset, and then designs strategies to liquidate a risky asset while creating transient price impact. We propose a novel approach for a nonparametric estimation of the propagator from a dataset containing correlated price trajectories, trading signals and metaorders. We quantify the accuracy of the estimated propagator using a metric which depends explicitly on the dataset. We show that a trader who tries to minimise her execution costs by using a greedy strategy purely based on the estimated propagator will encounter suboptimality due to spurious correlation between the trading strategy and the estimator. By adopting an offline reinforcement learning approach, we introduce a pessimistic loss functional taking the uncertainty of the estimated propagator into account, with an optimiser which eliminates the spurious correlation, and derive an asymptotically optimal bound on the execution costs even without precise information on the true propagator. Numerical experiments are included to demonstrate the effectiveness of the proposed propagator estimator and the pessimistic trading strategy.

Linear programming approach to mean-field games: theory, numerics and applications in economics and finance.

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Keywords:

The two main methods for solving mean-field games are the partial differential equation (PDE) approach pioneered by Larry and Lions, and the probabilistic approach of Carmona and Delarue. Here we present a new approach, based on the reformulation of the stochastic control problems associated to mean-field games in terms of linear programming problems.

This approach simplifies existence proofs, opens way for new efficient numerical algorithms, and is particularly useful in the context of mean-field games of optimal stopping, where lack of regularity makes it difficult to use the PDE approach. In this talk, we will review the linear programming approach for MFG of control and optimal stopping, discuss the numerical algorithms and illustrate the method with applications to models of electricity market dynamics and climate transition risk.

Risk measures: horizon longevity and BSDEs

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Keywords:

In this talk, we focus on monetary risk measures in a dynamic framework and critically discuss some commonly assumed features. Starting from the fact that risk measurement needs to be applied to positions referring to very different time horizons (e.g., in the case of trading operations or of pension funds), we then identify horizon risk as the possibility to fail the risk assessment because of the use of a non-adequate risk measure with respect to the time horizon. Horizon longevity is then introduced as an index of horizon risk. Some (financially sound) examples of dynamic risk measures able to capture horizon longevity are then provided in terms of generalized shortfall risk measures and of Backward Stochastic Differential Equations, with a special focus on the entropic case as well as on the generalized Tsallis entropy. Since a wide family of dynamic risk measures is induced by BSDEs, a part of our discussion will be devoted to them, not only in the context of horizon longevity but also beyond.

Bi-Revealed Utilities in a defaultable universe

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Keywords: Credit risk

This paper investigates the inverse problem of bi-revealed utilities in a defaultable universe, defined as a standard universe (represented by a filtration $\mathbb{F}$) perturbed by an exogenous defaultable time τ. The defaultable universe is represented by the filtration $\mathbb{G}$ *up to time* τ, where $\mathbb{G}$ stands for the progressive enlargement of $\mathbb{F}$ by τ. The basic assumption in force is that τ avoids $\mathbb{F}$-stopping times. The bi-revealed problem consists in recovering a consistent dynamic utility from the observable characteristic of an agent. The general results on bi-revealed utilities are stated in the defaultable $\mathbb{G}$-universe and then are interpreted in the $\mathbb{F}$-universe. Thanks to the characterization of $\mathbb{G}$-martingales stopped at τ in terms of $\mathbf{F}$-martingales, we establish a correspondence between $\mathbb{G}$-bi-revealed utilities from characteristic and $\mathbb{F}$-bi-revealed pair of utilities from characteristic and reserves. In a financial framework, characteristic can be interpreted as wealth and reserves as consumption. This result sheds a new light on the consumption in utility criterion: the consumption process can be interpreted as a certain quantity of wealth, or reserves, that are accumulated for the financing of losses at the default time.

Netting And Novation In Repo Networks With Rehypothecation: An Agent-Based Computational Model

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Keywords: Systemic risk

We propose an agent-based computational model for a financial system consisting of a network of banks with interconnected balance sheets comprising of fixed assets (e.g. loans to agents outside the network), liquid assets (e.g. cash or central bank reserves), general collateral (e.g. government debt), unsecured interbank loans and reverse-repos to other banks as assets, as well as deposits, unsecured interbank loans and repos from other banks as liabilities. Banks needs to satisfy liquidity, collateral, and solvency constraints. If the first two constraints are violated because of internal or external shocks, solvent banks attempt to restore them by rebalancing their assets, which might lead to the propagation of the shock because of fire-sale effects (if fixed assets are sold) or liquidity hoarding (if secured or unsecured loans are recalled). Insolvent banks, as well as banks that failed to restore the liquidity and collateral constraints after rebalancing, are removed from the network using a resolution algorithm that includes a netting step (i.e. removal of closed cycles of liabilities) and a novation step (i.e. redistribution of repo assets and liabilities to remaining banks). We show analytically that this proposed resolution algorithm has several desirable properties, most importantly the order-independence of the novation step, and investigate the stability properties of the network through a series of numerical experiments.

A Markov approach to credit rating migration conditional on economic states

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Keywords: Credit risk; Risk management

We develop a model for credit rating migration that accounts for the impact of economic state fluctuations on default probabilities. This model aligns with current banking regulations and accounting standards for financial institutions. The joint process for the economic state and the rating are modelled as a time-homogeneous Markov chain. First, we study conditions for the rating process to exhibit the Markov property as well as its asymptotic behaviour. Second, we establish a mathematical framework to study different rating philosophies, such as point-in-time (PIT) and through-the-cycle (TTC) ratings. Third, we introduce stochastic orders on the bivariate process' transition matrix to formalise the notions of "better" and "worse" ratings. Finally, we illustrate the construction of PIT and TTC ratings on a Merton-type firm-value process, demonstrating joint properties of PIT and TTC ratings.

Unwinding Stochastic Order Flow with Partial Information

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Keywords: Optimal stopping and stochastic control; Algorithmic trading

We consider the problem faced by a trader who wishes to unwind a stochastic order flow with uncertainty on the model parameterisation. Specifically, the order flow in this model is a stochastic process which is unknown to the agent and it is influenced by intraday, low-frequency toxicity which reacts to the trader's unwind strategy. As a result, the trader's problem is an optimal liquidation problem, where the amount to liquidate is stochastic and evolves, and the adversarial effect of the order flow toxicity is unknown.

Relative Arbitrage Under Transaction Costs

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Keywords: Algorithmic trading; Optimal stopping and stochastic control; Robust finance; Financial data science

A key result in Stochastic Portfolio Theory (SPT) is the existence of relative arbitrage under mild conditions on market diversity and volatility. However, this result is classically derived in a setting without transaction costs. In this work we formally incorporate proportional transaction costs into the SPT framework. We study the structure that these costs impose and consider what market conditions lead to relative arbitrage opportunities. For instance, we can leverage an "exploration" property of the market capital distribution to establish the existence of relative arbitrage in the presence of market frictions. We empirically analyze if our market assumptions are justified in practice and investigate if they are satisfied by existing equity market models. We also study the types of portfolios that generate relative arbitrage in our expanded setting. Unlike the original theory, continuously rebalanced functionally generated portfolios are no longer candidates as they incur infinite transaction costs. As a byproduct of our analysis, we are led to several new problems at the intersection of SPT, optimal control, and optimal stopping theory.

Optimal Portfolio Choice with Cross-Impact Propagators

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Keywords: Market microstructure; Optimal stopping and stochastic control

We consider a class of optimal portfolio choice problems in continuous time where the agent's transactions cause both linear transient cross-impact driven by a matrix-valued Volterra-type propagator as well as temporary impact. We formulate these problems as the maximisation of revenue-risk functionals, where the agent also exploits available information on a progressively measurable price predicting signal. We solve the maximisation problem explicitly in terms of operator resolvents, by reducing the corresponding first order condition to a coupled system of stochastic Fredholm equations of the second kind and deriving its closed form solution. In the second part of this work, we examine which properties need to be imposed on the matrix-valued propagator so that the model does not permit price manipulation.

Flow rider: tradeable ecosystems' relative entropy of flows as a determinant of relative value

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Keywords: Behavioral finance; Financial data science

Fund flow predictability based on prior-period returns is well-established in the literature; we study unexpected distribution divergences, quantified by relative entropy, between flows and prior-period returns in tradeable ecosystems as an exogenous price signal, which we hypothesise to represent the aggregate directional positioning of informed investors. We test our hypothesis, in pursuit of demonstrating informativeness and the additionality of the factor in augmenting traditional weighting schemes to produce superior systematic portfolios and in expanding the discretionary investor's toolbox in identifying "smart money" positioning in the aggregate. Our findings indicate that the relative entropy signal demonstrates relevance in predicting future returns and identifying relative value within our designated tradeable macro ecosystem and that it can contribute constructively to portfolio construction outcomes.

Dynamic capital allocation rules via BSDEs: an axiomatic approach

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Keywords: Risk measures

In this talk, we investigate capital allocation for dynamic risk measures, with an axiomatic approach but also by exploiting the relation between risk measures and BSDEs. Although there is a wide literature on capital allocation rules in a static setting and on dynamic risk measures, only a few recent papers on capital allocation work in a dynamic setting and, moreover, those papers mainly focus on the gradient approach. To fill this gap, we then discuss new perspectives to the capital allocation problem going beyond those already existing in the literature. In particular, we introduce and investigate a general axiomatic approach to dynamic capital allocations as well as an approach suitable for risk measures induced by g-expectations under weaker assumptions than Gateaux differentiability.

Computing dynamic risk measures: Convergence of the Deep BSDE method for FBSDE with quadratic growth

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Keywords: Risk measures; Computational finance

In this work we are interested in an effective method for the computation of dynamic and fully dynamic risk measures, which are often studied in connection with backward stochastic differential equations (BSDEs), with some important cases given by quadratic BSDEs, like the entropic risk measure or the q-entropic risk measure [1]. We choose to explore the so-called "Deep BSDE" method for forward/backward stochastic differential equations (FBSDEs), where the forward system represents the value process carrying the risk to be measured.

Since its introduction in [2] , there have been some works that have studied its convergence, in all cases assuming that the coefficients of the backward SDE are globally Lipschitz, which leaves out the class of quadratic BSDE. We finalize this work by presenting a straightforward proof of the convergence of the Deep BSDE in the globally-Lipschitz uncoupled case, which we then extend to the case where the BSDE is quadratic.

This presentation is based on a work in progress.

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[2] E, W., Han, J. & Jentzen, A. Deep Learning-Based Numerical Methods for High-Dimensional Parabolic Partial Differential Equations and Backward Stochastic Differential Equations. Commun. Math. Stat. 5, 349–380 (2017)

Dynamic Return and Star-Shaped Risk Measures via BSDEs

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Keywords: Risk measures

This paper presents characterization results for dynamic return and star-shaped risk measures induced through Backward Stochastic Differential Equations (BSDEs). The paper begins by characterizing any static star-shaped functional as the minimum of convex functionals in a locally convex Fréchet lattice. This generalization extends the findings regarding the dual representation of positively homogeneous functionals to include star-shaped functions. Additionally, the paper goes beyond the usual approach presented in literature by dropping the axioms of cash-additivity, normalization, and monotonicity.

Next, a regularization procedure is employed to construct a suitable family of convex drivers for BSDEs, which in turn induces a corresponding family of dynamic convex risk measures. The dynamic star-shaped risk measures are identified as essential minima within this family. Furthermore, it is shown that every driver of a star-shaped risk measure induced by BSDEs is star-shaped, establishing a connection to the converse comparison theorem for BSDEs. Conditions are also established under which the minimum of a family of convex risk measures can be obtained as the solution to a BSDE with a star-shaped driver. The paper further develops the theory of BSDEs supersolutions for star-shaped drivers.

Theoretical results are illustrated through a few examples, showcasing their usefulness in two applications: capital allocation and portfolio choice.

Uncertainty Propagation and Dynamic Robust Risk Measures

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Keywords: Risk management; Model risk and uncertainty; Optimal transport; Risk measures; Robust finance

We introduce a framework for quantifying propagation of uncertainty arising in a dynamic setting. Specifically, we define dynamic uncertainty sets designed explicitly for discrete stochastic processes over a finite time horizon. These dynamic uncertainty sets capture the uncertainty surrounding stochastic processes and models, accounting for factors such as distributional ambiguity. Examples of uncertainty sets include those induced by the Wasserstein distance and f-divergences.

We further define dynamic robust risk measures as the supremum of all candidates' risks within the uncertainty set. In an axiomatic way, we discuss conditions on the uncertainty sets that lead to well-known properties of dynamic robust risk measures, such as convexity and coherence. Furthermore, we discuss the necessary and sufficient properties of dynamic uncertainty sets that lead to time-consistencies of dynamic robust risk measures. We find that uncertainty sets stemming from f-divergences lead to strong time-consistency while the Wasserstein distance results in a new time-consistent notion of weak recursiveness. Moreover, we show that a dynamic robust risk measure is strong time-consistent or weak recursive if and only if it admits a recursive representation of one-step conditional robust risk measures arising from static uncertainty sets.

An optimisation framework for building realistic portfolios with equities and futures contracts

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Keywords: Computational finance; Risk management

By solving the portfolio selection problem, investment managers hope to produce financial decisions that skillfully balance risk and return. The literature in this field is extensive, encompassing various lines of research. One particularly well-studied aspect is that of exogenous constraints, which serve as valuable tools for refining portfolio selection strategies. These constraints help in producing more realistic portfolios and in avoiding some pitfalls of uncertain data estimation.

Several types of constraints have been introduced in literature in various contexts. In this paper, we propose an optimisation-based framework which goes a step further, by hoping to produce portfolios that can be immediately converted into real financial holdings. Our proposed framework is generic in the sense that it can be used in conjunction with any portfolio selection model, and consists of splitting the portfolio selection problem into two-stages. We combine futures contracts and equities in a single framework, and also consider borrowing costs in short positions.

We present extensive computational results illustrating the applicability of our approach and evaluating the overall quality of the solutions produced by the two-stage framework. We compare our approach with an alternative from the literature and find that our method effectively mitigates potential issues associated with the mentioned formulation at little cost.

Parametric portfolio policy, transaction costs and regularization

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Keywords: Risk management; FinTech Econometrics

We propose a new strategy for estimating parametric portfolio policies. We formulate the mean-variance portfolio optimization problem with transaction costs as a regularized estimation problem and, after recovering the stationary portfolio weight updates, we aim to predict them using firm characteristics and factors. In this way, we transform the parametric portfolio policy estimation into a learning problem, where the targets are the portfolio weight updates, meaning that we can accommodate different models and many characteristics. However, a major challenge in this approach is estimating the predictive means and covariance matrix of returns, which is addressed using a pseudo-out-of-sample strategy and shrinkage estimators. We use CRSP data and simulations to show that this new approach yields better Sharpe ratios than previous methods, with less sparse portfolios. A neat feature of this approach is that one can impose arbitrary constraints to the weights in the portfolio optimization problem with little impact to the method.

Portfolio Optimization Beyond Utility Maximization: The Case of Driftless Markets

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Keywords: Stochastic volatility and volatility modeling; Robust finance; Financial data science; FinTech; Option pricing and hedging; Generative Models in Finance

This paper presents a novel perspective on portfolio optimization by recognizing that prices can be expressed as a scaled likelihood ratio of state price densities. This insight leads to the immediate conclusion that the optimal portfolio has a simple representation in terms of the likelihood ratio between the agent-defined physical measure and the risk-neutral measure, eliminating the need for utility maximization. The agent only needs to specify her choice of the physical measure, and we demonstrate both frequentist and Bayesian approaches for this selection. Utility maximization can be seen as a specific method for choosing the physical measure. The resulting likelihood ratio is log-utility optimal with respect to all benchmarks, aligning our approach with finding the growth optimal portfolio described in the literature. Notably, the expected log return corresponds to the relative entropy between the physical and risk-neutral measures, establishing a fundamental link to information theory. As a proof of concept, we explore previously unexplored territory in portfolio optimization, specifically addressing perceived mean reversion in specific driftless markets, such as foreign exchange (FX) markets.

A tour in Sandwiched Volterra Volatility models

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Keywords: Stochastic volatility and volatility modeling; Option pricing and hedging

Sandwiched Volterra Volatility (SVV) models are a class of models driven by a continuous Gaussian Volterra process. They are able to capture both the long memory and the rough aspects of volatility, as well as the power law. Due to their nature, the dynamics will be sandwiched within pre considered bounds, this is a welcome feature in some applications. We present the SVV structure and the properties. Then we consider pricing and hedging. Keeping in mind applicability, we present the explicit computation of quadratic hedging strategies. The theoretical solution is well-known in terms of the non-anticipating derivative for all square integrable claims, the fact that these models are typically non-Markovian provides a concrete difficulty in the direct computation of conditional expectations at the core of the explicit hedging strategy. To overcome this difficulty, we propose a Markovian approximation of the model which stems from an adequate approximation of the kernel in the Volterra noise and it is built through out to guarantee the actual approximation of the theoretical. We show some numerical simulations performed with different methods.

Fokker-Planck equations for Volterra processes

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Keywords: Stochastic volatility and volatility modeling

We study a class of Stochastic Volterra Equations (SVEs) with multiplicative noise and convolution-type kernels. Our focus lies on rough volatility models and thus we allow for power-law kernels that are singular at the origin. Working with carefully chosen Hilbert spaces, we rigorously establish a link between the solution of the SVE and the Markovian mild solution of an associated Stochastic Partial Differential Equation (SPDE). Our choice of a Hilbert space solution theory allows access to well-developed tools from stochastic calculus in infinite dimensions. In particular, we obtain two types of Itô formulae for the solution of the SPDE and show that its law solves an infinite-dimensional Fokker-Planck-Kolmogorov equation. Time permitting, we shall discuss applications of our results to optimal control and long-time behaviour of SVEs. This is joint work with Alexandre Pannier (Université Paris Cité).

A small-time central limit theorem for stochastic Volterra integral equations and its implications on the Markov property

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Keywords:

In this work, we prove a small-time central limit theorem for the finite-dimensional distributions of solutions to stochastic Volterra integral equations as well as its extension to a functional CLT, where we focus on coefficients satisfying linear growth and Hölder conditions. As we consider the (potentially singular) Riemann-Liouville kernel, the Hurst parameter $H > 0$ plays an essential role in choosing the appropriate normalizing sequence for the CLT. As a consequence, we obtain also the small-time asymptotics for prices of at-the-money digital calls in market models with sufficient trading limitations. Finally, we prove the absolute continuity of the solution with respect to the Lebesgue measure under the additional assumption that the diffusion coefficient does not attain zero. Provided that the densities are sufficiently regular in time and in combination with the above CLT, we can, moreover, show the non-Markovianity of the process, which is of importance for applications in mathematical finance as it highlights the need for more sophisticated concepts for pricing and hedging financial derivatives. Joint work with Stefan Gerhold.

Orthogonal expansions in Volterra-Heston models

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Keywords: Option pricing and hedging; Stochastic volatility and volatility modeling; Computational finance

In this work we derive accurate and efficient approximations for option prices in Volterra-Heston models - a class of stochastic volatility models extending the rough Heston model of El Euch and Rosenbaum (2018). Our approach is based on the orthogonal polynomial expansions methodology recently developed by Kloster and Nicolato (2024). These expansions rely on using a simpler option pricing model as a building block and then approximating the true option price as a series of modified payoffs under this reference model. Here we choose the reference model in a similar fashion to the "poor man's rough Heston" approximation proposed by El Euch, Gatheral and Rosenbaum (2019). We test the orthogonal expansions for two concrete Volterra-Heston models: the classic rough Heston model associated with the power kernel, as well as the specification associated with the gamma kernel. In both cases, the resulting approximations closely match the exact implied volatilities, consistently yielding mean absolute errors below 15 basis points across a wide range of maturities and moneyness. Furthermore, the approximations are essentially as fast as pricing in the classical Heston (1993) model. As such, they provide an accurate and way more efficient alternative to the exact Fourier pricing in the class of Volterra-Heston models.

Randomisation with moral hazard: a path to existence of optimal contracts

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We discuss recent advancements in contracting theory. We consider a generic principal-agent problem in continuous time and introduce a framework in which the agent chooses relaxed controls. We characterize the agent's value process as a solution to a BSDE driven by a martingale measure. This, in turn, allows us to employ compactification techniques and show the existence of optimal contracts, even with very general constraints imposed on the contract. The talk is based on joint work with Dylan Possamaï.

Moral Hazard for Time-Inconsistent Agents

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We address the problem of Moral Hazard in continuous time between a Principal and an Agent that has time-inconsistent preferences. Building upon previous results on non Markovian time-inconsistent control for sophisticated agents, we are able to reduce the problem of the principal to a novel class of control problems, whose structure is intimately linked to the representation of the problem of the Agent via a so-called extended Backward Stochastic Volterra Integral equation. We will present some results on the characterization of the solution to the problem for different specifications of preferences for both the Principal and the Agent.

Optimal contract, consumption habit, and capital structure

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The paper examines a continuous-time principal-agent model in which agent's preference exhibits habit formation over consumption. As agent's concern over the standard of living strengthens, his continuation utility is less sensitive to current wealth but more sensitive to the standard of living, leading to lower demand for risk-sharing compensation. The optimal contract has lower pay-for-performance but incentivizes agent's higher effort. In the Leland (1994) capital structure model, agent's habit formation preference combined with the optimal contract lowers firm's leverage and mitigates the debt-overhang problem.

Sannikov's contracting problem with many Agents

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This work aims to study an extension of the celebrated Sannikov's Principal-Agent problem to the multi-Agents case. In this framework, the contracts proposed by the Principal consist in a running payment, a retirement time and a final payment at retirement. After discussing how the Principal may derive optimal contracts in the N-Agents case, we explore the corresponding mean field model, with a continuous infinity of Agents. We then prove that the Principal's problem can be reduced to a mixed control-and-stopping mean field problem, and we derive a semi-explicit solution of the first best contracting problem. This is a joint work with Thibaut Mastrolia and Nizar Touzi.

Smile Dynamics and Rough Volatility

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We investigate the dynamic characteristics of various stochastic and rough volatility models, including classical examples like the 2-factor Bergomi model, rough Bergomi model, Heston, and rough Heston. Specifically, we focus on the dynamics of option-implied volatilities induced by these models. While recent literature has extensively analyzed the static properties of some models, such as their calibration power or the term structure of ATM skews, their dynamic properties have received less attention. We examine the Skew-Stickiness Ratio (SSR) introduced by Bergomi as an indicator of joint spot price and implied volatility dynamics. Using different estimators, primarily Monte Carlo-based, we compare the results with empirical market SSR for large stock indices. This comparison sheds light on the suitability of certain modeling choices. This is joint work with Stefano De Marco and Jules Delemotte.

Computing the SSR

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The skew-stickiness-ratio (SSR), examined in detail by Bergomi in his book, is critically important to options traders, especially market makers. We present a model-free expression for the SSR in terms of the characteristic function. In the diffusion setting, it is well-known that the short-term limit of the SSR is 2; a corollary of our results is that this limit is $H + 3/2$ where H is the Hurst exponent of the volatility process. The general formula for the SSR simplifies and becomes particularly tractable in the affine forward variance case. The qualitative behavior of the SSR with respect to the shape of the forward variance curve is explained, at least in the affine case.

Fast Exact Joint S&P 500/VIX Smile Calibration in Discrete and Continuous Time

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We introduce a novel discrete-time-continuous-time exact calibration method: we first build an S&P 500/VIX jointly calibrated discrete-time model that is later extended to continuous time by martingale interpolation. The benefit is that both steps can be made much faster than the known methods that directly calibrate a continuous-time model. We propose Newton-Sinkhorn and implied Newton algorithms that are much faster than the Sinkhorn algorithm that (Guyon, Risk, April 2020) used to build the first arbitrage-free model exactly consistent with S&P 500 and VIX market data. Using a (purely forward) Markov functional model, we then quickly build an arbitrage-free continuous-time extension of this discrete-time model. Additionally, new model-free bounds on S&P 500 options emphasize the value of the VIX smile information. Extensive numerical tests are conducted. This is joint work with Florian Bourgey.

The quintic model that jointly calibrates SPX & VIX smiles

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he quintic model is a Markovian stochastic volatility model where the volatility process is a polynomial function of degree five of an Ornstein-Uhlenbeck process. The model has been shown to achieve remarkable joint fits of the SPX-VIX smiles for short maturities with only six effective parameters and an input curve that allows to match certain term structures. Even better, the model remains simple and highly tractable for pricing, hedging and calibration via 1) numerical integration against the Gaussian density for VIX derivatives, and 2) Fast Fourier inversion for SPX derivatives and its Greeks thanks to the model's affine structure (in infinite dimension). We also share some latest results, including the natural two-factor extension of the model to jointly calibrate longer maturities of SPX and VIX volatility smiles as well as the asymptotic behaviour of the VIX smiles. Based on joint works with Eduardo Abi Jaber (Ecole Polytechnique), Camille Illand (AXA Investment Managers) and Xuyang Lin (Ecole Polytechnique).

Dynkin Game for Lévy Processes

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Keywords:

In the work we solve the optimal stopping problem of two players (one trying to maximize his payoffs and the other to minimize them) with a common underlying Lévy processes observed through two different functions. This problem can be defined as a Dynkin Game and since 2000 has attracted interest in quantitative finance as an "American call option". Despite these possible applications, after obtaining a general verification result, we apply it to somehow the simplest possible cases, with linear payoff functions and simple processes, where close solutions can be obtained. This is joint work with Laura Aspirot and Ernesto Mordecki.

Equilibrium and Price Impact in Limit Order Market

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Keywords: Market microstructure

We consider the one-period Nash equilibrium among informed traders and competitive liquidity suppliers in the limit order market, where liquidity suppliers are uncertain about both the existence and quantity of informed traders in the market. We discuss how informed traders, if they exist, seek to exploit their information advantage and how liquidity suppliers adjust the limit prices in equilibrium based on their beliefs about these informed traders. Our findings confirm the existence of the equilibrium, obtained through a fixed-point mapping problem when the explicit solution is unavailable for general distributions of asset value and informed trader quantity. In equilibrium, we further show that fat-tailed trading asset returns lead to power law asymptotic market impact, while light tails cause logarithmic market impact. Furthermore, we provide the numerically solvable fixed-point equations for the exponents and parameters in power law impact and logarithmic impact.

Hedging of financial derivative contracts via Monte Carlo tree search

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Keywords:

The construction of replication strategies for the pricing and hedging of derivative contracts in incomplete markets is a key problem in financial engineering. We interpret this problem as a "game with the world", where one player (the investor) bets on what will happen and the other player (the market) decides what will happen. Inspired by the success of the Monte Carlo tree search (MCTS) in a variety of games and stochastic multiperiod planning problems, we introduce this algorithm as a method for replication in the presence of risk and market friction. Unlike model-free reinforcement learning methods (such as Q-learning), MCTS makes explicit use of an environment model. The role of this model is taken by a market simulator, which is frequently adopted even in the training of model-free methods, but its use allows MCTS to plan for the consequences of decisions prior to the execution of actions. We conduct experiments with the AlphaZero variant of MCTS on toy examples of simple market models and derivatives with simple payoff structures. We show that MCTS is capable of maximizing the utility of the investor's terminal wealth in a setting where no external pricing information is available and rewards are granted only as a result of contractual cashflows. In this setting, we observe that MCTS has superior performance compared with the deep Q-network algorithm and comparable performance to "deep-hedging" methods.

High Frequency Trading in Kyle-Back Model

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Keywords: Market microstructure

In traditional Kyle-Back models, the only source of information comes from the insider's signal. We consider a more realistic version of the Kyle-Back model with a private and a public signal. The insider observes both signals. The private signal, that is only directly observed by the insider, may be static, when the insider knows the value of the asset in advance, or dynamic, when it converges to the true value of the asset at the end of the trading period. The market maker receives a dynamic signal that also converges to the true value of the asset at the end of the trading period. In the dynamic case, we prove that the insider's valuation of the asset is given by a linear combination of both the public and private signals and it is a martingale the insider's filtration. Furthermore, we show that the price - which is the market maker's valuation of the asset - is also given by a linear combination of the public signal and the weighted demand. In addition, it is proven that it converges to the true price of the asset as it is expected in the traditional theory. An interesting fact that is observed is that it is possible to see an increase in the volatility of the price in the end of the trading period when trading becomes aggressive due to the convergence of both signals to the true price of the asset.

On the weak convergence of hyperplane alpha-quantile functionals and their continuity in the Skorokhod J1 topology

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Keywords: Option pricing and hedging

The alpha-quantile of a stochastic process has been introduced in (Miura, 1992) and important distributional results have been derived in (Akahori, 1995), (Dassios, 1995) and (Yor, 1995) with special attention given to the problem of pricing alpha-quantile options. We straightforwardly extend the classical monodimensional setting to Rd by introducing the hyperplane alpha-quantile and we find an explicit functional continuity set of the alpha-quantile as a functional mapping Rd-valued càdlàg functions to R. This specification allows us to use continuous mapping and assert that if a Rd-valued càdlàg stochastic process X a.s. belongs to such continuity set, then Xn converging to X weakly in the Skorokhod sense implies the convergence of the alpha-quantile weakly in the usual sense. We further the discussion by considering the conditions for convergence of a 'random time' functional of the alpha-quantile, its first hitting time, which Brownian distribution is studied e.g. in (Chaumont, 1999) and (Dassios, 2005) applied to sequences of càdlàg functions converging in the Skorokhod topology. We finally prove the fact that if the limit process of a sequence of càdlàg stochastic processes is a multidimensional Brownian motion with nontrivial covariance structure, such random time functional applied to the sequence of processes converges - jointly with the alpha-quantile - weakly in the usual sense.

Overfitting in Portfolio Optimization

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Keywords:

In this paper we measure the out-of-sample performance of sample-based rolling- window neural network (NN) portfolio optimization strategies. We show that if NN strategies are evaluated using the holdout (train–test split) technique, then high out-of-sample performance scores can commonly be achieved. Although this phenomenon is often employed to validate NN portfolio models, we demonstrate that it constitutes a "fata morgana" that arises due to a particular vulnerability of portfolio optimization to overfitting. To assess whether overfitting is present, we set up a dedicated methodology based on combinatorially symmetric cross-validation that involves performance measurement across different holdout periods and vary- ing portfolio compositions (the random-asset-stabilized combinatorially symmetric cross-validation methodology). We compare a variety of NN strategies with classi- cal extensions of the mean–variance model and the 1/N strategy. We find that it is by no means trivial to outperform the classical models. While certain NN strategies outperform the 1/N benchmark, of the almost 30 models that we evaluate explicitly, none is consistently better than the short-sale constrained minimum-variance rule in terms of the Sharpe ratio or the certainty equivalent of returns.

Stochastic Vol-of-Vol Model: Calibration and Pricing

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Keywords: Stochastic volatility and volatility modeling; Computational finance

The implied vol-of-vol as a source of risk for derivatives has recently attracted considerable interest in the quantitative finance field. The underlying assumption of volatility models is that this particular risk factor is a constant function over time. However, data suggests that this is not the case. Therefore, we propose a constant elasticity (CE) stochastic vol-of-vol model to capture these fluctuations. Such modification provides degrees of freedom in the model which enables it to replicate the market prices. The calibration of its parameters relies on regularization techniques from the inverse-problem theory. Using synthetic data, we show that the risk-neutral pricing solution under the Monte Carlo method converges to the one resulting from the transition probability density determined by the Fokker-Planck equation. Additionally, the robustness of the pricing algorithm is illustrated through S&P 500 options dataset.

Multi-period static hedging of European Options

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Keywords: Computational finance; Model risk and uncertainty; Option pricing and hedging; Robust finance; Optimal transport; Risk management; Stochastic volatility and volatility modeling

We begin our work by considering the hedging of European options when the price of the underlying asset follows a single-factor Markovian framework. By working in such a setting, [**?**] derived a spanning relation between a given option and a continuum of shorter-term options written on the same asset. In our paper, we have extended their approach to simultaneously include options over multiple short maturities. We then show a practical implementation of this for Black-Scholes and Merton Jump Diffusion models, with a finite set of shorter-term options to determine the hedging error using a Gaussian Quadrature method. As a part of our ongoing research, we further present possible extensions of this approach for robust static hedging using Optimal Transport.

Meta-labeling approuch to trade forward products from brazilian electricity market by technical analysis and spot price features

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Keywords: Algorithmic trading; Financial data science; Commodities and energy finance; Machine learning for Finance

Electricity markets can be simplified into spot and forward markets. The spot market price (M0) in Brazil is defined by a price-per-model approach, where a series of stochastic optimization mathematical models determine the operation of the National Interconnected System (SIN). The hourly pricing program, known as DESSEM, is run by the Energy Trading Chamber (CCEE) and sets the settlement of differences (PLD) index used in short-term trading contracts. The forward market aims to trade future energy, which will only be priced once the models are executed; however, agents already bilaterally negotiate its value. This study intends to evaluate the performance of a meta-labeling strategy where a primary model based on price action of financial markets will set the entries and a secondary logistic regression model will determine, based on the PLD relative to M0 and its lagged values, whether the operator should engage in the operation and how much

The Efficiency vs. Pricing Accuracy Trade-Off in GMM Estimation of Multifactor Linear Asset Pricing Models

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Keywords: Robust finance; Risk measures

Even though a multifactor linear asset pricing model can be equivalently represented in a Beta or in a stochastic discount factor (SDF) form, its inferential efficiency and pricing accuracy features may differ when estimated by the generalized method of moments (GMM), both in small and in large samples. Using a multifactor linear asset pricing model, we use bootstrapped simulations and analytical approximations to compare and test the estimated variances of the GMM estimators of parameters under the equivalent Beta. vs the SDF representations. We find that the SDF approach is likely to be less efficient but to yield more accurate pricing than the Beta method. We show that the main drivers of this trade-off are the higher-order moments of the factors that play an important role in the estimation process, and that the increased efficiency of the out-of-sample Beta risk premia estimation dominates the SDF increased pricing accuracy. the increased efficiency yielded by the Beta representation risk premia estimation in small samples translates into an increase of the out-of-sample Sharpe ratio in a trading exercise.

Benchmark region and country effects in Commercial loan loss forecasting

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Keywords: Risk measures; Computational finance; Model risk and uncertainty; Financial regulation and mechanism design; Risk management; Systemic risk; Credit risk

The estimation of future loan losses is not only important for financial institutions to effectively control the credit risk of commercial loan portfolio, but also an essential component in the capital plan submitted for regulatory approval in the annual CCAR/DFAST stress testing. Under the regulatory guidelines, The paper describes a methodology of estimating the point-in-time (PIT) default probability that can vary according to macro-economic scenarios and at same time capture the credit risk at the region and industry sector levels. The key to this modeling approach is the maximum likelihood estimation of credit index and correlation parameters calibrated to the historical default and rating migration data. The credit index in the model represents the "hidden" risk factor underlying the default while the correlation parameter can be attributed to the default clustering, and the estimation of credit index and correlation provides a compelling explanation for the original design of risk-weight function used in the calculation of credit risk capital charge in the Pillar 1 of Basel II capital rule. The methodology can be used as a benchmark model to validate the Bank's internal model, because it can be built in compliance with the bank's internal risk rating system and it can also be implemented with external data from the rating agency such as S&P and Moody's, thus making it practical for many institutions with only limited internal data of default and migration history.

Using Deep Learning Technique to Enhance the Portfolio Construction Based on PolyModel Theory

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Keywords: Machine learning for Finance; Financial data science; Risk management

When constructing portfolios, a key problem is that a lot of financial time series data are sparse, making it challenging to apply machine learning methods. Polymodel theory can solve this issue and demonstrate superiority in portfolio construction from various aspects. To implement the PolyModel theory for constructing a hedge fund portfolio, we begin by identifying an asset pool, utilizing over 10,000 hedge funds for the past 29 years' data. PolyModel theory also involves choosing a wide-ranging set of risk factors, which includes various financial indices, currencies and commodity prices. This comprehensive selection mirrors the complexities of the real-world environment. Leveraging on the PolyModel theory, we create quantitative measures such as Long-term Alpha, Long-term Ratio, and SVaR. We also use more classical measures like the Sharpe ratio or Morningstar's MRAR. To enhance the performance of the constructed portfolio, we also employ the latest deep learning techniques (iTransformer) to capture the upward trend, while efficiently controlling the downside, using all the features. The iTransformer model is specifically designed to address the challenges in high-dimensional time series forecasting and could largely improves our strategies. More precisely, our strategies achieve better Sharpe ratio and annualized return. The above process enables us to create multiple portfolio strategies aiming for high returns and low risks when compared to various benchmarks.

Yield Curve Modeling and Infinite Dimensional Stochastic Volatility Process

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Keywords: Yield curve modeling; Stochastic volatility and volatility modeling

We consider an infinite dimensional generalization of the SABR yield curve model, where both the yield curve and its volatility operator are modeled as solutions of some Hilbert space-valued stochastic differential equations. The volatility operator is modeled as a stochastic process in the space of Hilbert-Schmidt operators. We show that a mild solution exists under certain technical conditions on the volatility process with a regularization term (2nd order derivative operator) added to the usual risk-neutral drift term. With additional regularity conditions on the volatility process, we show that this mild solution is also a strong one.

To handle complex dependencies of the stochastic volatility operator process on the underlying interest rate, we propose a quite flexible model for the volatility processes which only requests that the square-norm of the interest rate dependent volatility operator process is bounded by any bounded square-norm of the underlying interest rate in the sense of expectation. And SABR model can be generalized to infinite dimension in this framework. Our proof is based on Leray-Schauder fixed point theorem and on some priori inequalities on the stochastic operator processes we construct.

We further discuss the nature of the 2nd order derivative operator added to the drift term and how it can be interpolated as an infinite dimension factor model valued in a weighted Hilbert space without producing arbitrage.

Index of Authors