SIAM 2023

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Conference on Financial Mathematics and Engineering (FM23)

June 6–9, 2023

This document was current as of June 2, 2023. Abstracts appear as submitted.

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IP1

American Student Loans

Federal student loans are fixed-rate debt contracts with three main special features: (i) borrowers can use income-driven schemes to make payments proportional to their income above subsistence; (ii) after several years of being in good standing, the remaining balance is forgiven but taxed as ordinary income; and (iii) accrued interest is simple, i.e., not capitalized. For a very small loan, the cost-minimizing repayment strategy dictates maximum payments until full repayment, forgoing both income-driven schemes and forgiveness. For a very large loan, the minimal payments allowed by income-driven schemes are optimal. For intermediate balances, the optimal repayment strategy may entail an initial period of minimum payments to exploit the noncapitalization of accrued interest, but when the principal is being reimbursed maximal payments always precede minimum payments. Income-driven schemes and simple accrued interest mostly benefit borrowers with very large balances.

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IP2

AI in Finance: Examples and Discussion

To follow.

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IP3

Sequential Statistics by Trading: E-processes and Coordinated Traders

The goal of sequential statistics is to draw inference from data that is gathered gradually through time. Sequential, or online, settings are typical in many applications both in finance and elsewhere, but naive application of standard statistical methods can produce misleading or incorrect conclusions. E-processes (‘E for ‘Evidence) form the basis of a recent approach to sequential statistics that simultaneously produces strong statistical error bounds and high statistical power. E-processes have an interesting connection with financial mathematics: they admit an equivalent description in terms of coordinated traders in a fictitious financial market, each of whom attempts to profit from the view that certain statistical (null) hypotheses are false while other (alternative) hypotheses are true. In this talk I will give an introduction to e-processes and discuss some problems where the financial perspective leads to new procedures for sequential testing.

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IP4

Unwinding Stochastic Order Flow in a Central Risk Book

We study the optimal execution problem for the Central Risk Book (CRB), a centralized trading unit recently established in many large banks and trading companies. The CRB aggregates order flows from the other business units within the organization in real time (in-flow), netting opposite orders and optimally executing outstanding positions in the market (out-flow). Thus, the in-flow orders of the CRB are a stochastic process. We introduce a tractable model for the price impact and spread cost paid by the out-flow and find the optimal execution strategy for a general class of in-flow processes. The strategy highlights how future in-flows are taken into account to determine the optimal trade-off between trading speed and transaction costs. (Joint work with Kevin Webster and Long Zhao.)

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IP5

Functional Expansions and Path Dependent Options

The classical Taylor expansion is obtained by iterating the fundamental theorem of calculus. We apply the same principle to the functional Stratonovich formula from the functional It calculus to obtain a functional Taylor expansion. It is a sum over the words of the functional derivative with respect to this word at the origin times the signature (iterated integral of the path) associated to the word. When applied to the intrinsic value of a path dependent option, it gives a simple representation that can be iterated, leading to the Intrinsic Expansion of a functional. We compare it with the Wiener chaos decomposition and establish new links. We distinguish the static expansion (around a path) from the dynamic expansion (after a path). We explore the implications of these expansions in terms of pricing and hedging of exotic options. This approach provides a fast alternative to Deep Hedging. This is a joint work with Valentin Tissot-Daguette.

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IP6

Optimal Bubble Riding in a Large Population

Recent financial bubbles such as the emergence of cryptocurrencies and “meme stocks” have attracted a large number of both retail and institutional investors. To study this phenomenon, we propose a game-theoretic model on optimal liquidation in the presence of an asset bubble. Our setup allows the influx of traders to fuel the price of the asset as they take advantage of the uptrend. However, traders face the risk of an inevitable (but unforeseen) market crash. In this talk we will argue that the above “bubble riding game gives rise to an interesting class mean field games. We will discuss solvability of the game and numerical simulations of the solution, which allow us to provide some intriguing insights on the relationship between the bubble burst and equilibrium strategies. This talk is based on a joint work with Camilo Hernnderz and Shichun Wang (Princeton University).

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IP7

Actuarial Modeling of Cyber Risk

With the rise of digital economy, cyber risk has become a major concern for all customer segments. Although the development of physical protection strategies against cyber attacks is fundamental, no protection is perfect and insurers are intended to play a crucial role in providing financial protection. The development of cyber-insurance market encounters some pitfalls, with important uncertainties on the real value of the guarantees, due to the nature of the risk itself. The emerging and evolving nature of cyber-risk and its potential systemic component make it one of the most important social and economic risks, and questions its insurability. After an introduction to the specificities on cyber-risk, this talk gives first steps towards a better understanding of cyber risk, by providing mathematical models and actuarial analysis. For a better quantification of cyber risk, we propose innovative models, both for the severity component (size of the claims) and the frequency component (accumulation risk and clustering features) of the risk.

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IP8

Green Monetary Policy

It is well documented that climate change adaptation and mitigation, including the transition to net zero emissions, require financial flows that are several times larger than what is currently observed. In this talk, I review a stock-flow consistent climate-economy model and explain the inherent instability associated with balancing the effects of economic damages caused by climate change and the financial burden incurred to prevent them. I then present a modification of the model that takes into account two different monetary policies that could be implemented by central banks in order to improve the stability of the system: green quantitative easing (that is to say, large scale purchases of financial instruments used to fund green investment) and green capital requirements (that is, measures aimed at making loans for green projects more attractive for banks to hold in their balance sheets). I illustrate the stabilization effects of these polices with examples calibrated to data and similar proposals in the literature.

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CP1

High-Frequency Risk Estimators Using Change Point Detection Methods

We introduce new high-frequency volatility estimators that account for possible breakpoints in the spot volatility process. We further extend our method to the multivariate case of estimating covariance matrix in both high-frequency and high dimensional low-frequency space using the group fused LASSO method. In the univariate case, the resulting estimators are ℓ_1-penalized versions of two classical high-frequency volatility estimators: quadratic variation and a jump-robust version of it, the bipower variation. We show that our estimators are consistent for the actual unobserved volatility. Numerically, the proposed estimators are fast in computations, and they accurately identify breakpoints close to the sample's end - both properties are desirable in the modern electronic trading environment. In terms of out-of-sample volatility prediction, qualitatively, the new estimators provide more smooth and realistic volatility forecasts; quantitatively, they outperform the aforementioned competitors and their extensions at various frequencies and forecasting horizons. In the multivariate case, the proposed estimator is used in minimum variance portfolio optimization and outperforms the benchmarks - realized covariance and multivariate heterogeneous autoregressive estimators in high-frequency and linear shrinkage and quadratic inverse shrinkage in low-frequency space.

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CP1

Adaptive Optimal Market-Making Strategies with Inventory Liquidation Costs

In this work, the general form of an optimal market-making strategy for a high-frequency market maker (HFM) under a discrete-time Limit Order Book (LOB) model is considered. An interesting feature of our model is that the optimal market-making strategy adapts to the past arrivals of market orders (MO) during previous time intervals, making the optimal placement strategy sensitive to previous market information. Furthermore, we also provide an admissible set of strategies and show that the optimal strategy belongs to such a set. Finally, we test our assumptions empirically while also we compare the optimal strategy to some deterministic benchmark strategies as well as a similar optimal strategy used computed under a non-adaptive framework where only the average information is considered.

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CP1

The Short-Term Predictability of Returns in Order

Book Markets: a Deep Learning Perspective

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.

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CP1

DeFi: Data-Driven Characterisation of Uniswap v3 Ecosystem an Ideal Crypto Law for Liquidity Pools

The Uniswap v3 ecosystem is built upon liquidity pools, where pairs of tokens are exchanged subject to a fee. We propose a systematic workflow to extract a meaningful but tractable sub-universe out of the current ¿ 6,000 pools. We filter by imposing minimum levels on individual pool features, e.g. liquidity locked and agents' activity, but also maximising the interconnection between the chosen pools to support broader dynamics. Then, we investigate liquidity consumption behaviour on the most relevant pools for Jan-June 2022. We describe each liquidity taker by a "transaction graph", which is a complete graph where nodes are transactions on pools and edges have weights from the time elapsed between pairs of transactions. Each graph is embedded into a vector by our own variant of the NLP rooted graph2vec algorithm. We investigate the structural equivalence of liquidity takers behaviour, and extract seven clusters with interpretable features. Finally, we introduce an "ideal crypto law" inspired from the ideal gas law of thermodynamics. Our model tests a relationship between variables that govern the mechanisms of each pool, i.e. liquidity provision, consumption, and price variation. If the law is satisfied, we say the pool has high "cryptoness" and argue that it constitutes a better venue for the activity of market participants. Our metric could be employed by regulators and practitioners for developing pool health monitoring tools and establishing minimum requirement levels.

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CP1

Second-Order Approximation of Limit Order Books in the Single-Scale Regime

We consider a fully state-dependent Markovian limit order book model and derive its second-order approximationin the single-scale regimeby means of a martingale problem. Unlikeinthe framework of Markovian queueing models, where the number of queues is kept constant and one obtainsamultidimensional diffusion in the limit, we let the tick size scale to zero and look at continuum approximations ofthevolume density functions. We start with the deterministic fluid limit consisting of an ODE-PDE system and study the critical case in which the rescaling rates for time, tick size and volume increments are equal. We then investigate fluctuations of the empirical distribution around the fluid limit and obtain a coupled distribution-valued SDE-SPDE approximation system, which preserves in the limit both, thespatial shift corresponding to the price fluctuations and the infinite-dimensional driver resulting from the placement/cancellation oflimit orders. We proceed by first showing moment estimates, then satisfying a tightness criterion for distribution-valued processes, characterizing the limiting system by a martingale problem andfinallyobtainingaweak solution by martingale representation. We demonstrate the applicability of our approximation on the order book data from Frankfurt Stock Exchange and indicate how it can be used to obtain confidence bounds for optimal trading problems. Based on joint work with Ulrich Horst and Drte Kreher.

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CP1

Principal-Agent Problem for Optimal Order Execution

We consider an institution ('the principal') that wishes to execute a large order in a model with price impact. The problem of how a firm with trading expertise should implement such a trade for itself is well-studied, but here we consider an institution that instead outsources the complexities of such a trade to another firm ('the agent') specializing in optimal order execution. The principal does not directly observe the trades made by the agent, only the market prices over that time period, but because of the price impact this provides a noisy signal of the agent's actions. We consider the continuous time case, and where the payment given to the agent is an affine function of the market prices. We show existence and uniqueness of the optimal affine contract for general linear price impact models, and obtain explicit solutions for it in some commonly used models, including those of Almgren and Chriss (2000), and Obizhaeva and Wang (2013).

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CP2

Deep Hedging and Portfolio Optimization in Financial Markets With a Large Trader

We study models of illiquid financial markets where a large trader can move market prices by means of her transactions. Having gained recent popularity, we focus on algorithmic strategies, a class of stochastic processes where artificial neural networks process market information to form trading decisions. We present a universal approximation theorem in the space of (nonlinear) stochastic integral processes in continuous time. A simple portfolio optimization problem highlights phenomena that arise due to the price impact of the large trader. In particular, numerical simulations show that optimal algorithmic strategies can lead to exploding or collapsing prices and completely destabilize the market.

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CP2

Robust Hedge Gans

The deep hedging framework presented in Buehler et al. (2019) has opened new horizons for solving hedging problems under a large variety of models and market conditions. At the same time, any model be it a traditional stochastic model or a modern market generator is at best an approximation of market reality, prone to model-misspecification and estimation errors. This raises the question, how to furnish this modelling setup with tools to address the risk of the discrepancy between model and market reality in an automated way to derive a more robust version of the hedging strategy. In this work, we build on the theory of rough-paths to suggest a GAN-based concept to the robustification challenge. Specifically, we revamp the original (deep) hedging setup in a way that is equipped to address uncertainty about the data generating process in a model-free manner. The approach is the interplay of three components: a hedging engine, a market generator, and a metric on the model space inspired by the Signature-MMD, a distance on path-space that is closely related to the Signature-Wasserstein distance. Our method can operate independently of the choice of data generating process and consistently extends from classical models to a model-free setting, as demonstrated in numerical experiments. Furthermore, since all individual components are already used in practice, the concept is easily adaptable for existing functional settings.

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CP2

Deep Gradient Flow Methods for Option Pricing in Diffusion Models

In this research, we consider neural network algorithms for option pricing in diffusion models. We derive the option pricing partial differential equation (PDE), which we solve with a neural network. We extend the Time Deep Nitsche Method [Georgoulis et.al., 2023], originally designed to solve problems in physics with a symmetric PDE operator, to be able to solve the option pricing PDE. 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 as a known function. We compare our method with the related Deep Galerkin Method (DGM) [Sirignano & Spiliopoulos, 2018] and with deriving the conditional characteristic function of the stock price which leads to the option price with the COS method [Fang & Oosterlee, 2009]. While the methods are comparable in the simple Black-Scholes model, our method outperforms the other two methods in the more realistic Heston model and lifted Heston model [Abi Jaber & El Euch, 2019]. Having twenty volatility processes, the curse of dimensionality makes deriving the characteristic function too slow and the DGM less accurate, while our method remains fast and accurate. It even remains accurate when adding model parameters as variables to the neural network.

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CP2

Chaotic Hedging with Iterated Integrals and Neural Networks

In this talk, we extend the Wiener-Ito chaos decomposition to the class of diffusion processes, whose drift and diffusion coefficient are of linear growth. By omitting the orthogonality in the chaos expansion, we are able to show that every p-integrable functional, for $p \in [1, \infty)$, can be represented as sum of iterated integrals of the underlying process. Using a truncated sum of this expansion and (possibly random) neural networks for the integrands, whose parameters are learned in a machine learning setting, we show that every financial derivative can be approximated arbitrarily well in the L^p-sense. Since the hedging strategy of the approximating option can be computed in closed form, we obtain an efficient algorithm that can replicate any integrable financial derivative with short runtime. This talk is based on joint work with Ariel Neufeld.

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CP2

Model Invariants and Functional Regularization

When modeling data, we would like to know that our models are extracting facts about the data itself, and not about something arbitrary, like the order of the factors used in the modeling. Formally speaking, this means we want the model to be invariant with respect to certain transformations. Here we look at different models and the nature of their invariants. We find that regression, MLE and Bayesian estimation all are invariant with respect to linear transformations, whereas regularized regressions have a far more limited set of invariants. As a result, regularized regressions produce results that are less about the data itself and more about how it is parameterized. To correct this, we propose an alternative expression of regularization which we call functional regularization. Ridge regression and lasso can be recast in terms of functional regularization, as can Bayesian estimation. But functional regularization preserves model invariance, whereas ridge and lasso do not. It is also more flexible, easier to understand, and can even be applied to non-parametric models.

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CP2

A Random Neural Network Approach to Pricing SPDEs for Rough Volatility

This paper examines the use of random weighted neural networks (RWNNs) to model the evolution of prices of European-style options in a non-Markovian framework, where the value function for a European option is not deterministic, but random and satisfies a backward stochastic partial differential equation (BSPDE). We combine classical BSDE approach with RWNNs and compare the results to existing approaches based on classical feed forward neural networks (NNs). We find that, not only did RWNNs approximate the solution just as well as NNs in terms of test error, but were in fact able to reduce the training times to mere seconds. Furthermore, simpler structure of RWNNs allows us to provide a more comprehensive analysis of the optimisation error.

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CP3

Rough Volatility: Fact Or Artefact?

We investigate the statistical evidence for the use of 'rough' fractional processes with Hurst exponent H¡ 0.5 for the modeling of volatility of financial assets, using a model-free approach. We introduce a non-parametric method for estimating the roughness of a function based on discrete sample, using the concept of normalized p-th variation along a sequence of partitions. We investigate the finite sample performance of our estimator for measuring the roughness of sample paths of stochastic processes. We then apply this method to estimate the roughness of realized volatility signals based on high-frequency observations. Detailed numerical experiments based on stochastic volatility models show that, even when the instantaneous volatility has diffusive dynamics with the same roughness as Brownian motion, the realized volatility exhibits rough behaviour corresponding to a Hurst exponent significantly smaller than 0.5. Comparison of roughness estimates for realized and instantaneous volatility in fractional volatility models with different values of Hurst exponent shows that, irrespective of the roughness of the spot volatility process, realized volatility always exhibits 'rough' behaviour with an apparent Hurst index H¡0.5. These results suggest that the origin of the roughness observed in realized volatility time-series lies in the microstructure noise rather than the volatility process itself.

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CP3

Transportation-Cost Inequalities for Rough Volatility Models

We consider a class of rough volatility models in which the volatility function is allowed to grow superlinearly and depends on a (non-Markovian) fractional Gaussian process. We prove transportation-cost inequalities for the law of the stock log-price using the regularity structure framework for rough volatility developed by Bayer, Friz, Gassiat, Martin and Stemper. Such inequalities can be viewed as a functional approach to the concentration of measure phenomenon and can be used to obtain short- and long-time estimates for the models of interest. Finally, we describe a link between these inequalities and sufficient conditions for the moments of the stock price to be finite.

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CP3

Hedging Time-Variant Model Risks: A Hidden Markov Regime-Switching Approach

Non-stationarity of the random environment is a critical yet challenging concern in decision-making under uncertainty. We illustrate the challenge from the non-stationarity and the solution framework using the portfolio selection problem, a typical decision problem in a time-varying financial market. This paper models the non-stationarity by a hidden Markov regime-switching (HMRS) ambiguity set. In particular, we incorporate the time-varying feature of the stochastic environment in the traditional Wasserstein ambiguity set to build our HMRS ambiguity set. This modeling framework has strong financial interpretations since the financial market exposes to different economic cycles, which yield different ambiguity sets under each regime. We show that the proposed optimization framework is computationally tractable. We further apply a data-driven hidden Markov model to determine the financial regimes. Extensive empirical studies are conducted to show that the proposed portfolio consistently outperforms the equally-weighted portfolio (the 1/N strategy) and other benchmarks across both time and datasets. In particular, we show that the proposed portfolio exhibits a prompt response to the regime change in the 2008 financial crisis by reallocating the wealth into appropriate asset classes, thanks to the time-varying feature of the HMRS formulation.

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CP3

Regulating Stochastic Clocks

Stochastic clocks represent a class of time change methods for incorporating trading activity into continuous-time financial models, with the ability to deal with typical asymmetrical and tail risks in financial returns. In this paper we propose a significant improvement of stochastic clocks for the same objective but without decreasing the number of trades or changing the trading intensity. Our methodology targets any Lvy subordinator, or more generally any process of nonnegative independent increments, and is based on various choices of regulating kernels motivated from repeated averaging. By way of a hyperparameter linked to the degree of regulation, arbitrarily large skewness and excess kurtosis of returns can be easily achieved. Generic-time Laplace transforms, characterizing triplets, and cumulants of the regulated clocks and subsequent mixed models are analyzed, serving purposes ranging from statistical estimation and option price calibration to simulation techniques. Under specified jump-diffusion processes and tempered stable processes, a robust moment-based estimation procedure with profile likelihood is employed for statistical estimation and a comprehensive empirical study involving SP500 and Bitcoin daily returns is conducted to demonstrate a series of desirable effects of the proposed methods.

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CP3

Heston-Hawkes Stochastic Volatility Model: Change of Measure and Forward Variance

We consider the stochastic volatility model obtained by adding a compound Hawkes process to the volatility of the well-known Heston model. A Hawkes process is a self-exciting counting process with many applications in mathematical finance, insurance, epidemiology, seismology and other fields. We prove a general result on the existence of a family of equivalent (local) martingale measures. We apply this result to a particular example where the sizes of the jumps are exponentially distributed. Finally, we also give the dynamics of the forward variance which can be used to add a tradable asset in this model.

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CP3

Stochastic Volatility Models with Jump Dynamics

Motivated by previous work on stochastic rough volatility models, we propose a novel model where the volatility is driven by two correlated Hawkes processes. Compared to the current literature, this construction has three conspicuous advantages. First, it allows us to show that this process itself instead of its integrated form will converge to rough Heston model under proper scaling. The intricate structure of the model makes the proof of C-tightness challenging, and our work fills this gap. On the other hand, such construction generalizes the volatility model to a jump dynamics setting, where the so-called jump is actually a sharp rise of volatility composed of a series of self-exciting increases. Moreover, by seeking for the exponential characteristic functional of the volatility, we show that the converge mentioned earlier is unique.

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CP4

Optimal Bailout in a Mean-Field Systemic Risk Model with Contagious Defaults

We propose a model for government bailouts of banks with mutual obligations and correlated exposures. The equity of financial institutions is represented by a system of interacting diffusions. A banks default intensity increases when its equity falls short of some threshold. Defaults wipe out a portion of the creditors equity, possibly leading to further defaults, whereby distress can spread through the whole system. To enhance stability and combat solvency contagion the government injects capital into the banking sector, but attempts to minimise its footprint. We formulate this bailout as an optimal control problem and rigorously justify a mean-field approximation in the limit with infinitely many banks. We can solve the mean-field control problem numerically using a policy gradient method to illustrate our results. We also connect our framework with the previously studied structural systemic risk model, in which hitting the threshold leads to an immediate default. We obtain this structural default mechanism as a limiting case of our model and, thereby, establish a novel existence result for the supercooled Stefan problem with general coefficients.

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CP4

Assessing and Mitigating Fire Sales Risk under

Partial Information

We consider the problem of assessing and mitigating fire sales risk under partial information. Using data from the European Banking Authority's stress tests, we consider the matrix of asset holdings of different institutions. We first analyse fire sales risk under both full and partial information using different matrix reconstruction methods. We then investigate how well some policy interventions aimed at mitigating fire sales risk perform if they are applied based on only partial information. We compare the performance of policy interventions under full and partial information. We find that even under partial information, using suitable network reconstruction methods to decide on policy interventions can significantly mitigate risk from fire sales. Furthermore, we show that some interventions based on reconstructed networks significantly outperform ad hoc methods that decide on interventions only based on the size of an institution and do not account for overlapping portfolios.

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CP4

Systemic Risk Models with Smoothed Endogenous Contagion

Structural models for default contagion typically take the approach of modelling entities via absorbing diffusions on the positive half line. Default occurs when an entity hits the origin and this causes contagion via a jump toward the origin from the other entities. In the large particle limit, this model leads to a McKeanVlasov equation with positive feedback which can have jumps in the limiting equation if the contagion is strong enough. We propose a new approach to constructing solutions to these limiting McKeanVlasov equations using an approximation via smoothed contagion. Smoothing the contagion in time removes the jumps in the system and we show that these smoothed approximations converge to the limiting McKeanVlasov problem. This provides a solution approach to problems of this type which allows more easily for general drift and diffusion coefficients. We also show a rate of convergence up to the first jump time under some regularity conditions on the contagion.

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CP4

Pricing and Hedging of SOFR Derivatives under Differential Funding Costs and Collateralization

Since the 1970s, the LIBOR has served as a fundamental measure for floating term rates across multiple currencies and maturities. Loans and many derivative securities, including swaps, caps and swaptions, still rely on LIBOR as the reference forward-looking term rate. However, in 2017 the Financial Conduct Authority announced the discontinuation of LIBOR from the end of 2021 and the New York Fed declared the backward-looking SOFR as a candidate for a new reference rate for interest rate swaps denominated in U.S. dollars. We first outline the classical single-curve modelling framework before transitioning to the multi-curve framework where we examine arbitrage-free pricing and hedging of SOFR-linked swaps without and with collateral backing. As hedging instruments, we take liquidly traded SOFR futures and either common or idiosyncratic funding rates for the hedge and margin account. For concreteness, a one-factor model based on Vasicek's equation is used to specify the joint dynamics of several overnight interest rates, including the SOFR, EFFR, and unsecured funding rate, although multi-factor term structure models could also be employed.

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CP4

Learning the Implied Contagion Risk with Network Approach

The interdependency of different institutions gives rise to the risk of contagion, making the system susceptible to failure. To assess these connections, many studies have used network approach. In this paper, we propose a simple yet effective method to build the networks to show the linear causal connections of different firms. The suggested state-space model can consider both systematic and idiosyncratic connections and because of this set-up, we can perform factor sensitivity analysis. In order to evaluate the contagion risk, we introduce an absolute centrality measure leveraging the Leontief inverse notion, which enables us to easily interpret and compare the system's contagion risk in different scenarios throughout time. We present two case studies based on this framework; one using simulation to assess the validity of the network construction approach and the centrality measure and the other using Credit Default Swap spread data as a real financial case. We observe that during distressed years, the Leontief measure exhibits larger values, mirroring the contagion risk within the system.

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CP4

Post-Trade Netting and Contagion

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.

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CP5

Cost-Efficient Payoffs under Model Ambiguity

A payoff that is the cheapest possible in reaching a given target distribution is called cost-efficient. In the presence of ambiguity the distribution of a payoff is no longer known. A payoff is called robust cost-efficient if its worst-case distribution stochastically dominates a target distribution and is the cheapest possible in doing so. We study the link between this notion of "robust cost-efficiency' and the maxmin expected utility setting of Gilboa and Schmeidler, as well as more generally with robust preferences in a possibly non-expected utility setting. We illustrate our study with examples involving uncertainty both on the drift and on the volatility of the risky asset.

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CP5

A Model-Free Approach to Continuous-Time Finance

We present a non-probabilistic, pathwise approach to continuous-time finance based on causal functional calculus. We introduce a definition of self-financing, free from any integration concept and show that the value of a self-financing portfolio is a pathwise integral (every self-financing strategy is a gradient) and that generic domain of functional calculus is inherently arbitrage-free. We then consider the problem of hedging a path-dependent payoff across a generic set of scenarios. We apply the transition principle of Isaacs in differential games and obtain a verification theorem for the optimal solution, which is characterised by a fully non-linear path-dependent equation. For the Asian option, we obtain explicit solution.

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CP5

Model Free Bounds for Multi-Asset Options under Market Information

In this work, we aim to compute model-free bounds or super-/sub- hedging prices for multi-asset options over a Frechet class which is equipped with partial knowledge of the market trends. More specifically we assume that the prices of certain multi-asset options are known in the market so we can embody them to the pricing problem. Firstly we show that the existence of a probability measure which satisfies the properties of known marginals and carries the additional information is equivalent to the absence of arbitrage in the market. Therefore the pricing problem of the multi-asset option can be approached as a result of the optimal transport duality and we can also give a characterisation of the optimal measure. The resulting optimization problem can then be solved by machine-learning methods, in the spirit of Eckstein Kupper (AMO, 2021).

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CP5

Equilibrium Transport with Time-Inconsistent Costs: An Application to Matching Problems in the Job Market

Given two probability measures on sequential data, we investigate the transport problem with time-inconsistent preferences under a discrete-time setting. Motivating examples are nonlinear objectives, state-dependent costs, and regularized optimal transport with general f-divergence. Under the bi-causal constraint, we introduce the concept of equilibrium transport and provide a characterization. We apply our framework to study inertia of two job markets, top-ranking executives and academia. The empirical analysis shows that a job market with stronger inertia is less efficient. The University of California (UC) postdoc job market has the strongest inertia even than that of executives, while there is no evidence of inertia in the UC faculty job market.

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CP5

Model-Free Bounds for Multi-Asset Options Using Option-Implied Information and Their Exact Computation

We consider derivatives written on multiple underlyings in a one-period financial market, and we are interested in the computation of model-free upper and lower bounds for their arbitrage-free prices. We work in a completely realistic setting, in that we only assume the knowledge of traded prices for other single- and multi-asset derivatives and even allow for the presence of bidask spread in these prices. We provide a fundamental theorem of asset pricing for this market model, as well as a superhedging duality result, that allows to transform the abstract maximization problem over probability measures into a more tractable minimization problem over vectors, subject to certain constraints. Then, we recast this problem into a linear semi-infinite optimization problem and provide two algorithms for its solution. These algorithms are efficient and allow the computation of bounds in high-dimensional scenarios (e.g., when d = 60). Moreover, these algorithms can be used to detect arbitrage opportunities and identify the corresponding arbitrage strategies. Numerical experiments using both synthetic and real market data showcase the efficiency of these algorithms, and they also allow understanding of the reduction of model risk by including additional information in the form of known derivative prices. This is joint work with Ariel Neufeld and Qikun Xiang, forthcoming in Management Science.

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CP6

Learning to Collude: A Partial Folk Theorem for Smooth Fictitious Play

To follow.

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CP6

Stability and Geometric Approximations of Nonlinear Filters

Nonlinear filtering consists in finding the best estimate for the true value of a system when only incomplete, noisy observations are available. Since the filtering equations are often very high dimensional, and not tractable from a practical perspective, many applications must rely on approximation methods. Understanding the error of several such approximations remains an open problem. In this poster we will focus on the case where the underlying process is a continuous-time finite-state Markov chain. Leveraging tools from information geometry, we will show how to obtain a contraction result for the filtering equations, strengthening now-classical results on the stability of filters. This allows us to characterize the error of approximate filters, and to construct a low-dimensional geometric approximation with a well-behaved, hopefully small, error.

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CP6

Computing the Set of All Nash Equilibria for Convex Nash Games

It was shown in [Feinstein, Rudloff:Characterizing and Computing the Set of Nash Equilibria via Vector Optimization] that the set of all possible Nash equilibria for an N-player noncooperative Nash game equals the intersection of the set of Pareto optimal elements of finitely many vector optimization problems. This result does hold for general Nash games. However when it comes to practical computations it might not be possible to derive the exact set of all Nash equilibria via vector optimization methods. The concept of approximate Nash equilibria is introduced for Nash games with convex cost functions and convex constraints Within this setting we present an algorithm using methods from convex vector optimization that computes a set where each element is an ϵ-approximate Nash equilibrium for some $\epsilon > 0$ while the set of true Nash equilibria remains a subset of the computed set for Nash games.

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CP6

N-Agent and Mean Field Games for Optimal Investment with HARA Utility Function and the Presence of Risk-Seeking Agents

This study aims to extend the work of Lacker and Zariphopoulou (2019) by considering the financial market where both risk averse and risk-seeking agents coexist instead of just only risk averse agents. Specifically, the N-agent and mean field games for optimal investment with the family of the hyperbolic absolute risk aversion (HARA) utility function under relative performance concern and motivation are studied. Several specific forms of the HARA family including exponential, power, and logarithmic form are investigated. With these specific forms, the results show that there exists a unique constant Nash equilibrium and a unique constant mean field equilibrium for both the N-agent and mean field games. Furthermore, the qualitative effects of the personal and market coefficients on the optimal investment strategy are discussed.

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CP7

Multilevel Function Approximator

We consider function approximations for which the synthetic training set is generated by means of expensive numerical methods and is, thus, the dominant part of the computational cost. We show that multilevel ideas can reduce the computational cost by generating most samples with low accuracy at a corresponding low cost, with relatively few high-accuracy samples at a high cost. As an application of the multilevel approach, we consider learning the function that maps the parameters of the model and of the financial product to the price of the financial product. In the simple case of one-layer neural networks and second-order accurate finite difference methods, the computational cost to achieve accuracy $\mathcal{O}(\varepsilon)$ is reduced from $\mathcal{O}(\varepsilon^{-4-d_X/2})$ to $\mathcal{O}(\varepsilon^{-4})$, where d_X is the dimension of the underlying pricing PDE. The analysis is supported by numerical results showing significant computational savings.

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CP7

Model Calibration with Optimal Transport

We calibrate a local volatility model with correlated stochastic interest rate using the framework of semimartingale optimal transport. We use Markovian projection to obtain a PDE formulation of the problem which is equivalent to the dynamical formulation of optimal transport. We are then able to use techniques in optimal transport to derive a dual formulation involving an HJB equation which we can numerically solve. We focus on two cases: (1) The stochastic interest rate dynamics are known and perfectly match the observed term structure in the market, however the asset local volatility and correlation are not known and must be calibrated to European options on the asset; (2) The dynamics of both the stochastic interest rate and the underlying asset are unknown, and we must jointly calibrate both state variables to European options on the interest rate and the asset.

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CP7

Wavelet Based Approximation Scheme for Solving Distributed Order Fractional Nonlinear Differential Equations

In this work, we solved nonlinear distributed-order fractional differential equations with the help of a wavelet approximation scheme. First, we construct wavelet-based operational matrices of distributed order fractional derivatives, integer order derivatives, and product operational matrices. After the construction of the operational matrices apply the standard tau method and convert the original problem into a system of nonlinear algebraic equations and solve the equations for finding the approximate solutions. For method validation, we have provided some test examples, convergence analysis, error estimation, and verify with the existing scheme.

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CP7

An Approximate Solution of Nonlinear Fractional Integral Equations of Abel Type via Orthogonal Polynomials

This paper provides a general framework for obtaining the approximate solution of nonlinear fractional integral equations of Abel type. This approach uses shifted Legendre Polynomials (SLPs) and Lagrangian interpolating polynomials (LIPs) as basis functions. Operational matrices of SLPs and LIPs are first constructed and then utilized to convert the original problem into a system of algebraic nonlinear equations. We have investigated the convergence and stability analysis of the presented schemes under some mild conditions. The inclusion of several test functions confirms the effectiveness of the method.

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CP7

Numerical Smoothing and Hierarchical Approximations for Efficient Option Pricing

When approximating the expectation of a functional of a stochastic process, in particular for option pricing, the performance of numerical integration methods based on deterministic quadrature, quasi-Monte Carlo (QMC), or multilevel Monte Carlo (MLMC) techniques may critically depend on the regularity of the integrand. To overcome this issue, we introduce our novel numerical smoothing approach in which we combine root-finding methods with one-dimensional integration with respect to a single well-selected variable, focusing on cases where the discretization of the asset price dynamics is necessary. We prove that, under appropriate conditions, the resulting function of the remaining variables is highly smooth, affording the improved efficiency of adaptive sparse grid quadrature (ASGQ) and QMC methods, particularly when combined with hierarchical transformations (i.e., Brownian bridge and Richardson extrapolation on the weak error). Our analysis demonstrates the advantages of combining numerical smoothing with ASGQ and QMC methods over ASGQ and QMC methods without smoothing, and the Monte Carlo approach. Moreover, we show that our numerical smoothing improves the robustness and complexity of the MLMC method. In particular, we recover the near-optimal MLMC complexities. Our approach is generic and can be applied

to compute financial Greeks and estimate risk quantities.

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CP7

Projection of Functionals and Fast Pricing of Exotic Options

We investigate the approximation of path functionals. In particular, we advocate the use of the Karhunen-Love expansion, the continuous analogue of Principal Component Analysis, to extract relevant information from the image of a functional. Having accurate estimate of functionals is of paramount importance in the context of exotic derivatives pricing, as presented in the practical applications. Specifically, we show how a simulation-based procedure, which we call the Karhunen-Love Monte Carlo (KLMC) algorithm, allows fast and efficient computation of the price of path-dependent options. We also explore the path signature as an alternative tool to project both paths and functionals.

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CP8

Utility Maximization and Optimal Stopping

A risk-averse investor hires a fund manager to manage his funds. The fund manager invests the wealth in a portfolio comprising of a risky asset and a money market account. The first problem addressed here is to find a stopping rule for the fund manager which maximizes the expected utility of the investor. Second, we consider a more realistic case where the investor has the right to terminate the contract with the fund manager at any time the portfolio underperforms relative to a benchmark. The investor and the fund manager initially agree to use a hazard-rate type model to measure the underperformance and to formulate a termination policy. This approach is closely related to reduced-form modeling in credit risk theory. We show that, the fund manager's optimal selling time is determined by a threshold for the wealth process. Moreover, higher hazard-rate densities lead to larger optimal selling times. We generalize our model to allow the manager to choose the portfolio process from a set of admissible strategies and obtain an optimal portfolio process. Numerical methods are utilized to study the relationship between the optimal decision threshold and the relevant policy variables.

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CP8

Optimal Stopping under Hawkes Optional Stopping Times (Host)

Motivated by asset-liquidity spirals, we analyze optimal stopping problems in which opportunities to exercise an option are stochastically constrained and the options underlying asset price and the occurrence of exercise opportunities are interrelated. We introduce a model with Hawkes optional stopping times (HOST) designed to allow for a variety of feedback effects between the asset price process and the process that generates the exercise opportunities. We derive some analytic properties of the corresponding value function and optimal stopping times. We study a discrete-time approximation of the optimal stopping problem, propose a modification of the Least-Squares Monte-Carlo algorithm by Longstaff and Schwartz to numerically compute option prices, and provide an error analysis. We show how to decompose the liquidity premia on these options into two components stemming from average liquidity restrictions and from the extent of stochastic variation in liquidity restrictions. References Hobson, D. G. (2021): The Shape of the value function under Poisson optimal stopping, Stochastic Processes and their Applications, 133, 229246. Zanger, D. Z. (2013): Quantitative error estimates for a least-squares Monte Carlo algorithm for American option pricing, Finance and Stochastics, 17, 503534.

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CP8

On the Optimal Impulse Control of Stochastic Portfolio in Finite-Time Horizon

We consider stochastic portfolio optimization problem in finite-time horizon with general utility function and general term transaction costs. We adopt an optimal impulse control theory approach to propose a new portfolio value process, and to characterize an optimal investment strategy maximizing the finite-time horizon expected discounted utility of the investors wealth. Indeed, we derive the dynamic programming equation (DPE) associated to the impulse control problem, then we show that the value function of the stochastic portfolio is the unique viscosity solution to the given equation. Therefore, by proving a verification theorem, we obtain an optimal investment strategy. Further, some numerical experiments are presented. The considered portfolio optimization problem turns to a stochastic impulse control problem with general in term of the form and cost of impulse, a problem that enjoys a wide range of applications in various fields.

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CP8

Differentiability of Solutions to Path-Dependent Stochastic Differential Equations and Its Applica-

tions to Option Pricing Theory

We investigate the differentiability of solutions to path-dependent stochastic differential equations (SDEs). Given an SDE with path-dependent coefficients having Fréchet derivatives, we prove the differentiability of the SDE solution with respect to the initial path. As applications, PDE representations and sensitivities of option prices are studied. Under pathdependent stock models, an option price is differentiable with respect to time and the path, and is given as a solution to the path-dependent PDE. In addition, we provide formulas for Greeks with path-dependent coefficient perturbations. A stock model having coefficients with time integration forms of paths is covered as an example.

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CP8

Non-Zero-Sum Optimal Stopping Game with Continuous Versus Periodic Observations

We introduce a new non-zero-sum game of optimal stopping with asymmetric exercise opportunities. Given a stochastic process modelling the value of an asset, one player observes and can act on the process continuously, while the other player can act on it only periodically at independent Poisson arrival times. The first one to stop receives a reward, different for each player, while the other one gets nothing. We study how each player balances the maximisation of gains against the maximisation of the likelihood of stopping before the opponent. In such a setup, driven by a Lvy process with positive jumps, we not only prove the existence, but also explicitly construct a Nash equilibrium with values of the game written in terms of the scale function. Numerical illustrations with put-option payoffs are also provided to study the behaviour of the players' strategies as well as the quantification of the value of available exercise opportunities.

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CP9

A Remark on Time-Fractional One-Factor Commodity Pricing Model and Its Solutions Using Banach Contraction Principle

Fractional models provide a novel area for exploration into financial systems, including portfolio management, derivative pricing, commodity pricing, and many other applications. In the context of finance and option pricing, the term "one-factor model" refers to the idea that there is only one Wiener process, or source of randomness, in the formulation of the short-rate process. The one-factor model, which helps predict the future existence of all interest rates in finance and economics, uses the spot price, which exhibits a mean-reverting tendency, as a single stochastic factor. Here, a time-fractional one-factor commodity pricing model is considered for an approximate-analytical solution using the Banach Contraction Principle and a coupled (blended) transform method. Some noteworthy remarks are made in comparison to the solutions of the model in its classical integer form. Consequently, they are suggested for additional financial models, including multi-factor and non-linear models.

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CP9

Fake Poisson Processes: Inverting the Markovian Projection for Processes with Jumps

A local stochastic intensity (LSI) model is a counting process whose jump intensity depends on the current value of the process as well as an exogenous stochastic factor. We study the problem of constructing LSI models whose one-dimensional marginals mimic those of a Poisson process, or equivalently, whose Markovian projection is a Poisson process. We refer to these as fake Poisson processes. We prove that fake Poisson processes can be constructed under minimal assumptions on the exogenous stochastic factor, allowing us to invert the Markovian projection. Our work can be used to construct calibrated LSI models for credit risk applications. Such models are jump process analogues of the notoriously hard to construct local stochastic volatility (LSV) models used in equity modeling.

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CP9

The Ito-Taylor Expansion Of Multivariate Jump-Diffusion Models With Time-Varying Jump Tails And Intensity

Adequate empirical evidence (e.g. Bollerslev and Todorov (2011, 2014)) point out that both the jump tails and intensities in asset returns are time varying. However, time inhomogeneous multivariate jump diffusion models are often intractable because the transition probabilities of such models are not explicitly known except for a handful of trivial examples. In this paper, we propose an innovative Ito-Taylor expansion based approach to deriving approximations to the density of a multivariate jump diffusion process with state-dependent time-varying drift, volatility, jump intensity, and jump magnitude. Our approach yields an explicit recursive relation among the expansion coefficients by which we can efficiently compute the approximation. Moreover, we manage to establish the convergence of the expansions to the true probability density under some regularity conditions. Numerical experiments demonstrate the accuracy and efficiency of the proposed approach under a wide spectrum of models with important financial applications.

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CP9

A Splitting Deep Ritz Method for Option Pricing in Lvy Models

Solving high-dimensional differential equations is still a challenging field for researchers. In recent years, many works have been presented that provide approximation by training neural networks using loss functions based on the differential operator of the equation at hand, as well as its initial/terminal and boundary conditions. In this work, we use a machine learning approach for pricing European (basket) options written with respect to a set of correlated underlyings whose dynamics undertake random jumps. We approximate the solution of the corresponding partial integrodifferential equation using a variant of the deep Ritz method that splits the differential operator into symmetric and asymmetric parts. The method is driven by a modified version of the neural network introduced in the deep Galerkin method. The structure of the proposed neural network ensures the asymptotic behaviour of the solution for large values of the underlyings. Moreover, it leads the outputs of the network to be consistent with the prior known qualitative properties of the solution. We test the robustness of the methods by considering cases of Lvy measures with finite (Merton model) and infinite (CGMY model) activity. Finally, a comparison of the results with the correspondings using the deep Galerkin method is presented.

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CP10

Convergence of Policy Gradient Methods for Finite-Horizon Stochastic Linear-Quadratic Control Problems

We study the global linear convergence of policy gradient (PG) methods for finite-horizon exploratory linear-quadratic control (LQC) problems. The setting includes stochastic LQC problems with indefinite costs and allows additional entropy regularisers in the objective. We consider a continuous-time Gaussian policy whose mean is linear in the state variable and whose covariance is state-independent. Contrary to discrete-time problems, the cost is noncoercive in the policy and not all descent directions lead to bounded iterates. We propose geometry-aware gradient descents for the mean and covariance of the policy using the Fisher geometry and the Bures-Wasserstein geometry, respectively. The policy iterates are shown to satisfy an a-priori bound, and converge globally to the optimal policy with a linear rate. We further propose a novel PG method with discrete-time policies. The algorithm leverages the continuous-time analysis, and achieves a robust linear convergence across different action frequencies. A numerical experiment confirms the convergence and robustness of the proposed algorithm.

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CP10

A Deep Solver for BSDEs with Jumps

The aim of this work is to propose an extension of the Deep BSDE solver by Han, E, Jentzen (2017) to the case of FBSDEs with jumps. As in the aforementioned solver, starting from a discretized version of the BSDE and parametrizing the (high dimensional) control processes by means of a family of ANNs, the BSDE is viewed as model-based reinforcement learning problem and the ANN parameters are fitted so as to minimize a prescribed loss function. We take into account both finite and infinite jump activity by introducing, in the latter case, an approximation with finitely many jumps of the forward process.

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CP10

An Approximation Scheme for Path-Dependent BSDEs

In this work, we study an approximation scheme for solutions to forward-backward stochastic differential equations (FBSDEs) with non-anticipative coefficients. When the non-anticipative coefficients have Fréchet derivatives or can be approximated by non-anticipative functionals having Fréchet derivatives, we show that the Picard-type iteration converges to the FBDSE solution and provide its convergence rate. Using this result, we establish a numerical method for solutions of second-order parabolic path-dependent partial differential equations. To achieve this, weak approximation of martingale representation theorem (Cont, Rama, and Yi Lu. “Weak approximation of martingale representations.” Stochastic Processes and their Applications 2016) is employed. Our results generalize the scheme for Markovian cases in (Bender, Christian, and Robert Denk. “A forward scheme for backward SDEs.” Stochastic processes and their applications, 2007)

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CP10

Random Terminal Time FBSPDEs with Applications to Perpetual Swap Pricing

This paper studies decoupled forward-backward stochastic differential equations (FBSDEs) with random terminal-time and evaluates risk-neutral perpetual swap prices as an application. The SDE coefficients in the FBSDE are uniformly Lipschitz continuous and the driver f satisfies the condition: there are positive constants k and C such that $(y - y')(f(t, x, y, z) - f(t, x, y', z) \leq -k\|y - y'\|^2$ for all $y, y' \geq C\|x\|$. Under these circumstances, we prove that there exists a solution to the decoupled FBSDE. Additionally under the uniform integrability condition on the SDE solution or some monotone decreasing condition on the driver, the solution is unique. To achieve this, finite-time BSDE theories are employed with the comparison principle and optional stopping theorem. As an application, we express risk-neutral prices of perpetual swaps traded in cryptocurrency markets as solutions to infinite-time BSDEs.

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CP10

Asymptotic Analysis and Efficient Numerical Solution of the Fokker-Planck Equations (with Application to Derivatives Pricing)

The Fokker-Planck Equations (FPEs) are ubiquitous in numerous disciplines, not least in financial mathematics, where a popular technique for the pricing of derivatives is enabled through the derivation of the density function via the FPE governing its evolution. Accuracy and efficiency are both key in the world of derivatives pricing, but satisfying both is a challenge due to the delicate mathematical structure often encountered. Generalised stochastic differential equations often lead to singular regions; common examples are OrnsteinUhlenbeck (OU) processes where the elasticity of variance parameter(s) induce(s) a degenerate region at the origin. For example, this can occur in problems involving fractional values of these elasticity parameters. Here, the solution structure can be quite intricate and standard computational methods fail as they violate the necessary 'particle-conserving' condition. We consider in some detail the FPEs arising from generalized OU processes, involving both one and two stochastic variables. We present rigorous asymptotic analyses to shed light on the aforementioned intricate/singular mathematical structures which render standard numerical techniques unfeasible. By incorporating these structures into our numerical schemes, together with ensuring that the particle-conservation condition is fully satisfied, we obtain robust numerical solutions (as confirmed by extensive numerical-scheme experimentation) with modest computational facilities.

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CP10

A BSDE Approach to the Large-Time Optimal Expected Utility in Incomplete Markets

In this study, we are interested in the long-term expected utility of optimal portfolios for an investor. Under an incomplete market given by a factor model on the Euclidean state space, we consider the utility maximization problem with long-time horizon. Using the duality method and the control theory, this problem can be solved by analyzing the long-time behavior of solutions to semi-linear parabolic PDEs with quadratic term in gradients. Under certain conditions on the market price of risk, we conclude that the parabolic PDE induces an eigenpair which characterizes the long-term expected utility of optimal portfolios. To achieve this, we apply BSDE techniques and PDE theories to an approximated PDE and show that solutions of the approximated PDE converge to the eigenpair. This is a joint work in progress with Hyungbin Park and Stephan Sturm.

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CP11

Stock Market Simulator using Hidden Markov Model and Wasserstein Generative Adversarial Network with Gradient Penalty

Financial time-series modelling is a challenging task, as the data is known to exhibit complex and time-dependent statistical properties. A model-based approach is limited as only a subset of those properties can be captured by design. We propose a novel data-driven approach that simulates financial data using hidden Markov model (HMM) and Wasserstein generative adversarial network with gradient penalty (WGAN-GP). Heuristically, our framework characterizes the invisible hand in financial markets as painters, and different market regimes as different painting styles. Each market painter has a distinct painting style. We first train a HMM to identify the market painters for historical data using a set of exogenous features, while the painting style for each painter is then learned via WGAN-GP. Upon identification and learning, the market painter for the following day is predicted using the trained HMM and the consequent financial data (i.e. painting) is then simulated using the predicted market painter's trained WGAN-GP model. Unlike other prediction and simulation models, our framework strives to simulate multivariate financial data that fulfils well known empirical statistical properties. Furthermore, we observe superior risk measurement of our data-driven approach, over a model-based approach, when applied to value-at-risk calculations for stock-only portfolios.

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CP11

Equilibrium Control under Cumulative Prospect Theory via Reinforcement Learning

Cumulative prospect theory (CPT) optimization [Tversky Kahneman, 1992] extends the well-known expected utility maximization, by distorting probabilities and incorporating S-shaped utility functions, to better capture human decisions or preferences. In this work, we investigate CPT optimization from the lens of reinforcement learning (RL). Firstly, noting that CPT can be rewritten as a function of quantiles, we review selected distributional RL techniques, that deal with the prediction of quantile functions and range from tabular to deep function approximation (e.g., [Dabney et al., 2018a; Dabney et al., 2018b]), and highlight both their applicability and limitations for CPT Q-function prediction. Secondly, noting the time inconsistency [He Zhou, 2022] introduced by probability distortions, we show that these RL algorithms aim to learn the subgame-perfect equilibrium (SPE) policy class [Lesmana Pun, 2021]. Drawing on these two perspectives, we propose a novel RL algorithm that is able to learn a (deep, approximate) SPE policy under CPT. We empirically test the performance of our algorithm on several benchmark environments such as casino gambling [Barberis, 2012] and behavioral portfolio selection [Shi et al., 2015].

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CP11

Duality Based Reinforcement Learning and Its Regret Bounds

We propose a novel duality based reinforcement learning algorithm for episodic Markov decision processes. It extends the framework of the information-relaxation duality on stochastic control proposed in Davis (1989, 1991), Davis and Zervos (1995), Rogers (2007), Brown et al. (2010) to model free setups. Combined with the technique of experience replay, our algorithm can effectively learn the optimal penalty and thereby the confidence intervals of the stochastic control problem without requiring the model knowledge as a priori. We can show the regret bound of our algorithm is at most $O\left(SAH^2 + AL\sqrt{H^4ST}\right)$, where H is the time horizon of the problem, S the number of states, A the number of actions, T the total amount of the data used for training, and L = ln(SAT). Note that this regret bound is near optimal in terms of the order of T, as it matches the information theoretic lower bound of $\Omega\left(\sqrt{H^2SAT}\right)$ established in Jin et al. (2018) up to a logarithmic factor. Our analysis highlights the crucial role of the martingale-difference structure in the duality presentation in improving the regret bounds of some other well-known UCB based algorithms, such as Jin et al. (2018) and Menard et al. (2021). Moreover, we present some numerical experiments, including maze solving, American option, and option hedging in the stochastic volatility environment, to illustrate the efficiency of the algorithm.

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CP11

Reinforcement Learning for Mean Field Control Games

We present a new combined mean field control game (MFCG) problem which can be interpreted as a competitive game between collaborating groups and its solution as a Nash equilibrium between the groups. Within each group the players coordinate their strategies. A three-timescale reinforcement learning algorithm is designed to approximate the solution of such MFCG problems. We apply the MFCG framework to the classical trader's optimal liquidation problem and the bankers liquidity problem, and test the algorithm on benchmark linear-quadratic specifications for which we have analytic solutions.

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CP11

A Machine Learning Approach to Support Decision in Insider Trading Detection

Identifying market abuse activity from data on investors' trading activity is very challenging both for the data volume and for the low signal to noise ratio. Here we propose two complementary unsupervised machine learning methods to support market surveillance aimed at identifying potential insider trading activities. The first one uses clustering to identify, in the vicinity of a price sensitive event such as a takeover bid, discontinuities in the trading activity of an investor with respect to his/her own past trading history and on the present trading activity of his/her peers. The second unsupervised approach aims at identifying (small) groups of investors that act coherently around price sensitive events, pointing to potential insider rings, i.e. a group of synchronised traders displaying strong directional trading in rewarding position in a period before the price sensitive event. As a case study, we apply our methods to investor resolved data of Italian stocks around takeover bids.

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CP11

Tailgan: Nonparametric Scenario Generation for Tail Risk Estimation

The estimation of loss distributions for dynamic portfolios requires the simulation of scenarios representing realistic joint dynamics of their components, with particular importance devoted to the simulation of tail risk scenarios. Commonly used parametric models have been successful in applications involving a small number of assets, but may not be scalable to large or heterogeneous portfolios involving multiple asset classes. We propose a novel data-driven approach for the simulation of realistic multi-asset scenarios with a particular focus on the accurate estimation of tail risk for a given class of static and dynamic portfolios selected by the user. By exploiting the joint elicitability property of Value-at-Risk (VaR) and Expected Shortfall (ES), we design a Generative Adversarial Network (GAN) architecture capable of learning to simulate price scenarios that preserve tail risk features for these benchmark trading strategies, leading to consistent estimators for their Value-at-Risk and Expected Shortfall. We demonstrate the accuracy and scalability of our method via extensive simulation experiments using synthetic and market data. Our results show that, in contrast to other data-driven scenario generators, our proposed scenario simulation method correctly captures tail risk for both static and dynamic portfolios.

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CP12

Graphon Mean-Field Backward Stochastic Differential Equations with Jumps and Associated Dynamic Risk Measures

We study graphon mean-field backward stochastic differential equations (BSDEs) with jumps and associated dynamic risk measures. The graphon mean-field BSDE with jumps has the following form:

$$X_u(t) = \xi_u + \int_t^T \int_I \int_{\mathbb{R}} G(u,y) f(s, x, X_u(s), Z_u(s), \ell_{u,s}(\cdot)) \mu_{y,s}(dx) dy ds - \int$$
$$- \int_t^T \int_E \ell_{u,s}(e) \widetilde{N}_u(ds, de), \quad u \in I, \quad \text{for} \quad t \in [0,T],$$

where $\mu_y := \mathcal{L}(X_y)$ and $\mu_{y,s} := \mathcal{L}(X_y(s))$. $\{W_u : u \in I\}$ is a family of i.i.d. Brownian motions, $\{N_u(dt, de) : u \in I\}$ is a family of independent Poisson measures with $\{\widetilde{N}_u(dt, de) : u \in I\}$ be their compensator processes. We establish the existence, uniqueness and measurability of solutions under some regularity assumptions and provide some estimates for the solutions. We study the stability and continuity of the graphon BSDE system, and obtain the convergence of an interacting mean-field particle system with inhomogeneous interactions to the graphon mean-field BSDE. We then provide some comparison theorems for the graphon mean-field BSDEs. As an application, we introduce the graphon dynamic risk measure induced by the solution of a graphon mean-field BSDE system and study its properties. We finally provide a dual representation theorem for the graphon dynamic risk measure in the convex case.

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CP12

Major-Minor Lqg Risk-Sensitive Mean Field Games and Applications in Interbank Markets

We present linear-quadratic risk-sensitive mean-field games where there exists one major agent as well as many minor agents. The major agent has a significant impact on each minor agent and its impact does not collapse with the increase in the number of minor agents. We characterize an ϵ-Nash equilibrium for such games. Then as an application, we model the interbank borrowing and lending between a large bank and many small minor banks where banks are sensitive to risk and control their borrowing/lending rate to the central bank to maintain a certain level of log-reserve. Subsequently, we discuss the impact of the large bank and risk sensitivity on the individual banks default probability and systemic risk.

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CP12

An SPDE with Robin-Type Boundary for a System of Elastically Killed Diffusions on the Positive Half-Line

We consider a particle system on the positive half-line to model a large basket of defaultable entities such as large credit portfolios or the banking system. Individual particles in the system represent the financial health of an entity. Each particle follows a diffusion process driven by an idiosyncratic Brownian motion and a common Brownian motion that represents the impact of a market factor. We consider the case of delayed defaults where default is not immediately triggered when a particle hits the boundary. This allows for restructuring of debt and the possibility of multiple missed payments. This is reflected in the model through an elastic boundary at zero where a particle is not immediately removed after hitting the boundary but only after its local time at the boundary exceeds an exponential random variable. We represent the particle system by its empirical measure process and show weak convergence of this process in a suitable topology to the unique solution of a stochastic partial differential equation. This allows us to approximate the system using a single equation.

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CP12

Dynamic Distribution-Optimal Portfolio in Infinite Horizon Using McKean Vlasov FBSDEs and Deep Learning

We consider an optimal portfolio allocation and benchmark portfolio out-performance problem as a mean-field stochastic control problem in a time-inhomogeneous infinite horizon setting. The mean-field contribution is modeled after the user-specified risk appetite, designed in a way that it is Lions differentiable and convex in the measure space. The portfolio consists of stocks modeled as geometric Brownian motion with historically-fitted drift and volatility and the control is the trading speed for these assets, contrary to the conventional setting where the number of each asset is controlled. This allows us to penalize higher trading speeds, thus reducing market impact. The mean-field stochastic control problem is shown to be equivalent to solving a coupled McKean Vlasov forward-backward stochastic differential equation (MKV FBSDE). Owing to the recent developments in the use of deep learning methods for solving BSDEs, we develop a deep neural network model for solving the MKV FBSDE.

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CP12

Mean-Field Limits of Rank Jacobi Model

The rank Jacobi model was recently introduced in the context of Stochastic Portfolio Theory as a model for the market weights of a large number d of stocks. In this work we study the large-d asymptotic behavior of the rank Jacobi model under mean-field scaling. Under suitable assumptions on the initial distributions and coefficients of the d-particle systems, we prove that the empirical distributions converge along subsequences to a limit which concentrates on the solutions of an evolution equation associated with a certain square-root process of McKean-Vlasov type. Our results complement the existing literature on the mean-field behavior of Atlas models and related rank-based models.

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CP13

Mean Expectile Portfolio Optimization Model with Short Selling

An expectile is a statistical functional defined as the minimizer of an asymmetric quadratic loss function. Owing to its unique property of being both coherent and elicitable, expectile has recently been explored as an alternate measure of risk to value-at-risk (VaR) and expected shortfall (ES). Analogously, as a risk measure, it is defined as expectile-based value-at-risk (EVaR). This study extends the mean expectile-based VaR portfolio optimization model when short selling is allowed. To assimilate different practical arrangements of a short-sale transaction, we analyze several constraints such as proportional bounds, 1-norm constraint, bounded budget, and turnover constraints. We conduct extensive in-sample and out-of-sample analyses using historical data of the stocks listed in the SP 500 and FTSE 100 index over a period of ten years using a rolling window strategy. While the 1-norm constraint and the bounded budget help restrict the total short-sale budget, the turnover constraint helps tune the portfolio turnover, thereby reducing the overall transaction cost. The empirical results highlight the benefits of choosing specific constraints to assist practical decision-making for short-selling scenarios.

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CP13

Topological Data Analysis in Investment Decisions

This article explores the applications of Topological Data Analysis (TDA) in finance addressing the primordial problem of asset allocation. Firstly, we build a rationale on why TDA can be a better alternative to traditional risk indicators such as standard deviation using real data sets. We apply Takens embedding to reconstruct the time series of returns in a high dimensional space. We adopt the sliding window approach to draw time-dependent point cloud and associate a topological space with them. We then apply the persistent homology to discover the topological patterns that appear in the multidimensional time series. The temporal changes in the persistence landscapes are captured via L^p norm. We explore an application of TDA in Enhanced Indexing (EI). We propose a two-step procedure to accomplish this task. In step one, we utilize the L^p norms of the assets to propose a filtration technique of selecting a few assets from a larger pool of assets. In step two, we propose an optimization model to construct an optimal portfolio from the class of filtered assets. To test the efficiency of this enhanced algorithm, experiments are carried out on ten data sets from financial markets. Our extensive empirical analysis exhibits that the proposed strategy delivers superior performance on several measures, including excess mean returns from the benchmark index and tail reward-risk ratios.

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CP13

Portfolio Choice in Dynamic Thin Markets: Merton Meets Cournot

We consider an augmented version of Mertons canonical portfolio choice problem, where trading by individual investors influences the price of the underlying traded financial asset. In a market with two such large investors, this gives rise to strategic interaction among investors, in which investors decide their trading rates independently and simultaneously at each instant in the spirit of dynamic Cournot competition, which we model and analyze as a non-zero sum singular stochastic differential game. We establish an equivalence result for an investors best response problem, which is a singular stochastic optimal control problem, and an auxiliary classical optimal control problem by proving that the value functions for the two problems are equal. The equivalence result is obtained by exploiting the invariance of the value functions with respect to an integral flow associated with the drift coefficient of the original control problem. Under mild regularity conditions, we also show that the optimal trajectories of the two control problems coincide, which permits analytical characterization of investors best-response mappings. Finally, in the special case when stock price volatility is constant, we show that the unique Nash equilibrium is deterministic.

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CP13

Portfolio Optimization with Allocation Constraints and Stochastic Factor Market Dynamics

We study the expected utility portfolio optimization problem in an incomplete financial market where the risky asset dynamics depend on stochastic factors and the portfolio allocation is constrained to lie within a given convex set. We employ fundamental duality results from real constrained optimization to formally derive a dual representation of the associated HJB PDE. Using this representation, we provide a condition on the market dynamics and the allocation constraints, which ensures that the solution to the HJB PDE is exponentially affine and separable. This condition is used to derive an explicit expression for the optimal allocation-constrained portfolio up to a deterministic minimizer and the solution to a system of Riccati ODEs in a market with CIR volatility and in a market with multi-factor OU short rate.

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CP13

Portfolio Optimization Incorporating Social-Media Sentiment

Incorporating social media sentiment into the prediction of stock returns has been studied widely in literature. In this context, portfolio optimization indirectly considers social media sentimentsentiments are used for predicting returns and the predicted returns are used in the optimization model. Our work directly links portfolio optimization and sentiment by using machine learning models tuned on the accuracy of predicting the optimal portfolio. Numerical studies using Twitter sentiment and voting results from Reddit subgroup wallstreetbets show that our proposed approach provides useful guidance on setting hyperparameters and results in improved portfolios.

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CP13

Quantum Lasso Algorithms in Portfolio Selection

We study the high dimensional aspect of linear regression with an ℓ_1 penalty. While classical, numerical algorithms are available for Lasso, our focus is on developing a hybrid quantum algorithm that offers new insights and speedup. Quadratic speedup is possible over the classical Homotopy (Least Angle Regression) method. In particular, we provide a general setup for Lasso solutions as the penalty term varies. We also study an enhanced version of this algorithm to tackle constrained Lasso problems with applications to portfolio selection.

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CP14

O-Equivalent Measures and Arbitrage

In this paper we introduce the notion of O-equivalence between probability measures. This is a weaker, but similar notion to the usual equivalence between measures. We prove that this notion of O-equivalence, combined with certain topological property of portfolios, can be used to transfer arbitrage properties between models, in a similar way that equivalence between probability measures is used traditionally in finance for that purpose. We consider different topologies on the canonical spaces corresponding to various models. We show that arbitrage can be excluded within certain large classes of portfolios, even under non-semimartingale models for which equivalent martingale measures do not exist.

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CP14

The Stress-Dependent Random Walk

A log-normal random walk with parameters that are functions of market stress naturally accounts for volatility clustering and fat-tailed return distributions. Fitting this model to a stock and a bond index we find no evidence of significant misspecification despite the fact that the model has no adjustable parameters. This model can be interpreted as a stochastic volatility model without latent variables. We obtain a closed-form expression for the Value at Risk (VaR) that accommodates returns of any magnitude and discuss several other applications.

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CP14

Graph-Based Methods for Forecasting Realized Covariances

We forecast the realized covariance matrix of asset returns in the U.S. equity market by exploiting the predictive information of graphs in volatility and correlation. Specifically, we augment the Heterogeneous Autoregressive (HAR) model via neighborhood aggregation on these graphs. Our proposed method allows for the modeling of interdependence in volatility (also known as spillover effect) and correlation, while maintaining parsimony and interpretability. We explore various graph construction methods, including sector membership and graphical LASSO (for modeling volatility), and line graph (for modeling correlation). The results generally suggest that the augmented model incorporating graph information yields both statistically and economically significant improvements for out-of-sample performance over the traditional models. Such improvements remain significant over horizons up to one month ahead, but decay in time. The robustness tests demonstrate that the forecast improvements are obtained consistently over the different out-of-sample sub-periods, and are insensitive to measurement errors of volatilities.

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CP15

Simulation Schemes for the Ornstein-Uhlenbeck Driven Stochastic Volatility Model with the Karhunen-Love Expansions

This study proposes a fast exact simulation scheme for the Ornstein–Uhlenbeck driven stochastic volatility model. With the Karhunen–Love expansions, the stochastic volatility following the Ornstein–Uhlenbeck process is expressed as a sine series, and the time integrals of volatility and variance are analytically derived as the sum of independent normal random variates. The new method is several hundred times faster as it avoids the costly numerical transform inversion in the existing method. The simulation variance is further reduced with conditional simulation and the control variate.

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CP15

Replacing the Monte Carlo Simulation with the Cos Method for Potential Future Exposure Calculations

To fulfil the need in the industry for fast and accurate quantification of counterparty credit risk (CCR), in this paper a new Fourier method of calculating the potential future exposure (PFE) for CCR is developed, tested and analyzed. The key insight is that the cumulative distribution function can be recovered semi-analytically using Fourier-cosine expansion, whereby the series coefficients are readily available from the characteristic function (ch.f.) of the total exposure. The ch.f. itself can be solved numerically via advanced quadrature rules. Herewith we focus on liquid IR and FX portfolios involving up to three correlated risk factors: a domestic and foreign short rate and the exchange rate of this currency pair. Both netting-set level and counterparty-level PFEs are covered in our research. The short rates are modelled under the one-factor Hull-White model and for the exchange rate, we assume they follow geometric Brownian motion. Our theoretical analysis predicts stable convergence of this method and observed exponential convergence. It was observed that this method is at least twice as accurate as the Monte Carlo (MC) simulation method and takes only one-tenth of the CPU time. The advantage of this method becomes even more prominent when the number of derivatives in a portfolio increases. Extending the method to involve more risk factors is ongoing, but we already foresee that it can be a much more efficient alternative to the MC method for liquid portfolios.

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CP15

Running Large-Scale Financial Simulations on AWS Cloud

Numerical simulations have been widely used in financial industry to solve some of the most complex problems where no analytic solution can be easily found, but it could be very time-consuming and computationally intensive for large-scale simulations. Cloud computing gains its popularity in financial industry recently as the result of growing demand on compute power and the benefit of improving overall productivity with cost reductions. To illustrate the simulations can be done on cloud easily, we choose to calculate American Option pricing using Monte Carlo simulations with Quantlib, which is a free open-source library for quantitative finance. We will show how we can take advantage of the elastic compute resources from Amazon Web Services (AWS) to run large-scale simulations on tens of thousands of CPUs with AWS Batch efficiently and cost-effectively. For smaller jobs requiring fast turnaround within a couple of minutes, we choose to use AWS Lambda to reduce latency to less than 1 second. An event-driven architecture following best practices along with the code to deploy the infrastructure will be presented to allow financial engineers/quantitative developers to have their own compute cluster within minutes. A continuous integration and continuous deployment (CI/CD) CodePipeline is used to improve application delivery throughout development life cycle via automation.

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CP15

Monte Carlo Methods for Real Options under Parameter Uncertainty in Multi-Dimensional Models

We introduce new simulation based methods to solve optimal stopping problems for ambiguity-averse agents in financial models built on multi-dimensional stochastic differential equations with uncertainty in the drift coefficients. We first reformulate the problem in terms of reflected backward stochastic differential equations (RBSDEs) with a uniformly Lipschitz continuous generator and propose two Monte Carlo algorithms - one based on the theory of RBSDEs and stratification and the other on approximate dynamic programming. Through extensive numerical experiments, we demonstrate the convergence of our proposed schemes. The RBSDE based algorithm with stratification is found to be more efficient when an explicit formula for the optimal generator is available. Finally, we demonstrate how parameter uncertainty affects the optimal exercise time and the exercise threshold, contributing to the important literature on how the level of risk and uncertainty delays or accelerates the exercise of real options.

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CP16

Assessing the Profitability of Large Scale Batteries in the UK Electricity Market

The transition towards an electricity market with a high penetration of renewable energy is characterized by higher price volatility compared to the more traditional electricity market dominated by conventional generation. The increasing share of intermittent generation requires a method of securing supply and matching demand with supply. Integrating batteries as fully controllable energy storage into the system is a solution to handling this issue. The inclusion and operation of batteries can contribute to the green transition if market participants can operate them profitably. This project aims to quantify these batteries' economic viability. In this paper, we run a two-stage optimization model based on forecasts of electricity prices in the day-ahead and in the intra-day market. The model's performance relies on forecasts of the electricity prices, which we obtain using machine learning methods such as Decision Trees and Random Forests and simpler methods such as historical average prices. We compute the profit from operating the batteries according to our algorithm during 2020 and 2021 in the UK power market. The chosen forecast methods can obtain profits in the range of 30-40% compared to the profit generated from perfect foresight of price developments, i.e., supplying the models with realized prices. In addition, we investigate how participating in both the day-ahead and intra-day markets yields superior results compared to focusing on just one of the markets.

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CP16

Consumption and Labor-Leisure Choices with Recursive Utility: Is YOLO Sustainable

This paper studies what individual preference factors cause YOLO-like behaviors of consumption and labor-leisure choices in a rational economic agent's framework. We examine whether these YOLO life patterns are sustainable in the long run. To do so, we set up a dynamic optimal consumption, labor-leisure choice, and risky investment decision problem of an agent with recursive preference. The flexible labor-leisure choice setup leads to a non-linear free-boundary value problem. We suggest a novel method to derive optimal policies in closed form by which we categorize types of agents, and then investigate their long-run sustainability.

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CP16

Uncovering the Price of Growth and Value with Explanatory Gain Decomposition

The talk demonstrates the Big Growth and Value components of the Fama-French HML factor transparently and explicitly as the sampling of assets based on their fundamental characteristics. The study builds on and extends the research methodology presented at the SIAM FM'21 talk on understanding the source of the 2010-19 momentum effect. In comparison with the momentum challenge, explaining the HML factor performance represents a more complex problem encompassing a dynamic knot of multiple effects. Therefore, the study extends the decomposition methodology for identifying the dominant models behind the price of growth and value. As a result, for data spanning US stocks from 1980-2020, the research uncovers the redundancy effect of the value factor within the 5-factor model.

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CP16

Formation of Optimal Interbank Lending Networks under Liquidity Shocks

We formulate a game-theoretic model of the financial system in which banks control both their supply of liquidity and their exposures to each others' risky assets. Banks are periodically struck by liquidity shocks, which can cause the value of their risky asset to jump downwards if the shock size exceeds their supply of liquidity. In two distinct settings, we: (1) derive the non-local HJB partial differential equations for the value functions, (2) find explicit solutions, and (3) prove existence and uniqueness of the optimal controls. In the first setting, banks maximize their own utility in a decentralized manner. Second, a central planner aims to maximize the sum of all banks' utilities. We find that both of the resulting financial networks exhibit a 'core-periphery' structure. However, the optimal allocations differ - decentralized banks are more susceptible to liquidity crises, while the planner ensures that banks with more debt hold greater liquidity. We characterize the asymptotic behavior of the planner's optimal allocation as the size of the system grows. Interestingly, the 'price of anarchy' is of constant order. Finally, we show that the decentralized system replicates the planner's optimal allocation if banks with greater debt have higher stake in their risky asset. Namely, systemically important banks must face the greatest losses when they suffer liquidity crises - ensuring that their individual incentives can realize the planner's optimal allocation.

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CP16

Transaction Tax in a General Equilibrium Model

In this talk we consider the effects of a quadratic tax rate levied against two agents with heterogeneous risk aversions in a continuous-time, risk-sharing equilibrium model. The goal of each agent is to choose a trading strategy according to a mean variance criterion, for which an optimal strategy exists in closed form, as the solution to an FBSDE. This tractable setup allows us to analyse the utility loss incurred from taxation and show why an agent can benefit from taxation before redistribution. Moreover, we additionally model the situation where agents have heterogeneous beliefs about the traded asset and discuss whether there exists an optimal tax that benefits the agents.

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CP16

Propagation of Carbon Tax in Credit Portfolio Through Macroeconomic Factors

We study how the introduction of a carbon price in a closed economy propagates in a credit portfolio. Precisely, we adapt a stochastic multisectoral model to take into account carbon taxes on both sectoral firms' production and sectoral households' consumption. Carbon taxes are calibrated on carbon prices, provided by the transition scenarios, as well as on sectoral households' consumption and firms' production, together with their related greenhouse gases emissions. This yields the dependence of firms' production and households' consumption of each sector to carbon price and the relationships between sectors. This allows us to analyze the short-term effects of carbon taxes as opposed to standard IAMs, which are deterministic and only capture long-term trends of climate transition policy. Moreover, we use the discounted cash flow methodology to compute firms' values and use them in the Merton model to describe how carbon price impacts credit risk metrics. We observe that the introduction of a carbon price increases banking fees charged to clients (via the expected loss), and reduces banks' profitability (via the unexpected loss). The randomness introduced in our model provides extra flexibility to take into account uncertainties on sectoral productivity and on transition scenario. Finally, we compute the sensitivities of the credit risk metrics with respect to changes in the carbon price, yielding further criteria for a more accurate assessment of climate transition risk.

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CP17

Optimal Consumption and Investment in General Affine GARCH Models

We present the first optimal analytical solution for an investor maximizing both consumption and terminal wealth within expected utility theory in the realm of GARCH models. Targeting a general family of affine GARCH models which allows for non-Gaussian innovations, we incorporate negatively skewed and leptokurtic asset returns. We derive an affine GARCH optimal wealth process, with analytical representations for optimal allocation, consumption and value functions. In particular, the optimal consumption ratio avoids the undesirable scenario of investors consuming all wealth prior to maturity. Our numerical study highlights the importance of formally accounting for consumption as it disrupts the level of optimal risky allocations. We find, for reasonable parametric settings, that wealth-equivalent losses incurred by investors that rely on optimal homoscedastic or Gaussian-GARCH solutions, in actual non-Gaussian markets, could be in the double digits.

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CP17

Optimal Consumption and Investment for General Preferences

We propose a new approach to determine optimal strategies for consumption and investment under uncertainty for a general class of utility functions. It is based on the extension of an existing method to solve optimal investment and indifference pricing problems to the more complicated case which involves consumption. We define a new class of utility functions for which *exact* solutions can be found, and use these to generate sequences of approximating preferences and discretization schemes for the stochastic dynamics of the risky assets. We then prove convergence to viscosity solutions of Hamilton-Jacobi-Bellman equations for the fast recursive algorithm that exploits the properties of such sequences. We illustrate our approach using known results for a number of different optimization problems and then show how the method can be used for cases for which no closed-form solutions are available. This makes it possible to treat consumption and valuation problems that involve empirically observed preferences.

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CP17

Heterogeneous Beliefs with Uninsurable Income

I study the general equilibrium of a pure-exchange economy with several agents who receive uninsurable income, trade a dividend-paying stock, and borrow from and lend to each other. Agents are heterogeneous in risk-aversion and time-preference, and hold differing beliefs on the growth rates of both the dividend and all agents' incomes. I find closed-

form expressions for the interest rate, the stock price, and the agents' consumption and investment policies in equilibrium. Positive correlation of the optimists' incomes with the dividend process lowers the interest rate; in equilibrium beliefs on hedgeable processes and those on unhedgeable incomes are aggregated differently; agents with atypical beliefs have high subjective utility, but potentially unboundedly negative expected utility under the objective probability measure.

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CP17

Revisiting Alfonsi, Fruth, and Schied's Non-Linear Price Impact Model

Portfolio managers' orders trade off return and trading cost predictions. Return predictions rely on alpha models, whereas price impact models quantify trading costs. This paper revisits the non-linear price impact proposed by Alfonsi, Fruth, and Schied with stochastic liquidity. We derive a closed-form solution for the optimal trading strategy and study three applications. First, we derive a straightforward no-price manipulation condition. Second, we examine what happens when trades are based on an incorrect price impact model. The corresponding model misspecification costs are tractable, and we illustrate them by fitting the model on proprietary trading data and measuring the cost of getting model parameters wrong. Finally, we study the symmetric trading game with non-linear price impact and derive a tractable Nash equilibrium.

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CP17

Dynamic and Static Fund Separations and Their Stability for Long-Term Optimal Investments

This paper investigates dynamic and static fund separations and their stability for long-term optimal investments under non-affine models. An investor maximizes the expected utility with constant relative risk aversion under an incomplete market consisting of a safe asset, several risky assets, and a single non-affine state process. The 3/2 process and inverse Bessel process are dealt as non-affine state models. We show that the dynamic optimal portfolio of this utility maximization consists of $m+3$ portfolios: the safe asset, the myopic portfolio, the m time-independent portfolios, the intertemporal portfolio. The intertemporal portfolio vanishes in the long run, and thus the dynamic portfolio converges to $m+2$ portfolios, which is called the static portfolio. We also prove that the convergence is stable under model parameter perturbations. Sensitivities of the intertemporal portfolio with respect to small parameters perturbations vanishes in the long run. The convergence rate for the intertemporal portfolio and its sensitivities are computed explicitly for the two non-affine models.

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CP18

Accelerating the Generic Method for Calculations of Counterparty Exposures

A highly flexible simulation-based framework for counterparty credit risk gives rise to significant computational challenges when faced with portfolios of many financial derivatives. In this talk, we will present a general function approximation approach for the complexity reduction of the simulation-based framework. Specifically, we propose to replace the expensive derivative pricers, which are frequently called in exposure calculations, with efficient approximations. We will give a theoretical guarantee that the error induced by the complexity reduction in any exposure measurement is no larger than the error in the underlying pricing function, measured in the uniform norm. On the other hand, we will show that a small L^2 norm of the function approximation error does not guarantee an equally small error for a general exposure measurement. Motivated by the obtained theoretical results, we will investigate a practical method for complexity reduction based on the uniform approximation with the Chebyshev polynomials. For higher-dimensional problems, we will show how the standard multivariate interpolation can be combined with low-rank tensor decomposition techniques for further efficiency gains. Finally, we will present numerical results covering a variety of pricing setups to highlight the effectiveness and flexibility of the proposed approach.

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CP18

Pircing the Convertible Bonds under Tsiveriotis and Fernandes Framework

Pricing the Convertible Bonds has an important role in financial engineering. In this talk, the system of non-linear and penalized Black-Scholes PDEs are solved using the finite element method. The Newton-Raphson iteration is applied to deal with non-linearity coming from penalty terms. The finite element method produces comparable results with the finite difference method. However, by using quadratic elements convergence is obtained using less grid points than in finite difference or linear finite elements. Numerical result is verified with reference solution. Subsequently, the Greeks are calculated using the quadratic finite elements producing favorable solutions. Moreover, the numerical scheme is verified based on the method of manufactured solutions.

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CP18

The Valuation of Real Options for Risky Barrier to Entry with Hybrid Stochastic and Local Volatility

and Stochastic Investment Costs

Real options are sorts of investment choices which support agents in making better decisions in management strategic cases as well as reducing uncertainty in investment simultaneously. In this paper, we present the new model for investors to handle uncertain environments in investment flexibly: (i) First, we adopt a hybrid stochastic and local volatility model to efficiently describe the external uncertain environment affecting the value of the project in decision making cases, and (ii) we set up the investment cost (or sunk cost) as geometric Brownian motion (GBM) to illustrate the value of the opportunity costs which arise from things given up by choosing to invest in complex decision making circumstances. We derive partial differential equations (PDEs) for the value of real options and then use asymptotic analysis to obtain analytical solutions for that of the real options. In addition, we analyze the price accuracy of the approximated formulas compared to the solutions obtained from Monte-Carlo simulation. Finally, we investigate the effects of various parameters related to stochastic volatility on real options numerically to observe economic implications.

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CP18

Parasian Over Parisian, How Much Earlier Should One Exercise?

With only one character difference between the two words "Parisian" and "Parasian", pricing an American-style Parasian option is drastically different from pricing its former counterpart. In this talk, I shall demonstrate how we have overcome, through an integral equation approach, the major difficulty of numerically solving a pair of coupled three-dimensional (3-D) PDE systems instead of a 2-D PDE system coupled with another 3-D one (for Parisian options) with the existence of a moving boundary that has fully nonlinearized the entire PDE systems. Utilizing the computed optimal exercise price, we are able to quantitatively discuss how much earlier an American-style up-and-out Parasian option should be exercised than its Parisian counterpart with a change of the accumulativeness of the so-called "tracking clock" time, which measures the risk of a contract being potentially knocked out, as well as the financial insights in terms of the nonlinear interactions between the holder's early exercise right and the effect of the knock-out barrier.

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MS1

Multi-Agent Reinforcement Learning for Collaborative Games: a Mean-Field Perspective

Multi-agent reinforcement learning (MARL) has enjoyed substantial successes in many applications including real-time resource allocation, order matching for ride-hailing, and autonomous driving. Despite the empirical success of MARL, general theories behind MARL algorithms are less developed due to the intractability of interactions, complex information structure, and the curse of dimensionality. Instead of directly analyzing the multi-agent systems, the mean-field theory provides a powerful approach to approximate the games under various notions of equilibria. Moreover, the analytical feasible framework of mean-field theory leads to efficient and tractable learning algorithms with theoretical guarantees. In this talk, we will demonstrate how mean-field theory can contribute to analyzing a class of simultaneous-learning-and-decision-making problems under cooperation, with unknown rewards and dynamics. Moreover, we will show that the learning procedure can be further decentralized and scaled up if a network structure is specified. Our result lays the first theoretical foundation for the so-called "centralized training and decentralized execution" scheme, a widely used training scheme in the empirical works of cooperative MARL problems.

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MS2

A Linear Programming Approach for Mean-Field Games of Optimal Stopping and Applications to Energy Markets

In this talk, we present recent results on the linear programming approach to stopping mean-field games in a general setting. This relaxed control approach allows to prove existence results under weak assumptions, and lends itself well to numerical implementation. We consider mean-field game problems where the representative agent chooses the optimal time to exit the game, where the instantaneous reward function and the coefficients of the state process may depend on the distribution of the other agents. Furthermore, we establish the equivalence between mean-field games equilibria obtained by the linear programming approach and the ones obtained via other approaches used in the previous literature. We then present a fictious play algorithm to approximate the mean-field game population dynamics in the context of the linear programming approach. Finally, we give an application of the theoretical and numerical contributions introduced in the first part of the talk to an entry-exit game in electricity markets. The talk is based on several works, joint with R. Ad, G. Bouveret, M. Leutscher and P. Tankov.

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MS2

A Stationary Mean-Field Equilibrium Model of Irreversible Investment in a Two-State Economy

In this talk, I present results on a stationary mean-field model with singular controls for a Markov modulated Itō-diffusion, in which the representative agent interacts with a long-time conditional weighted average of the population through a discounted performance criterion. Natural applications are in the context of irreversible production expansion in dynamic oligopolies, where the dynamics of the production capacity is affected by the market's business cycles and the price of the produced good depends on the aggregate stationary production of the whole economy. We prove existence and uniqueness of the mean-field stationary equilibrium and we characterize it through a system of nonlinear equations. Along the way, explicit results for the joint stationary distribution of the controlled production capacity and the Markov chain at equilibrium are also derived. A numerical analysis allows to understand the dependency of the mean-field equilibrium with respect to the model's parameters. [This is based on a joint (ongoing) work with Ren Aid and Matteo Basei.]

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MS2

MF-OMO: An Optimization Formulation of Mean-Field Games

The literature on theory and computation of mean-field games (MFGs) has grown exponentially since its inception. In this talk, we present MF-OMO (Mean-Field Occupation Measure Optimization), a mathematical framework to analyze MFGs. This approach is not limited to contractive or monotone settings, nor will it need an apriori assumption of the uniqueness of the Nash equilibrium (NE). MF-OMO reformulates the problem of finding NE solutions in MFGs as a single optimization problem. This formulation thus allows for directly utilizing various optimization tools, algorithms and solvers to find NE solutions of MFGs. We also provide convergence guarantees for finding (multiple) NE solutions using popular algorithms such as projected gradient descent. For MFGs with linear rewards and mean-field independent dynamics, solving MF-OMO can be reduced to solving a finite number of linear programs, hence solved in finite time.

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MS2

Mean Field Optimal Stopping

We are interested in the study of the mean field optimal stopping problem, that is the optimal stopping of a McKean-Vlasov diffusion, when the criterion to optimize is a function of the distribution of the stopped process. This problem models the situation where a central planner controls a continuous infinity of interacting agents by assigning a stopping time to each of them, in order to maximize some criterion which depends on the distribution of the system. We study this problem via a dynamic programming approach, which allows to characterize its value function by a partial differential equation on the space of probability measures, that we call obstacle problem on Wasserstein space. We introduce a notion of viscosity solution for this equation and show that, under appropriate assumptions, the value function of the mean field optimal stopping problem is its unique viscosity solution. We also study the corresponding finite population problem and prove its convergence to the mean field problem. This is a joint work with Nizar Touzi and Jianfeng Zhang.

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MS3

Pricing by Stake in Decentralized Insurance

In blockchain architectures, consensus mechanisms, such as the *proof-of-stake*, have been used for processing transactions and building new blocks in a blockchain. It requires participants to stake digital assets to validate transactions in order to settle disagreements. The concept has been extended in decentralized finance (DeFi) applications to use staking mechanisms for decision-makings in financial services. In this article, we examine the *pricing by stake* in DeFi insurance applications, where the ratemaking, typically done by centralized actuarial approaches in traditional insurance, is replaced by pricing formulas of digital assets staked on underwritten insurance policies. We show in this study that such a consensus mechanism may not always lead to a Nash equilibrium and, when it does, the mechanism may fail to reflect the true risk of underwritten policies. While such a mechanism is intuitive and can be the only viable approach for emerging risks such as smart contract risks without long history of claims data, it may not be economically viable over time.

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MS3

Modeling Agents Preferences by Recursive Utility

with Markov Decision Processes

Various economic consumption problems can be addressed by applying the recursive utility specification of Epstein and Zin, such as asset pricing puzzles like the equity premium puzzle, the excess volatility puzzle, and the credit spread puzzle. This class of utility functions is favored in economic consumption problems on account of the ability to represent an agents elasticity of intertemporal substitution in addition to her risk aversion. Closed form solutions to specific problems in continuous time can be found via the HJB equations under restrictive assumptions on the data generation process. In this talk, we formulate discrete time Markov Decision Processes for a wide class of economic consumption problems using a recursive utility specification with minor restrictions on the data generation process. This class of MDPs proves challenging to approximately solve with conventional computational methods due to the recursive utility and the coupling between action and state variables. We present new Q-reinforcement learning, LSMC, and Binomial Tree methods to approximate MDPs with recursive utility and compare and contrast their convergence properties on the optimal consumption portfolio problem with a EZ utility. This is joint work with Dominic OKane (EDHEC) and Ivan Gvozdanovic (Illinois Tech).

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MS3

Implied Volatility in Decentralized Finance from Automated Market Makers

Automated Market Makers (AMMs) are a decentralized approach for creating financial markets by allowing investors to invest in liquidity pools of assets against which traders can transact. Liquidity providers are compensated for making the market with fees on transactions. The collected fees, along with the final value of the pooled portfolio, act as a derivative of the underlying assets with price given by the pooled assets. Following this notion, we study the implied volatility constructed from different AMMs. Special attention is given to the constant product market makers.

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MS4

A Theoretical Study of Guyon's Toy Volatility Model

We provide a thorough analysis of a path-dependent volatility model introduced by Guyon, proving existence and uniqueness of a strong solution, characterising its behaviour at boundary points, providing asymptotic closed-form option prices as well as deriving small-time behaviour estimates.

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MS4

The 4-Factor Path-Dependent Volatility Model

The natural Markovian continuous-time version of the empirical path-dependent volatility (PDV) uncovered in [Guyon and Lekeufack, Volatility Is (Mostly) Path-Dependent, 2022] is the 4-Factor PDV model. Two factors describe the short and long dependence of volatility on recent returns (trend), while the two other factors describe the short and long dependence of volatility on recent returns squared (historical volatility). We show that this model, which is inferred from the empirical joint behavior of returns and volatility, captures all the important stylized facts of volatility: leverage effect, volatility clustering, large volatility spikes followed by a slower decrease, roughness at the daily scale, very realistic SPX and VIX smiles, joint calibration, Zumbach effect and time-reversal asymmetry. Being Markovian in low dimension, the model is very easy and fast to simulate. It can easily be enhanced with stochastic volatility (PDSV) to account for exogenous shocks. This is joint work with Jordan Lekeufack.

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MS4

Volatility Is (Mostly) Path-Dependent

We learn from data that volatility is mostly path-dependent: up to 90% of the variance of the implied volatility of equity indexes is explained endogenously by past index returns, and up to 65% for (noisy estimates of) future daily realized volatility. The path-dependency that we uncover is remarkably simple: a linear combination of a weighted sum of past daily returns and the square root of a weighted sum of past daily squared returns with different time-shifted power-law weights capturing both short and long memory. This simple model, which is homogeneous in volatility, is shown to consistently outperform existing models across equity indexes and train/test sets for both implied and realized volatility. It suggests a simple continuous-time path-dependent volatility (PDV) model that may be fed historical or risk-neutral parameters. The weights can be approximated by superpositions of exponential kernels to produce Markovian models. In particular, we propose a 4-factor Markovian PDV model which captures all the important stylized facts of volatility, produces very realistic price and volatility paths, and jointly fits SPX and VIX smiles remarkably well. We thus show that a continuous-time Markovian parametric stochastic volatility (actually, PDV) model can practically solve the joint SPX/VIX smile calibration problem.

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MS4

Sig-SDEs Model for Quantitative Finance

In this work, we propose a novel framework for data-driven model selection by integrating a classical quantitative setup with a generative modeling approach. Leveraging the properties of the signature, a well-known path-transform from rough path, we develop the Sig-SDE model. Sig-SDE provides a new perspective on neural SDEs and can be calibrated to exotic financial products that depend, in a non-linear way, on the whole trajectory of asset prices. Furthermore, we our approach enables to consistently calibrate under the pricing measure Q and real-world measure P. Finally, we demonstrate the ability of Sig-SDE to simulate future possible market scenarios needed for computing risk profiles or hedging strategies. Importantly, this new model is underpinned by rigorous mathematical analysis that, under appropriate conditions, provides theoretical guarantees for convergence of the presented algorithms.

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MS5

Modeling the Covid Effect on Gasoline Price Changes Using Mixture Models

The COVID-19 pandemic has made impacts on many things in our lives. The pandemic has definitely affected the commodities that people use every day. This paper investigates the changes in the gasoline price during the pandemic and attempts to uncover any change points in the gasoline price as a response to the spikes in the COVID outbreak. A finite mixture model with continuous outcome is applied to the price changes in the gasoline price, and compared with a hidden Markov model. The daily gasoline prices from Western Australia has been used with whole sale prices in the same region.

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MS5

Risk Estimation in the High Dimensional, Low Sample Size Regime

Portfolio risk forecasts require an estimate of the covariance matrix of asset returns, often for a large number of assets. When only a small number of relevant observations are available, we are in the high-dimension-low-sample-size (HL) regime in which estimation error dominates. Factor models are used to decrease the dimension, but the factors still need to be estimated. We describe a shrinkage estimator for the first principal component, called James-Stein for Eigenvectors (JSE), that is parallel to the famous James-Stein estimator for a collection of averages. In the context of a 1-factor model, JSE substantially improves optimization-based metrics for the minimum variance portfolio. With certain extra information, JSE is a consistent estimator of the leading eigenvector. This is based on joint work with Lisa Goldberg, Hubeyb Gurdogan, and Alex Shkolnik.

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MS5

Manoeuvring and Investing in Yield Farms

We investigate strategies seeking rewards in the form of transaction fees by depositing tokens into a decentralized application. We demystify the investment process and quantify transaction costs, returns, and risks using historical data from a major decentralized exchange. We reveal the economic mechanisms providing a mathematical (optimization) framework which resembles the yield farming investment process including the direct modelling of returns, transaction costs, and sources of risk.

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MS5

Total Positivity and Option Pricing

Option prices in the Black-Scholes model have a little appreciated property: the price of an option with strike K is a convex function of the price of an at-the-money option with the same maturity. We show that this property is just one of several consequences of total positivity (TP) for option prices and the risk-neutral density. The talk explores the implications of total convexity for option prices. Total positivity holds for many models popular in financial practice, including scalar diffusions, mixture models and certain Levy processes. We derive implications for empirical option prices, including constraints on the at-the-money skew.

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MS6

Automatic Continuities of Law-Invariant Risk Measures

Automatic continuity has long been an interesting topic and possibly has its roots in the well-known fact that a real-valued convex function on an open interval is continuous. In the context of risk measures, the following result is striking.
Theorem (Jouini et al '06). A real-valued, convex, decreasing, law-invariant functional on L^∞ has the Fatou property and is thus $\sigma(L^\infty; L^1)$ lower semicontinuous.
In this talk, we show that, on nearly all classical model spaces including Orlicz spaces, every real-valued, law-invariant, coherent risk measure automatically has the Fatou property at every point whose negative part has a "thin tail". The result is also sharp in the sense that automatic Fatou property cannot be expected at other points.

The talk is based on joint work with Shengzhong Chen, Denny Leung Lei Li.

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MS6

Generalization and Regularization of Risk Minimization via Wasserstein Distributionally Robust Optimization

Wasserstein distributionally robust optimization (DRO) has found success in operations research and machine learning applications as a powerful means to obtain solutions with favourable out-of-sample performances. Two compelling explanations for the success are the generalization bounds derived from Wasserstein DRO and the equivalency between Wasserstein DRO and the regularization scheme commonly applied in machine learning. Existing results on generalization bounds and the equivalency to regularization are largely limited to the setting where the Wasserstein ball is of a certain type and the decision criterion takes certain forms of an expected function. In this work, we show that for Wasserstein DRO problems with affine decision rules, it is possible to obtain generalization bounds and the equivalency to regularization in a significantly broader setting where the Wasserstein ball can be of a general type and the decision criterion a general measure of risk, i.e., nonlinear in distributions. This allows for accommodating many important classification, regression, and risk minimization applications that have not been addressed using Wasserstein DRO. Our results are strong in that the generalization bounds do not suffer from the curse of dimensionality and the equivalency to regularization is exact. As a by-product, our regularization results broaden considerably the class of Wasserstein DRO models that can be solved efficiently via regularization formulations.

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MS6

Risk Budgeting Allocation for Dynamic Risk Measures

We develop an approach for risk budgeting allocation – a risk diversification portfolio strategy – where risk is measured using time-consistent dynamic risk measures. For this, we introduce a notion of dynamic risk contributions that generalise the classical Euler contributions and which allow us to obtain dynamic risk contributions in a recursive manner. Moreover, we show how the risk allocation problem may be recast as a convex optimisation problem and develop an actor-critic approach to solve for risk allocations using deep learning techniques.

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MS6

Avoiding Zero Probability Events when Computing Value at Risk Contributions

In this talk I will discuss the process of risk allocation for a generic multivariate model when the risk measure is chosen as the Value-at-Risk (VaR). We recast the traditional Euler contributions from an expectation conditional on an event of zero probability to a ratio involving conditional expectations whose conditioning events have strictly positive probability. We derive an analytical form of the proposed representation of VaR contributions for various parametric models. Our numerical experiments show that the estimator using this novel representation outperforms the standard Monte Carlo estimator in terms of bias and variance. Moreover, unlike the existing estimators, the proposed estimator is free from hyperparameters under a parametric setting.

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MS8

The Factor Model Failure Puzzle

After six decades of research work, we still do not have a factor model that can price the cross section of U.S. equities. We empirically show that the most recent, cutting-edge asset pricing models developed to date using economic theory and machine learning cannot explain the average returns of the implied mean-variance efficient portfolios of other models. We create a theoretical model that suggests we may need hundreds of years of additional data to develop a factor model that can price the cross section.

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MS8

A Unified Approach to Informed Trading via Monge-Kantorovich Duality

We solve a generalized Kyle model type problem using Monge-Kantorovich duality and backward stochastic partial differential equations. First, we show that the the generalized Kyle model with dynamic information can be recast into a terminal optimization problem with distributional constraints. Therefore, the theory of optimal transport between spaces of unequal dimension comes as a natural tool. Second, the pricing rule of the market maker and an optimality criterion for the problem of the informed trader are established using the Kantorovich potentials and transport maps. Finally, we completely characterize the optimal strategies by analyzing the filtering problem from the market maker's point of view. In this context, the Kushner-Zakai filtering SPDE yields to an interesting backward stochastic partial differential equation whose measure-valued terminal condition comes from the optimal coupling of measures.

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MS8

Information Acquisition and Model Uncertainty in Financial Markets

Investors allocate their attention among a range of predictor variables and use them to form earning expectations. Predictor observations serve two objectives: i) prediction of next-period earnings and ii) model update for forecast improvements further in the future. When investors are certain about their prediction model, they focus on variables useful for short-term predictions. The sensitivities of earnings to these variables are updated with high accuracy, while the remaining variables might be ignored. Significant earning surprises, however, cast doubt on existing variables' explanatory power and force investors to explore unvisited predictors. These learning behaviors generated correlated movements of expectation and subjective uncertainty of future earnings growth, inducing correlations in cash flow and discount rate components of stock returns.

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MS8

Rational Expectations Equilibrium Under General Von-Neumann Preferences

In this talk, we establish the existence of equilibrium in the presence of both asymmetric information and general preferences for the uninformed agent. Specifically, there is an insider who possesses a private signal about the terminal value of the traded asset, and an uninformed agent who possesses no private signal. While the insider has CARA (exponential) preferences, the uninformed agents preferences are described by a general utility function defined for positive wealths. The terminal value of the traded asset is a function of a time homogeneous diffusion. In this setting, and under mild conditions on the diffusion, terminal payoff function, and uninformed preferences, we establish existence of a partially revealing equilibrium, where a market signal is communicated to all agents at time zero. Additionally, the equilibrium is a rational expectations equilibrium in the univariate case. As the uninformed agent preferences are general, we are able to obtain sensitivity of the asset price, volatility, and market price of risk, to the uninformed agents initial endowment, as we will show through examples. This is joint work with Jerome Detemple of Boston University.

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MS9

Portfolio Optimization in the Family of 4/2 Stochastic Volatility Models

The state-of-the-art 4/2 stochastic volatility model was recently proposed by Grasselli in 2017 and has gained great attention ever since. This model is a superposition of a Heston (1/2) component and a 3/2 component, bringing the best of the two nested models. This talk gives an overview of recent progress in the application of the model, as well as a multivariate generalization, to portfolio optimization, in particular within expected utility theory. The work includes the study of CRRA and HARA utilities, the presence of consumption, as well as considerations about complete/incomplete markets and ambiguity-aversion. All is complemented with the analysis of wealth-equivalent losses to gain insight into popular suboptimal strategies.

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MS9

Diversification Quotients: Quantifying Diversification via Risk Measures

We introduce the diversification quotient (DQ) to quantify portfolio diversification by addressing several theoretical and practical limitations of existing indices. Defined through a parametric family of risk measures, DQ satisfies three natural properties, namely, non-negativity, location invariance and scale invariance, which are shown to be conflicting for any traditional diversification index based on a single risk measure. Together with another three properties related to monotonicity, continuity and normalization, we uniquely characterize the family of DQ. DQs based on the popular risk measures Value-at-Risk and Expected Shortfall enjoy many convenient features and are efficient to optimize in portfolio selection. Moreover, we find that DQ can properly capture tail heaviness and common shocks which are neglected by traditional diversification indices. When illustrated with financial data, DQ is intuitive to interpret, and its performance is competitive against other diversification indices.

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MS9

Imbalanced learning for insurance using Modified Loss Functions in Tree-Based Models

Tree-based models have gained momentum in insurance claim loss modeling; however, the point mass at zero and the heavy tail of insurance loss distribution pose the challenge to apply conventional methods directly to claim loss modeling. With a simple illustrative dataset, we first demonstrate how the traditional tree-based algorithm's splitting function fails to cope with a large proportion of data with zero responses. To address the imbalance issue presented in such loss modeling, this paper aims to modify the traditional splitting function of Classification and Regression Tree (CART). In particular, we propose two novel modified loss functions, namely, the weighted sum of squared error and the sum of squared Canberra error. These modified loss functions impose a significant penalty on grouping observations of non-zero response with those of zero response at the splitting procedure, and thus significantly enhance their separation. Finally, we examine and compare the predictive performance of such modified tree-based models to the traditional model on synthetic datasets that imitate insurance loss. The results show that such modification leads to substantially different tree structures and improved prediction performance.

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MS9

Optimal Consumption and Life Insurance Under Shortfall Aversion and a Drawdown Constraint

This paper studies a life-cycle optimal portfolio-consumption problem when the consumption performance is measured by a shortfall aversion preference under an additional drawdown constraint on consumption rate. Meanwhile, the agent also dynamically chooses her life insurance premium to maximize the expected bequest at the death time. By using dynamic programming arguments and the dual transform, we solve the HJB variational inequality explicitly in a piecewise form across different regions and derive some thresholds of the wealth variable for the piecewise optimal feedback controls. Taking advantage of our analytical results, we are able to numerically illustrate some quantitative impacts on optimal consumption and life insurance by model parameters and discuss their financial implications.

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MS10

Statistical Error Bounds for Weighted Mean and Median, with Application to Robust Aggregation of Cryptocurrency Data

We study price aggregation methodologies applied to crypto-currency prices with quotations fragmented on different platforms. An intrinsic difficulty is that the price returns and volumes are heavy-tailed, with many outliers, making averaging and aggregation challenging. While conventional methods rely on Volume-Weighted Average Prices (called VWAPs), or Volume-Weighted Median prices (called VWMs), we develop a new Robust Weighted Median (RWM) estimator that is robust to price and volume outliers. Our study is based on new probabilistic concentration inequalities for weighted means and weighted quantiles under different tail assumptions (heavy tails, sub-gamma tails, sub- Gaussian tails). This justifies that fluctuations of VWAP and VWM are statistically important given the heavy-tailed properties of volumes and/or prices. We show that our RWM estimator overcomes this problem and also satisfies all the desirable properties of a price aggregator. We illustrate the behavior of RWM on synthetic data (within a parametric model close to real data): our estimator achieves a statistical accuracy twice as good as its competitors, and also allows to recover realized volatilities in a very accurate way. Tests on real data are also performed and confirm the good behavior of the estimator on various use cases.

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MS10

Automated Market Makers: Mean-Variance Analysis of LPs Payoffs and Design of Pricing Functions

We analyze the performance of Liquidity Providers (LPs) providing liquidity to different types of Automated Market Makers (AMMs). This analysis is carried out using a mean / standard deviation viewpoint la Markowitz, though based on the PnL of LPs compared to that of agents holding coins outside of AMMs. We show that LPs tend to perform poorly in a wide variety of CFMMs under realistic market conditions. We then explore an alternative AMM design in which an oracle feeds the current market exchange rate to the AMM which then quotes a bid/ask spread. This allows us to define an efficient frontier for the performance of LPs in an idealized world with perfect information and to show that the smart use of oracles greatly improves LPs' risk / return profile, even in the case of a lagged oracle.

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MS10

Mining Pool and Centralization in Proof-of-Work Equipped Blockchain

Mining in isolation is no longer possible in popular Proof-of-Work blockchains these days. Miners join mining pools to mitigate the financial risk induced by mining activity. The presentation focuses on mining pools that apply the Pay-per-Share reward system. A value function based on the surplus of miners and pool managers is defined to better understand the agent's decision whether or not to join a mining pool. Will these interactions between miners and pool managers result in a balanced situation in terms of distribution of computing power between mining pools?

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MS10

Unbiasing and Robustifying Implied Volatility Calibration in a Cryptocurrency Market with Large Bid-Ask Spreads and Missing Quotes

We design a novel calibration procedure that is designed to handle the specific characteristics of options on cryptocurrency markets, namely large bid-ask spreads and the possibility of missing or incoherent prices in the considered data sets. We show that this calibration procedure is significantly more robust and accurate than the standard one based on trade and mid-prices.

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MS11

LQG Risk-Sensitive Mean Field Games with a Major Agent

Risk sensitivity plays an important role in the study of finance and economics as risk-neutral models cannot capture and justify all economic behaviors observed in reality. Risk-sensitive mean field game (MFG) theory was developed recently for systems where there exists a large number of indistinguishable, asymptotically negligible and heterogeneous risk-sensitive players, who are coupled via the empirical distribution of state across population (average state of the population in the LQG case). In this work, we extend the theory of LQG risk-sensitive MFGs to the setup where there exists one major agent as well as a large number of minor agents. The major agent has a significant impact on each minor agent and its impact does not collapse with the increase in the number of minor agents. Each agent is subject to linear dynamics with an exponential-of-integral quadratic cost functional. Moreover, all agents interact via the average state of minor agents (so-called empirical mean field) and the major agent's state. We use a change of measure technique together with a variational analysis to derive the best response strategies of agents in the limiting case where the number of agents goes to infinity. We establish that the set of obtained best-response strategies yields a Nash equilibrium in the limiting case and an ϵ-Nash equilibrium in the finite player case.

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MS11

Mean Field Control Games

I will present MFCGs which describe competitive games between large numbers of large collaborative groups.

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MS11

Mean-Field Game Price Models Revisited

In this talk we revisited the price model by J. Saude and D. Gomes in the context of stochastic supply. We discuss monotonicity properties, calculus of variations methods, and the use of recurrent neural networks and potential methods for the effective computation of the price.

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MS11

A Rank-Based Reward Between a Principal and a Field of Agents: Application to Energy Savings

We consider a problem where a Principal aims to design a reward function to a field of heterogeneous agents. In our setting, the agents compete with each other through their rank within the population in order to obtain the best reward. We first explicit the equilibrium for the mean-field game played by the agents, and then characterize the optimal reward in the homogeneous setting. For the general case of a heterogeneous population, we develop a numerical approach, which is then applied to the specific case study of the market of Energy Saving Certificates.

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MS12

Sure Replication of Derivatives with Gamma Hedging and Rough Paths

We show that the gamma hedging trading strategy allows sure replication of a derivative payoff. This holds if the price of the securities used for hedging are given by risk-neutral prices and does not require the underlying to follow a path arising from the probability model. We will see how the result follows by applying rough path theory to derivative replication. We will prove the robustness of the result by evaluating the sensitivity of the replication to errors in the pricing model. We will describe how the meaning of gamma-hedging should be extended to path-dependent options.

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MS12

Signature SDEs with Jumps and Their Connections with Polynomial Processes

Signature-based models have recently entered the field of stochastic modeling, in particular in Mathematical Finance. The choice of the signature as main building block is mainly explained by a universal approximation theorem (UAT) according to which continuous functions of continuous paths can be approximated by linear functionals of the time-extended signature. This powerful result, however, leaves open the question of approximating continuous functions of the more general set of cdlg paths. Based on recent advances on the signature of cdlg paths and by using appropriate topologies thereon, we present a UAT that solves this question. Relying on this approximation result, we then introduce a generic class of jump-diffusion models and recognize them as projections of infinite dimensional polynomial processes. This allows to get power series expansions in terms of the process' initial value for the expected value of analytic functions of the process' marginals. Our results apply in particular to so-called Lvy type-signature models, a new class of signature models that extend the class of continuous signature models for asset prices proposed so far, while still preserving universality and tractability properties.

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MS12

A Gaussian Process Point of View on Signature Kernels and Their Regularization Properties

We introduce a functional analytic setting, namely the setting of weighted spaces (often stemming from weak star topologies), which allows to construct Gaussian processes with corresponding signature kernels as covariance function. We then analyze the regularization properties of the corresponding reproducing kernel Hilbert spaces and put them in context of certain training tasks, in particular in the two important cases of learning of generic dynamics and learning of path space functionals.

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MS13

Ergodic Properties of Rank-Based Diffusions

We investigate the long-time behavior of rank-based diffusions with infinitely many particles where the drift and diffusivity of each particle depends on its relative rank in the system. Unlike their finite dimensional analogues, such systems have infinitely many stationary measures and domains of attraction and extremality properties of such measures have been long-standing open questions. In this talk, we will explore some of these questions and provide answers to them in certain cases.

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MS13

Transaction Costs in Stochastic Portfolio Theory

A key result in Stochastic Portfolio Theory (SPT) is the existence of relative arbitrage under fairly mild conditions on market diversity and volatility. However, this result is classically derived in a setting without transaction costs. In this work we incorporate proportional transaction costs in the SPT framework. We study mathematically the structure that these costs impose and consider how the usual assumptions can be modified to allow for relative arbitrage. We empirically analyze if these strengthened assumptions are justified in practice and investigate some portfolios that generate relative arbitrage in our expanded setting.

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MS13

Stochastic Volatility in Bond Modeling

We apply stochastic volatility modeling for Treasury bond market. We compute spreads and premia of zero-coupon Treasury bonds, chosen since it is easy to compute their prices. Instead of inferring volatility from the rate data, we use the VIX index for the stock market. Surprisingly, it works well for bonds as well. A simple Markov model describes the empirical behavior of the markets.

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MS13

Macroscopic Properties of Equity Markets: An Empirical Study

Empirical properties of stock prices have clear implications in portfolio management. In financial econometrics and empirical asset pricing, a great deal has been discovered about the statistical properties of individual assets at low and high frequencies. Previous research also studied cross-sectional properties of stock returns in relation to macroeconomic, fundamental and statistical factors. Nevertheless, relatively little attention has been paid to macroscopic properties such as the capital distribution curve. To give a metaphor, we know quite a lot about individual stars [stocks] but little about the galaxy [equity market] (e.g., how it spirals). In this talk, we present a careful empirical study of macroscopic properties for the US market. In particular, we consider the capital distribution curve, market diversity, intrinsic market volatility, and their effects on portfolio performance. We not only validate well-known facts but also point out interesting new observations. Finally, we will discuss their implications in the construction of realistic stochastic models.

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MS14

Finite-Sample Guarantees for Wasserstein Distributionally Robust Optimization: Breaking the Curse of Dimensionality

Wasserstein distributionally robust optimization (DRO) aims to find robust and generalizable solutions by hedging against data perturbations in Wasserstein distance. Despite its recent empirical success in operations research and machine learning, existing performance guarantees for generic loss functions are either overly conservative due to the curse of dimensionality, or plausible only in large sample asymptotics. In this paper, we develop a non-asymptotic framework for analyzing the out-of-sample performance for Wasserstein robust learning and the generalization bound for its related Lipschitz and gradient regularization problems. To the best of our knowledge, this gives the first finite-sample guarantee for generic Wasserstein DRO problems without suffering from the curse of dimensionality. Our results highlight that Wasserstein DRO, with a properly chosen radius, balances between the empirical mean of the loss and the variation of the loss, measured by the Lipschitz norm or the gradient norm of the loss. Our analysis is based on two novel methodological developments that are of independent interest: 1) a new concentration inequality controlling the decay rate of large deviation probabilities by the variation of the loss and, 2) a localized Rademacher complexity theory based on the variation of the loss.

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MS14

A New Concentration Inequality for the Optimal Transport Cost Between the True and Empirical Measure

Let μ be a probability measure on $\mathbb{R}^d$ and μ_N be an empirical measure of μ with sample size N. We prove a concentration inequality of the optimal transport cost between μ and μ_N where the cost function has local polynomial growth but can have superpolynomial global growth. This result generalizes and improves upon the estimates by Fournier and Guillin. The main novelty is to combine rates for compactly supported μ with estimates from empirical process theory. By partitioning $\mathbb{R}^d$ into small cubes, we infer a global estimate from local estimates on these cubes and conclude that the difference between these can be controlled by imposing benign moment conditions on μ.

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MS14

Backward Propagation of Chaos and the Mean Field Schrdinger Problem

The mean field Schrdinger problem (MFSP) is the problem of finding the most likely path of a McKean-Vlasov type particle with constrained initial and final configurations. It was first introduced by Backhoff et al. (2020) who studied its existence and long time behavior. The aim of this talk is to show how ideas from propagation of chaos for backward particle systems allows to derive the MFSP as the (large population) limit of a sequence of classical Schrdinger problems among finite (but interacting) particles. The method rests upon the study of suitably penalized problems using stochastic control techniques, and it further allows to derive other interesting results on the MFSP. This talk is based on a join work with Camilo Hernandez.

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MS14

Optimal Transport Projections of Martingales and Applications to Machine Learning and Finance

Martingales play a key role in finance because they characterize arbitrage-free markets, thus verifying that models (especially those constructed via synthetic simulators) are arbitrage-free is an important task. Another important task in machine learning involves the non-parametric estimation of regression functions. This task can be seen as searching for a two-step martingale. Motivated by these applications we focus on the problem of projecting a sample of vectors to the space of martingales using the causal Wasserstein distance under several ground transportation. If the data-generating process forms a martingale, we obtain the asymptotic distribution of this projection as well as finite sample guarantees (including under weak dependence assumptions). This can be used to build, for example, non-parametric tests for the martingale property. If the data-generating process fails to form a martingale the projection can also be used to gain insight into exactly how the data-generating distribution differs from a martingale by linking a certain subspace with the growth of the normalized projection statistic. This can be used to improve the power of a martingale test as a function of certain design parameters. This is joint work with Johannes Wiesel, Erica Zhang, Zhenyuan Zhang.

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MS15

Considerations on Fourier Valuation in High Dimensions

The increasing complexity of financial markets calls for increasingly sophisticated products, whose pricing requires multidimensional dynamics. From the point of view of computing values from any model, Fourier-based valuation methods are the common choice due to their efficiency and ease of implementation. The curse of dimensionality though can significantly hamper their applicability. In this talk, we discuss potential strategies based on Monte Carlo integration to overcome this issue and illustrate their tractability by considering the case of variable annuities. Further considerations regarding other related computational bottlenecks are offered.

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MS15

The Sinc Way: A Fast and Accurate Approach to Fourier Pricing

The talk investigates the SINC approach to Fourier pricing, as it was outlined by P. Rossi in [Cherubini et al., Fourier Transform Methods in Finance, John Wiley & Sons Inc., 2009]. We detail its derivation from a version of the Shannon Sampling Theorem revisited for functions with bounded support, and provide important theoretical and numerical results: 1) a rigorous proof for the convergence of the SINC formula to the true option price when the support of the (truncated) pdf grows and the number of Fourier frequencies increases; 2) a systematic evaluation of the accuracy of the method via comparison with the COS [Fang and Osterlee, A novel pricing method for european options based on Fourier-cosine series expansions, SIAM Journal on Scientific Computing, 2009]; 3) a numerical challenge against standard FFT specifications, such as [Carr and Madan, Option valuation using the fast Fourier Transform, Journal of Computational Finance, 1999] and [Lewis, Option Valuation Under Stochastic Volatility with Mathematica Code, Finance Press: Newport Beach, 2000]; 4) an extensive pricing exercise under the rough Heston model. This suggests that the SINC provides the most accurate and fast pricing computation, when compared to the above benchmark methodologies. Also, ease of transposition to a form that accommodates for the Fast Fourier Transform proves very powerful for calibration. The paper recently appeared in Quantitative Finance (preprint at https://ssrn.com/abstract=3684706).

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MS15

Optimal Damping with Hierarchical Adaptive Quadrature for Efficient Fourier Pricing of Multi-Asset Options in Lvy Models

Efficient pricing of multi-asset options is a challenging problem in quantitative finance. When the characteristic function is available, Fourier-based methods become competitive compared to alternative techniques because the integrand in the frequency space has often higher regularity than in the physical space. However, when designing a numerical quadrature method for most of these Fourier pricing approaches, two key aspects affecting the numerical complexity should be carefully considered: (i) the choice of the damping parameters that ensure integrability and control the regularity class of the integrand and (ii) the effective treatment of the high dimensionality. To address these challenges, we propose an efficient numerical method for pricing European multi-asset options based on two complementary ideas. First, we smooth the Fourier integrand via an optimized choice of damping parameters based on a proposed heuristic optimization rule. Second, we use sparsification and dimension-adaptivity techniques to accelerate the convergence of the quadrature in high dimensions. Our extensive numerical study on basket and rainbow options under the multivariate geometric Brownian motion and some Lvy models demonstrates the advantages of adaptivity and our damping rule on the numerical complexity of the quadrature methods. Moreover, our approach achieves substantial computational gains compared to the Monte Carlo method.

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MS15

A Novel Solution Method for Multivariate Expectation Problems Based on Dimension-Reduced Fourier-Cosine Series Expansion

A wide range of problems faced by practitioners in the financial industry are in essence multivariate expectation problems. Typical examples of such include the valuation of multi-asset options and risk quantification on portfolio level. Very often there exist no analytical solutions for those expectation problems and we thus have to rely on numerical methods. In this paper, we tackle these problems from a novel angle. The idea is to directly solve the characteristic function (ch.f.) of the combined dynamics of the driving random variables, with which the targeted expectation can be easily recovered. The ch.f. itself is again defined by a multivariate expectation, which is approximated by a dimension-reduced Fourier-cosine series expansion of the joint density function of the driving random variables, based Canonical Polyadic Decomposition (CPD). Hence, we name this method "dimension-reduced COS method". We illustrate its application using XVA pricing as an example. The error convergence is proved mathematically and the performance is tested to be much superior to straightforward numerical integration or Monte Carlo simulation.

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MS16

Parameter Estimation of Discretely Observed Interacting Particle Systems

We consider the problem of joint parameter estimation for drift and volatility coefficients of a stochastic McKean-Vlasov equation and for the associated system of interacting particles. The analysis is provided in a general framework, as both coefficients depend on the solution of the process and on the law of the solution itself. Starting from discrete observations of the interacting particle system over a fixed interval [0, T], we propose a contrast function based on a pseudo likelihood approach. We show that the associated estimator is consistent when the discretization step (Δ_n) goes to 0 and the number of particles N goes to ∞, and asymptotically normal when additionally the condition $\Delta_n N \to 0$ holds. We will also compare our results (and our condition on the decay of the discretization step) with the results known for classical SDEs. The talk is based on a joint work with A. Heidari, V. Pilipauskaite and M. Podolskij.

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MS16

Estimation of Stationary Distribution for Diffusion Process: Impact of the Sampling and of the Asynchronicity

We aim at estimating in a non-parametric way the density π of the stationary distribution of a d-dimensional stochastic differential equation $(X_t)_{t\in[0,T]}$, for $d \geq 1$, from the discrete observations of a finite sample X_{t_0}, ... , X_{t_n} with $0 = t_0 < t_1 < ... < t_n$. We propose a kernel density estimator and we study its convergence rates for the pointwise estimation of the invariant density under anisotropic Hölder smoothness constraints. We discuss condition on the discretization step that ensures it is possible to recover the same rates as if the continuous trajectory of the process was available. When such condition on the discretization step is not satisfied, we identify the convergence rate for the estimator of the invariant density over anisotropic Hölder classes, which is the same convergence rate as for the estimation of a probability density belonging to an anisotropic Hölder class, associated to n iid random variables $X_1, ..., X_n$. and we prove that this rate cannot be improved when $d = 1$. We also study the asynchronous case, in which each component can be observed at different time points. The asynchronicity introduces noticeable difficulties for the computation of the variance of the estimator. Furthermore, the estimator suffers from an additional bias term due to the asynchronicity. We exhibit some sufficient condition on the level of asynchronicity of the sampling step which makes this additional bias term negligible.

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MS17

Fire Sales, Default Cascades and Complex Financial Networks

In this talk, we present a general tractable framework for understanding the joint impact of fire sales and insolvency cascades on systemic risk in financial networks. Our limit theorems quantify how price mediated contagion across institutions with common asset holding could worsen cascades of insolvencies in a heterogeneous financial network. We show that the equilibrium prices of illiquid assets have asymptotically Gaussian fluctuations. Our numerical studies investigate the effect of heterogeneity in network structure and price impact function on the final size of default cascade and fire sales loss.

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MS17

Percolation in Random Graphs of Unbounded Rank and Implications for Assessing Systemic Risk

Bootstrap percolation in (random) graphs is a contagion dynamic triggered by a set of initially infected vertices. It has been used to understand the amplification of shocks in financial systems. This process has been studied extensively in so called rank one models. These models can generate random graphs with heavy-tailed degree sequences but they are not capable of clustering. In this paper, we treat a class of random graphs of unbounded rank which allow for extensive clustering. Our main result determines the final fraction of infected vertices as the fixed point of a non-linear operator defined on a suitable function space. We propose an algorithm that facilitates neural networks to calculate this fixed point efficiently. We discuss the application to systemic risk and derive criteria based on the Frchet derivative of the operator that allows one to determine whether small shocks to the financial system spread through the entire system or rather stay local.

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MS17

Backtesting of Systemic Risk Measures

Risk measures traditionally express the riskiness of a financial position by a single number. When determining the risk of an entire financial system, it has been argued that a risk measure should be set-valued, describing the collection of all capital allocations to the constituent parts which make the system acceptable. Banks use statistical models to determine their risk. The relevant task of backtesting these models amounts to statistical model validation and model comparison. The latter is performed in terms of consistent loss functions for the risk measure at hand. That means, these loss functions are minimized in expectation by the correctly specified model. A risk measure is elicitable if it admits a strictly consistent loss. Likewise, identification functions serve for model validation. While elicitability and identifiability have been extensively studied for traditional scalar risk measures, this paper is the first to formally study these desirable properties for set-valued measures of systemic risk. We establish the elicitability and identifiability of many systemic risk measures. The theoretical results are accompanied by an easy to use traffic-light approach.

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MS18

Quasiconvex Systemic Risk Measures

Systemic risk measures have been introduced in the recent literature as scalar or set-valued functionals on a space of random vectors. In this talk, we will consider the simpler scalar case where the systemic risk measure is defined as the composition of an aggregation function acting on the random vector and a quasiconvex risk measure acting on the aggregate random output. In order to derive a dual representation for this functional, we study quasiconvex compositions of functions on infinite-dimensional vector spaces in greater generality. We calculate an explicit formula for the penalty function of the composition in terms of the penalty functions of the ingredient functions. The proof makes use of a nonstandard minimax inequality (rather than equality as in the standard case) that is available in the literature. Then, we apply our results for quasiconvex systemic risk measures, in particular, in the context of Eisenberg-Noe clearing model. We also provide novel economic interpretations of the dual representations in these settings.

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MS18

Deep Learning for Systemic Risk Measures

The aim of our research is to study a new methodological framework for systemic risk measures by applying deep learning method as a tool to compute the optimal strategy of capital allocations. Under this new framework, systemic risk measures can be interpreted as the minimal amount of cash that secures the aggregated system by allocating capital to the single institutions *before aggregating* the individual risks. This problem has no explicit solution except in very limited situations. Deep learning is increasingly receiving attention in financial modelings and risk management and we propose our deep learning based algorithms to solve both the primal and dual problems of the risk measures, and thus to learn the *fair* risk allocations. In particular, our method for the dual problem involves the training philosophy inspired by the well-known Generative Adversarial Networks (GAN) approach and a newly designed direct estimation of Radon-Nikodym derivative. In the end, we show substantial numerical studies of the subject and provide interpretations of the risk allocations associated to the systemic risk measures. In the particular case of exponential preferences, numerical experiments demonstrate excellent performance of the proposed algorithm, when compared with the optimal explicit solution as a benchmark.

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MS18

Set-Valued Bellman's Principle: Evidence from the Mean-Risk Problem

Selecting a portfolio of risky assets which maximizes the expected terminal values at the same time as it minimizes portfolio risk is known as the mean-risk problem. The usual approach in the literature is to combine the mean and the risk to obtain a problem with a single objective. In a dynamic setting this scalarization, however, comes at the cost of time inconsistency. We show that these difficulties disappear by considering the problem in its natural form, that is, as a bi-objective optimization problem. As such the mean-risk problem satisfies an appropriate notion of time consistency, closely related to existence of a moving scalarization. Moreover, the mean-risk problem satisfies a Bellman's principle appropriate for a bi-objective optimization problem: a set-valued Bellman's principle.

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MS18

Decomposable Sums and Their Implications on Naturally Quasiconvex Risk Measures

Convexity and quasiconvexity are two properties that capture the concept of diversification for risk measures. Between the two, there is natural quasiconvexity, an old but not so well-known property weaker than convexity but stronger than quasiconvexity. A detailed discussion on natural quasiconvexity is still missing and this paper aims to fill this gap in the setting of conditional risk measures. We relate natural quasiconvexity to additively decomposable sums. The notion of convexity index, defined in 1980s for finite-dimensional vector spaces, plays a crucial role in the discussion of decomposable sums. We propose a general treatment of convexity index in topological vector spaces and use it to study naturally quasiconvex risk measures. We prove that natural quasiconvexity and convexity are equivalent for conditional risk measures on L^p spaces, $p \geq 1$, under mild continuity and locality conditions. Finally, we discuss an alternative notion of locality with respect to an orthonormal basis in L^2.

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MS19

Mean Field Social Optimization: Dynamic Programming and Person-by-Person Optimality

We consider a large population optimal control problem and apply dynamic programming from the point of view a representative agent, instead of directly treating a continuum of agents. This leads to a special HJB equation, called the master equation. For performance analysis, we employ a further two-scale master equation system to prove person-by-person optimality.

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MS19

Approximately Optimal Distributed Stochastic Controls Beyond the Mean Field Setting

We study high-dimensional stochastic optimal control problems in which many agents cooperate to minimize a convex cost functional. We consider both the full-information problem, in which each agent observes the states of all other agents, and the distributed problem, in which each agent observes only its own state. Our main results are sharp non-asymptotic bounds on the gap between these two problems, measured both in terms of their value functions and optimal states. Along the way, we develop theory for distributed optimal stochastic control in parallel with the classical setting, by characterizing optimizers in terms of an associated stochastic maximum principle and a Hamilton-Jacobi-type equation. By specializing these results to the setting of mean field control, in which costs are (symmetric) functions of the empirical distribution of states, we derive the optimal rate for the convergence problem in the displacement convex regime. Joint work with Joe Jackson.

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MS20

Model-free Portfolio Theory: A Rough Path Approach

Based on a rough path foundation, we develop a model-free approach to stochastic portfolio theory (SPT). Our approach allows to handle significantly more general portfolios compared to previous model-free approaches based on Follmer integration. Without the assumption of any underlying probabilistic model, we prove a pathwise formula for the relative wealth process which reduces in the special case of functionally generated portfolios to a pathwise version of the so-called master formula of classical SPT. We show that the appropriately scaled asymptotic growth rate of a far reaching generalization of Cover's universal portfolio based on controlled paths coincides with that of the best retrospectively chosen portfolio within this class. We provide several novel results concerning rough integration, and highlight the advantages of the rough path approach by showing that (non-functionally generated) log-optimal portfolios in an ergodic Ito diffusion setting have the same asymptotic growth rate as Cover's universal portfolio and the best retrospectively chosen one.

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MS20

Optimal Stopping with Signatures

We present a new method for solving optimal stopping problems based on a representation of the stopping rule by linear and non-linear functionals (deep n.n.) of the rough path signature and prove that maximizing over these classes of signature stopping times, in fact, solves the stopping problem. Using the algebraic properties of the signature, we can then recast the problem as a deterministic optimization problem depending only on the (truncated) expected signature. The theory encompasses processes such as fractional Brownian motion, which fail to be either semimartingales or Markov processes. This is from a joint work with C. Bayer, S. Riedel and J. Schoenmakers.

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MS20

PCF-GAN: Generating Financial Time Series via the Characteristic Function of Measures on the Path Space

Implicit Generative Models (IGMs) have demonstrated the superior capacity in generating high-fidelity samples from the high dimensional space, especially for static image data. However, these methods struggle to capture the temporal dependence of joint probability distributions induced by time-series data. To tackle this issue, we directly compare the path distributions via the characteristic function of measures on the path space (PCF) from rough path theory, which uniquely characterises the law of stochastic processes. The distance metric via PCF enjoyed theoretical properties, including boundedness and differentiability with respect to generator parameters. The PCF can also be regarded as a variant of the MMD loss on the path space, which enjoys linear time complexity in the sample size, in contrast with the quadratic-time Maximum Mean Discrepancy (MMD). Furthermore, the PCF loss can be optimised based on the path distribution by learning the optimal unitary representation of PCF, which avoids the need for manual kernel selection, and leads to an improvement in test power relative to the original PCF. Numerical results demonstrate that the proposed PCF-GAN consistently outperforms state-of-the-art baselines on several financial datasets in terms of various test metrics.

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MS20

Economic Nowcasting with Signatures

Economic nowcasting refers to the inference (“forecast’) of the current (“now’) state of the economy. This is necessary as key economic variables are often published with significant delays. The nowcasting literature focuses on the need to have fast, reliable estimates of these delayed indicators from available data sources. The path signature is a mathematical object arising from rough analysis which captures geometric properties. By embedding the observed data in continuous time, we can naturally handle missing data from mixed frequency and/or irregular sampling – issues often encountered when merging multiple data sources. We look at the nowcasting problem by applying regression on signatures and show that this simple linear model subsumes the popular Kalman filter in theory and performs well in practice.

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MS21

Supermartingale Brenier's Theorem with Full Marginals Constraints

We explicitly construct the supermartingale version of the Frchet-Hoeffding coupling in the setting with infinitely many marginals constraints. This extends the results of Henri-Labordre, Tan and Touzi (Stochastic Processes and their Applications, 126: 28002834, 2016) obtained in the martingale setting. Our construction is based on the Markovian iteration of one-period optimal supermartingale couplings. In the limit, as the number of iterations goes to infinity, we obtain a pure jump process that belongs to a family of local Lvy models. Our limit process differs significantly from Henri-Labordre, Tan and Touzi in that there exists a phase transition curve which can be crossed only one-sidedly by the limit process. Moreover, the increasing and decreasing SMOT cases demonstrate completely different figures.

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MS21

Optimal Consumption with Loss Aversion and Reference to Past Spending Maximum

This talk studies an optimal consumption problem for a loss-averse agent with reference to past consumption maximum. To account for loss aversion on relative consumption, an S-shaped utility is adopted that measures the difference between the non-negative consumption rate and a fraction of the historical spending peak. We consider the concave envelope of the realization utility with respect to consumption, allowing us to focus on an auxiliary HJB variational in- equality on the strength of concavification principle and dynamic programming arguments. By applying the dual transform and smooth-fit conditions, the auxiliary HJB variational inequality is solved in closed-form piecewisely and some thresholds of the wealth variable are obtained. The optimal consumption and investment control of the original problem can be derived analytically in the piecewise feedback form. The rigorous verification proofs on optimality and concavifica- tion principle are provided. Some numerical sensitivity analysis and financial implications are also presented.

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MS21

Periodic Portfolio Selection with Quasi-Hyperbolic Discounting

We introduce a continuous-time portfolio selection problem faced by an agent with S-shaped preference and quasi-hyperbolic discount function, who maximizes the expected discounted utilities derived from the portfolio's periodic performance over an infinite horizon. Quasi-hyperbolic discounting induces time-inconsistency where multiple notions of optimality arise. The optimal strategies under different optimality criteria are characterized. In the case that the agent is "sophisticated" who seeks a consistent planning strategy, the problem can be analyzed via a static mean field game. This is a joint work with Yushi Hamaguchi.

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MS21

Optimal Investment under Block-Shaped Order Books

We study an optimal investment problem of a CARA investor trading in a block-shaped limit order book market, which synergizes three key features of market microstructure: bid-ask spread, market depth, and finite market resilience. Under a Bachelier model for the fundamental value of the asset, we derive an explicit solution to this problem, including investors optimal trading strategy characterized by buy, sell, and no-trading regions. We also study an extension of this model by incorporating return-predicting signals, where we derive an asymptotic expansion for the strategies under small signal changes. Our results show a significant impact of market resilience on the optimal trading strategy, and unveil how to strike a balance among the competing goals of achieving current optimal risk exposure, incorporating signals about future, and minimizing trading costs, in the limit order book setting.

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MS22

The Uniform Diversification Strategy is Optimal for Expected Utility Maximization under High Model Ambiguity

In a one-period model with d risky assets, we investigate an expected utility maximization problem when there is ambiguity on the probability P modeled by a Wasserstein ball of radius k around P. We show that when k goes to infinity, the optimal solutions tend to some (rescaled) uniform diversification strategy.

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MS22

An Efficient Frontier of Wealth Distributions with Connections to Utility Maximisation

In this talk, we extend the notion of efficient portfolios to efficient wealth distributions. These correspond to portfolios that are not first-order stochastically dominated by other portfolios. Under general settings, we use classical results in optimal transport to explicitly characterise the set of efficient wealth distributions and their corresponding portfolios. Moreover, by studying the dual formulation, we form connections between this efficient frontier and utility maximisation problems, and show that every such efficient wealth distribution is the maximiser of a concave utility function.

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MS22

Adapted Wasserstein Distance Between the Laws of SDEs

To understand the sensitivity of an optimisation problem to changes in an underlying model, one needs to define an appropriate distance on the space of models. When these models are stochastic processes, one can consider the usual weak topology and the Wasserstein distance from optimal transport. However, this distance fails to encode the information structure of the stochastic processes. One approach to encoding this information is to define an adapted Wasserstein distance. This is the value of an adapted optimal transport problem that arises by restricting the usual set of couplings to those that respect the flow of information in the stochastic processes. We consider the adapted optimal transport problem between the laws of Markovian stochastic differential equations (SDE) and establish the optimality of the synchronous coupling between these laws. The proof of this result is based on time-discretisation and reveals an interesting connection between the synchronous coupling and the celebrated discrete-time Knothe–Rosenblatt rearrangement. We also prove a result on equality of topologies restricted to a certain subset of laws of continuous-time processes. Our results further provide an efficient method to compute adapted Wasserstein distances.

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MS22

The Out-of-Sample Prediction Error of the Square-Root Lasso and Related Estimators

We study the classical problem of predicting an outcome variable, Y, using a linear combination of a d-dimensional covariate vector, X. We are interested in linear predictors whose coefficients solve:

$$\inf_{\beta}(E[(Y-<\beta,X>)^r])^{(1/r)}+d||\beta||,$$

where $r>1$ and $d>0$ is a regularization parameter. We provide conditions under which linear predictors based on these estimators minimize the worst-case prediction error over a ball of distributions determined by a type of max-sliced Wasserstein metric. A detailed analysis of the statistical properties of this metric yields a simple recommendation for the choice of regularization parameter. The suggested order of, after a suitable normalization of the covariates, is typically d/n, up to logarithmic factors. Our recommendation is computationally straightforward to implement, pivotal, has provable out-of-sample performance guarantees, and does not rely on sparsity assumptions about the true data generating process. This is joint work with Jose Montiel Olea, Amilcar Velez and Cindy Rush.

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MS23

Optimal Dynamic Regulation of Carbon Emissions Market

In this article, we deal with optimal dynamic carbon emission regulation of a set of firms. On the one hand, the regulator dynamically allocates emission allowances to each firm. On the other hand, firms face idiosyncratic, as well as common, economic shocks on emissions, and they have linear quadratic abatement costs. Firms can trade allowances so as to minimize total expected costs, which arise from abatement, trading, and terminal penalty. Using variational methods, we first exhibit in closed form the market equilibrium in function of the regulator's dynamic allocation. We then solve the Stackelberg game between the regulator and the firms. The result is a closed-form expression of the optimal dynamic allocation policies that allow a desired expected emission reduction. The optimal policy is unique in the presence of market impact. In absence of market impact, the optimal policy is nonunique, but all the optimal policies share common properties. The optimal policies are fully responsive, and therefore induce a constant abatement effort and a constant price of allowances. Our results are robust to some extensions, like different penalty functions.

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MS23

Supply Chain Climate Exposure

To manage climate risks, investors need reliable climate exposure metrics. This need is particularly acute for climate risks along the supply chain, where such risks are recognized as important, but difficult to measure. We propose an intuitive metric that quantifies the exposure a company has to customers, or suppliers, who may in turn be exposed to climate risks. We show that such risks are not captured by traditional climate data. For example, a company may seem green on a standalone basis, but may still have meaningful, and potentially material, climate risk exposure if it has customers, or suppliers, whose activities could be impaired by transition or physical climate risks. Our metric is related to scope 3 emissions and may help capture economic activities such as emissions offshoring. However, while scope 3 focuses on products sold to customers and supplies sourced from suppliers, our metric captures the strength of economic linkages and the overall climate exposure of a firms customers and suppliers. Importantly, the data necessary to compute our measure is broadly accessible and is arguably of a higher quality than the currently available scope 3 data. As such, our metrics intuitive definition and transparency may be particularly appealing for investors.

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MS23

Optimal Impact Investing and the Risk and Reward of Green Portfolios

We propose a quantitative framework for assessing the financial impact of any form of impact investing, including socially responsible investing (SRI), environmental, social, and governance (ESG) objectives, and other non-financial investment criteria. Under general bivariate distributions of the impact factor and residual returns from a multifactor asset-pricing model, the construction and performance of optimal impact portfolios depend critically on the dependence structure (copula) between the two, which reduces to a correlation under normality assumptions. We explicitly derive the optimal portfolio weights under several copula families. We apply this framework to study the performance of green portfolios in both the US and Chinese markets, constructed using a broad range of climate-related environmental metrics including, in particular, carbon emissions.

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MS24

Estimation of Integrated Volatility Functionals with Kernel Spot Volatility Estimators

For a continuous It semimartingale, we revisit the problem of estimating integrated volatility functionals. Jacod and Rosenbaum studied a plug-in type estimator based on a Riemann sum approximation of the integrated functional and a spot volatility estimator with a forward uniform kernel. Motivated by recent results that show that spot volatility estimators with general two-side kernels are more accurate, an estimator using a general kernel spot volatility estimator as plug-in is considered. A central limit theorem for estimating the integrated functional with a general kernel estimator is established with an optimal convergence rate. An unbiased central limit theorem for the estimator with a proper de-biasing term is also obtained. Our results show that one can significantly reduce the estimators bias by adopting a general kernel instead of the standard uniform kernel, even without bias correcting them.

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MS24

State-Dependent Hawkes and Multi-Scale Neural Hawkes Processes for Lob Modelling

Analysis of high-frequency limit order book (LOB) data suggests that order flows dynamics are strongly state-dependent, and that metrics such as spread or imbalances are prominent features to be incorporated in LOB models. Some recent point process models include both state-dependence and Hawkes-like excitation features (e.g., intensity ratios, marked intensity ratios, and several formulations of state-dependent Hawkes processes). In this talk we review some of the properties of these LOB models, in particular regarding estimation procedures and modelling capabilities. We then consider a deep learning extension of the Hawkes processes (neural Hawkes) in which the intensities evolve using a continuous-time LSTM. We extend the basic model to explicitly use multi-scale kernels. This allows for longer-term temporal dependencies than in the original model in a parsimonious way. We calibrate the model on tick-by-tick limit order book data and observe that this extension speeds up learning and yields superior performance for long-memory point processes.

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MS25

Robust Risk Quantification via Shock Propagation in Financial Networks

Given limited network information, we consider robust risk quantification under the Eisenberg-Noe model for financial networks. To be more specific, motivated by the fact that information on interbank networks is not completely available in practice, we propose a robust optimization approach to obtain the worst-case default probabilities and associated capital requirements for a specific group of banks (e.g., SIFIs) under network information uncertainty. With this analytical tool, we observe the effects of various incomplete network information on those worst-case quantities and provide managerial insights into the collection of network information from the perspective of financial regulators. All the claims are numerically illustrated by data from the European banking system.

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MS25

Should Bank Stress Tests Be Fair?

Regulatory stress tests have become the primary tool for setting capital requirements at the largest U.S. banks. The Federal Reserve uses confidential models to evaluate bank-specific outcomes for bank-specific portfolios in shared stress scenarios. As a matter of policy, the same models are used for all banks, despite considerable heterogeneity across institutions; individual banks have contended that some models are not suited to their businesses. Motivated by this debate, we ask, what is a fair aggregation of individually tailored models into a common model? We argue that simply pooling data across banks treats banks equally but is subject to two deficiencies: it may distort the impact of legitimate portfolio features, and it is vulnerable to implicit misdirection of legitimate information to infer bank identity. We compare various notions of regression fairness to address these deficiencies, considering both forecast accuracy and equal treatment. In the setting of linear models, we argue for estimating and then discarding centered bank fixed effects as preferable to simply ignoring differences across banks. We present evidence that the overall impact can be material. We also discuss extensions to nonlinear models.

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MS25

Endogenous Network Valuation Adjustment and the Systemic Term Structure in a Dynamic Interbank Model

In this talk, I will introduce a dynamic interbank model with multiple maturities in order to study the yield curve of bank debt under an endogenous network valuation adjustment. The main idea is to capture, in one go, the effect of valuing liabilities according to the risk of defaults and the appertaining risk of contagion across the interbank network. As we will see, this naturally entails a forward-backward approach in which the future probabilities of default are required to determine the present values of debt. I will end the talk by showing some numerical case studies to highlight important takeaways and discuss potential policy implications.

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MS25

Systemic Risk in Markets with Multiple Central Counterparties

We provide a framework for modelling risk and quantifying payment shortfalls in cleared markets with multiple central counterparties (CCPs). Building on the stylised fact that clearing membership is shared among CCPs, we show how this can transmit stress across markets through multiple CCPs. We provide stylised examples to lay out how such stress transmission can take place, as well as empirical evidence to illustrate that the mechanisms we study could be relevant in practice. Furthermore, we show how stress mitigation mechanisms such as variation margin gains haircutting by one CCP can have spillover effects on other CCPs. The framework can be used to enhance CCP stress-testing, which currently relies on the "Cover 2' standard requiring CCPs to be able to withstand the default of their two largest clearing members. We show that who these two clearing members are can be significantly affected by higher-order effects arising from interconnectedness through shared clearing membership. Looking at the full network of CCPs and shared clearing members is therefore important from a financial stability perspective.

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MS26

Deep Backward and Deep Galerkin Methods for Learning Finite State Master Equations

We study two methods designed to efficiently solve high-dimensional PDEs in the setting of mean field master equations. Such master equations are independently interesting because they fully characterize the value of a game with a large number of players and have myriad applications in economics, finance, epidemiology, and more. The first method we explore is the deep backward dynamic programming (DBDP) method—we derive BSDEs for the master equation along some exploratory process and use this structure to train neural networks to approximate the master equation solution. Then we revisit the deep Galerkin method (DGM) as applied to the master equation and compare the efficacy of the two methods.

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MS26

Multi Discount Curve Learning with Kernels

We introduce a matrix-valued kernel based learning method for the joint estimation of discount curves in multiple fixed income markets. We first review the theory of vector-valued reproducing kernel Hilbert spaces, and derive a representation result for the separable case, where the reproducing kernel can be factorized into a constant covariance matrix and a scalar kernel. We then cast the multi-curve learning problem as vector-valued kernel ridge regression with a matrix-valued kernel. We also derive a Bayesian perspective, based on multivariate Gaussian processes, which allows for the quantification of the estimation uncertainty. Our core implementation is modular and builds on independent single-curve estimators based on a common scalar kernel, with individually calibrated regularity parameters. We aggregate and enhance the stand-alone estimators by adding regularity penalties on the mutual spread curves. We show that this boils down to a vector-valued kernel ridge regression with respect to the separable matrix-valued kernel that results from the common scalar kernel and a covariance matrix, which is fully determined by the regularity parameters. In an empirical study, we show that our kernel based multi-curve learning approach adds information and precision to the individual discount curves.

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MS26

Copula Process Models for Financial Risk Management

Financial data is inherently non-stationary and non-Gaussian. We address this stylized fact by a novel modelling approach. We model conditional multivariate risk, given financial information, by a stochastic process indexed by the observed asset-level and macro-economic features. Excluding asset identifier and time from the feature set, our model adapts to any cross-section of assets and can effectively learn about conditional future return distributions from observations of past returns. We conduct an empirical analysis on a large cross-section of US stocks and study applications of our model for risk assessment and portfolio optimization.

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MS26

Accelerated American Option Pricing with Deep Neural Networks

Given the competitiveness of a market-making environment, the ability to speedily quote option prices consistent with an ever-changing market environment is essential. Thus, the smallest acceleration or improvement over traditional pricing methods is crucial to avoid arbitrage. We propose a novel method for accelerating the pricing of American options to near-instantaneous using a feed-forward neural network. This neural network is trained over the chosen (e.g., Heston) stochastic volatility specification. Such an approach facilitates parameter interpretability, as generally required by the regulators, and establishes our method in the area of eXplainable Artificial Intelligence (XAI) for finance. We show that the proposed deep explainable pricer induces a speed-accuracy trade-off compared to the typical Monte Carlo or Partial Differential Equation-based pricing methods. Moreover, the proposed approach allows for pricing derivatives with path-dependent and more complex payoffs and is, given the sufficient accuracy of computation and its tractable nature, applicable in a market-making environment.

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MS28

Fourier-Based Efficient Pricing of Variable Annuity with Surrender Guarantee under a Stochastic Volatility Framework with Jumps

In this paper, we ascertain the valuation of variable annuity (VA) contracts embedded with early surrender guarantees. Specifically, the guarantees are minimum accumulated benefit riders, which allow policyholders a choice of surrendering their contract any time before maturity. Formally, such surrender benefits may be considered guarantees as they protect policyholders from downturns in the financial market, which negatively affects their account value, over the life of the contact. We shall price the VA contracts under a stochastic volatility model with jumps embraced in the underlying asset price process. The inclusion of these innovations will adequately accommodate for the various phenomena and stylised facts commonly observed in the financial market, rendering a more realistic pricing framework. Our work focus on the surrender guarantee valuation as an American option pricing problem. This gives rise to the long standing challenge whereby closed-form solutions are not readily available. We tackle this opportunity numerically through advanced Fourier pricing techniques, which are well-documented in the literature to provide accurate yet efficient solutions to complex pricing problems.

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MS28

Importance Sampling with Quasi-Monte Carlo for Efficient Fourier Pricing of Multi-Asset Options

High-dimensional option pricing using Fourier-based approaches is still an active area of intensive research. When the expression of characteristic function is available, carefully designed Fourier pricing methods are prominent because they profit from the high regularity of the integrand in the frequency space. In this work, we propose the use of Randomized Quasi-Monte Carlo (RQMC) method to efficiently evaluate multi-asset European options expressed via Fourier valuation formula. RQMC takes advantage of the smoothness of the integrand to achieve faster convergence, and allows for computation of error estimates. However, the use of RQMC requires a change of variable mapping the unbounded integration domain to the hypercube, which very often results in singularities at the corners of the domain. Moreover, a naive choice of the proposal density in the change of variable may deteriorate the rate of convergence of the RQMC. To overcome this difficulty, we propose a tailored importance sampling procedure coupled with our previously suggested heuristic rule for the choice of damping parameters which allows us to preserve sufficient regularity of the integrand and consequently retain near-optimal convergence rates of RQMC. We showcase the effectiveness of combining the proposed importance sampling technique and optimal damping rule with RQMC to compute the option price in the Fourier space for various multivariate pricing models and payoff functions.

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MS28

A New and Efficient Fourier Method for Risk Quantification and Allocation of Credit Portfolios

We present a new but efficient Fourier method for risk quantification and risk allocation of credit portfolios in the factor-copula framework. The key insight is that, compared to directly estimating the portfolio loss distribution, it can be much more efficient to compute the characteristic function (ch.f.) instead, and, the inversion of ch.f. back to the cumulative distribution function (CDF), can be done semi-analytically via the popular Fourier-cosine

(COS) method (with some extension). The same applies to Euler allocation of risk measures, once we transform the problem of risk allocation to the evaluation of conditional loss distributions by applying the Bayes law. Thus, this method fills the niche in literature that an accurate numerical method for risk allocation is lacking, besides serving as a fast solution for risk quantification. We also provide a theoretical proof of the error convergence, which justifies the stability and accuracy of the COS method in recovering CDFs of discrete random variables in general. For real-sized portfolios, the calculation speed and accuracy are tested to be significantly superior to Monte Carlo in the two-factor set-up. Value-at-Risk, Expected Shortfall (ES) and Euler allocation of ES are selected to represent common risk metrics. The application scope is wide: from the calculation of Economic Capital and Regulatory Capital for Banking Book and Trading Book to the valuation of credit derivatives.

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MS28

Pricing Discretely Monitored Asian Options under Regime-Switching and Stochastic Volatility Models with Jumps: Fourier-Cosine Approach

We propose a Fourier-cosine approach for the pricing of discretely monitored Asian options under a large class of important regime-switching and stochastic volatility models with jumps in finance. The randomness in volatility can be introduced by regime-switching among discrete market states, a diffusive stochastic variance process that may be correlated with the underlying asset price, or a random time-change applied to a background process. In this paper, we conduct delicate analysis on the conditional Fourier transform of log price increments, and develop change-of-measure approaches to reduce the additional state variables in the recursion of Asian option prices brought by the path dependency of Asian option payoffs. Based on these results, we apply the Fourier-cosine approach to conduct the computation of Asian option price which is reduced to explicit recursions of expansion coefficients. Our approach nests fixed-strike and floating-strike Asian options in a unified framework and can be extended naturally to deal with other types of financial derivatives and variable annuity contracts. Comprehensive error analysis and numerical experiments under a wide range of regime-switching and stochastic volatility models with jumps confirm that our algorithms are competitive in terms of stability, efficiency, and accuracy.

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MS29

Robo-Advising Systems Based on Dynamic Black-Litterman and Hidden Markov Models

We propose a new robo-advising system built on classical Black-Litterman methodology elevated to a discrete time dynamic setup in combination with Hidden Markov Models. We introduce a model setup, including the risk-reward criteria, that capture prevailing industry features of a robo-advisor. Finally, using stochastic model predictive control to solve the underlying stochastic control problem, we illustrate the performance of theoretical results and their comparison with other methods through numerical examples based on real market data.

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MS29

Stochastic Model Predictive Control for Robo-Advisors

Stochastic Model Predictive Control (SMPC) is a methodology that provides a suboptimal but computationally efficient method to deal with various control problems. It has been widely demonstrated by numerical evidence that, typically, the loss of optimality is not severe. Using SMPC methodology, we build a robo-advising system based on a dynamic risk-averse criteria rooted in classical mean-variance and risk parity paradigm.

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MS29

The Evolution of Blockchain: From Public to Private Mempools

We study the economic incentives behind the adoption of private mempools. Some validators may choose to not monitor private pools to preserve rents extracted from arbitrageurs, hence creating execution risk for users. Private pools neither eliminate frontrunning risk nor reduces transaction costs. The payoff of users and validators on private pools increases, but profits of arbitrageurs and validators who only stay on the public pool go down. We find that a 1% increase in the probability of being frontrun raises users' adoption rate of private pools by 0.6%. Arbitrageurs increase their cost-to-revenue ratio by a third, if they can transact on private pools.

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MS30

Does the Term-Structure of Equity At-the-Money

Skew Really Follow a Power Law?

In this work, we empirically show that the term-structure of the at-the-money (ATM) skew of equity indexes (S&P500, Eurostoxx 50 and DAX) does not follow a power law for short maturities and is much better captured by simple parametrizations that do not blow up for vanishing maturity. The ATM skew produced by the two-factor Bergomi model provides the best fits. Two other models built using non-blowing-up kernels are introduced and shown to produce similar results. By contrast, the fits of the rough Bergomi model and power law deteriorate quickly as we get closer to the first monthly options maturity.

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MS30

Pricing in Affine Forward Variance Models

In affine forward variance (AFV) models, the moment generating function may be expressed as the convolution of the forward variance curve and the solution of an associated convolution integral equation. In the case of the rough Heston model, this convolution integral equation may be solved numerically using the Adams scheme and approximately using a Pad approximation technique. We show that in the general case, AFV models may be simulated efficiently using a hybrid version of Andersen's QE scheme. We illustrate convergence of this hybrid scheme numerically in the special case of the rough Heston model.

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MS30

Rough Volatility, Path-Dependent PDEs and Weak Rates of Convergence

We first prove a path-dependent Feynman-Kac formula for stochastic Volterra equations, based on the functional It formula developed by [Viens, F., & Zhang, J. (2019). A martingale approach for fractional Brownian motions and related path dependent PDEs. *Ann. Appl. Probab.*]. We then leverage on these tools to study weak rates of convergence for discretised stochastic integrals of smooth functions of a Riemann-Liouville fractional Brownian motion with Hurst parameter $H \in (0, 1/2)$. These integrals approximate log-stock prices in rough volatility models. We obtain weak error rates of order 1 if the test function is quadratic and of order $H + 1/2$ for smooth test functions.

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MS30

Statistics and Calibration for Rough Volatility: Misconceptions and Optimal Procedures

Rough volatility models have gained considerable interest in the quantitative finance community. In this paradigm, the volatility of the asset price is driven by a fractional Brownian motion with a small value for the Hurst parameter H. In this work, we provide a rigorous statistical analysis of these models, addressing several concerns raised in the literature in the recent years. To do so, we establish minimax lower bounds for parameter estimation, design procedures based on wavelets attaining them and provide central limit theorems. We notably obtain an optimal speed of convergence of $n^{-1/(4H+2)}$ for estimating H based on n sampled data, extending results known only for the easier case $H > 1/2$ so far. We therefore establish that the parameters of rough volatility models can be inferred with optimal accuracy in all regimes.

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MS32

Bridging Shared Socioeconomic Pathways of GHG Emission and Credit Risk

We investigate the impact of transition risk on a firms low-carbon production. As the world is facing global climate change, the Intergovernmental Panel on Climate Change has set the idealized carbon-neutral scenario around 2050. In the meantime, many carbon reduction scenarios, known as Shared Socioeconomic Pathways (SSPs) have been proposed in the literature for different production sectors in a more comprehensive socio-economic context. We consider, on the one hand, a firm that aims to optimize its emission level under the double objectives of maximizing its production profit and respecting the emission mitigation scenarios. Solving the penalized optimization problem provides the optimal emission according to a given SSP benchmark. On the other hand, such transitions affect the firms credit risk. We model the default time by using the structural default approach. We are particularly concerned with how, by following different SSPs scenarios, the adopted strategies may influence the firms default probability. We then show how to incorporate physical risk and extend the previous framework to a large-sized portfolio.

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MS32

Optimal Ecological Transition Path of a Credit Portfolio Distribution, Based on Multidate Monge-Kantorovich Formulation

Accounting for climate transition risks is one of the most important challenges in the transition to a low-carbon economy. Banks are encouraged to align their investment portfolios to CO2 trajectories fixed by international agreements, showing the necessity of a quantitative methodology to implement it. We propose a mathematical formulation for this problem and a multistage optimization criterion for a transition between the current bank portfolio and a target one. The optimization Problem combines the Monge-Kantorovich formulation of optimal transport, for which the cost is defined according to the financial context, and a credit risk measure. We show that the problem is well-posed, and can be embedded into a saddle-point problem for which Primal-Dual algorithms can be used. We design a numerical scheme that is able to solve the problem in available time, with nice scalability properties according to the number of decision times; its numerical convergence is analysed. Last we test the model using real financial data, illustrating that the optimal portfolio alignment may differ from the naive interpolation between the initial portfolio and the target.

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MS32

Uncertainty-Based Regulation for Climate Risk

By now it is widely agreed that climate change poses a substantial risk to financial markets and institutions. We discuss risk management strategies in this context and advocate the use of a pre-commitment approach. Utilizing our general framework, we turn to several specific examples relating to the measurements of risks for insurance and financial companies. We also develop a method to assess the credibility of net-zero commitments, which may be applied to control the carbon budget in loan and investment portfolios. The talk relies on joint work with Gerhard Stahl, (HDI), Andrej Bajic (Deloitte FSI-Audit-Garage), Alexander Blasberg and Kateryna Chekriy (both University Duisburg-Essen).

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MS32

Optimal Business Model Adaptation Plan for a Company Under an Energy Transition Scenario

We propose a model whose goal is to assess how a firm is likely to react to a given energy transition scenario. Precisely, we aim to model its business model transition in order to keep up with new markets requirements and its implications, such as the need for new investment. In order to do so, we use stochastic control theory. We differ from other models which use a purely deterministic approach to determine the companys adaptation. Moreover, contrarily to other models where companies reactions are not anticipated but modelled as an instantaneous reaction to carbon price shocks, we put an emphasis on companies anticipation and long-term investment strategy given a transition scenario.

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MS33

On Pricing of Discrete Asian and Lookback Options under the Heston Model

We propose a new, data-driven approach for efficient pricing of – fixed- and float-strike – discrete arithmetic Asian and Lookback options when the underlying process is driven by the Heston model dynamics. The model relies on the Seven-League scheme, where artificial neural networks are employed to "learn" the distribution of the random variable of interest utilizing stochastic collocation points. The method results in a robust procedure for Monte Carlo pricing. Furthermore, semi-analytic formulae for option pricing are provided in a simplified, yet general, framework. The model guarantees high accuracy and a reduction of the computational time up to thousands of times compared to classical Monte Carlo pricing schemes.

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MS33

Accelerated Computations of Sensitivities for xVA

Exposure simulations are fundamental to many xVA calculations and are a nested expectation problem where repeated portfolio valuations create a significant computational expense. Sensitivity calculations which require shocked and unshocked valuations in bump-and-revalue schemes exacerbate the computational load. A known reduction of the portfolio valuation cost is understood to be found in polynomial approximations, which we apply in this article to interest rate sensitivities of expected exposures. We consider a method based on the approximation of the shocked and unshocked valuation functions, as well as a novel approach in which the difference between these functions is approximated. Convergence results are shown, and we study the choice of interpolation nodes. Numerical experiments with interest rate derivatives are conducted to demonstrate the high accuracy and remarkable computational cost reduction. We further illustrate how the method can be extended to more general xVA models using the example of CVA with wrong-way risk.

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MS33

Incorporating Smile in Valuation Adjustments Through the Randomization of Short-Rate Models

Short-rate models, falling in the category of Affine Diffusion (AD) processes, are frequently used for the computation of Valuation Adjustments (xVA). However, these models cannot be calibrated to the entire market volatility surface. We use the class of Randomized AD (RAnD) models to extend standard short-rate models to generate and control skew and smile from the model, to match the volatility patterns observed in financial markets. RAnD allows for exogenous stochasticity to be defined while remaining within the AD class for individual realizations of stochastic parameters, and therefore preserving analytic tractability. Prices under RAnD are recovered as a weighted sum of prices at quadrature points, where for each of the underlying prices the fast analytic pricer can be used. This allows us to calibrate the randomized short-rate model to the market efficiently. Furthermore, we can now assess the effect of market smile on xVA in an efficient way, in a practically relevant setting, with portfolios containing derivatives in multiple currencies for multiple underlyings.

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MS34

Deep Survival Analysis in the Lob: A Data-Driven Approach to Estimating Fill Probabilities

Whether to execute a trade with a limit order or a market order is an important problem in optimal execution strategies. At the crux of this decision lies an appropriate estimation of the fill probability of a limit order over time at different depths of the LOB, which can give insights into its optimal placement. To this end, we propose a deep learning method to estimate the fill times of limit orders posted in the LOB, which is tailored to the the problem of survival analysis from time-series data. We compare our method to competing benchmarks from the survival analysis literature in terms of proper scoring rules, and perform an interpretability analysis to shed light on the informativeness of features when calculating fill probabilities.

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MS34

Optimal Execution and Speculation with Trade Signals

We present a liquidity driven price impact model where we distinguish between orders that increase liquidity and orders that deplete liquidity. The stochastic price impact of orders and their arrival rates are modeled as functions of the market liquidity process which exhibit Hawkes-like dynamics that model the resilience of liquidity. We use the theory of Meyer-σ-fields to introduce a short-term signal process from which an investor learns about impending changes in price and liquidity of the traded asset. In this setting, we examine an optimal investment and execution problem and derive the Hamilton–Jacobi–Bellman (HJB) equation for the value function. The HJB equation is solved numerically and we implement the investment problem and illustrate the optimal strategy, in particular how the trader uses the signal. Finally, we showcase how signals enhance the performance of execution and of speculative strategies.

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MS34

On Adaptive Robust Optimal Execution and Machine Learning Surrogates

We investigate optimal order execution in a discrete time, stochastic linear transient price impact model based on Obizhaeva and Wang (2013), using the lens of adaptive robust stochastic control. This methodology combines dynamic statistical learning of model parameters with a worst-case min-max optimization. Specifically, adaptiveness means that the controller is dynamically learning model parameters based on her observations; and robustness implies that the controller explicitly accounts for the fact that the model parameters are unknown and their learned values are only estimates. We propose a modeling framework which allows a time-consistent 3-way marriage between dynamic learning, dynamic robustness and dynamic control. Numerically, we tackle the resulting high dimensional adaptive robust optimal order execution problem using an algorithm based on deep learning and dynamic programming.

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MS36

Robust Reinforcement Learning for Dynamic Coherent Risk Measures

Most reinforcement learning (RL) approaches seek to optimise discounted rewards for risk-neutral agents. While there is some work in risk-aware RL, they typically ignore model uncertainty or consider time-inconsistent risk-aware agents. Here, instead, we make use of dynamic coherent risk measures to assess the risk of a sequence of rewards, and robustify the agent's actions to protect against model uncertainty. Specifically, we develop a robust risk-aware RL approach for optimising strategies and illustrate the efficacy of our framework within financial applications.

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MS36

Continuous-Time Incentives in Hierarchies

In this talk, we will study a model of continuoustime optimal contracting in a hierarchy, which generalizes the one-period framework of Sung (2015). The hierarchy is modeled by a series of interlinked principal-agent problems, leading to a sequence of Stackelberg equilibria. More precisely, the principal (she) can contract with a manager (he), to incentivise him to act in her best interest, despite only observing the net benefits of the total hierarchy. The manager in turn subcontracts the agents below him. We will see through a simple example that, while the agents only control the drift of their outcome, the manager controls the volatility of the Agents continuation utility. Therefore, even this relatively simple introductory example justifies the use of recent results on optimal contracting for drift and volatility control, and therefore the theory on 2BSDEs. We will also discuss some possible extensions of this model, in particular when the outcome processes can be impacted by negative random jumps, representing accidents, and the workers can only control their intensity. Joint work in progress with Sarah Bensalem and Nicolas Hernandez-Santibanez.

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MS36

Controlled Measure-Valued Martingales: a Viscosity Solution Approach

We consider a class of stochastic control problems where the state process is a probability measure-valued process satisfying an additional martingale condition on its dynamics, called measure-valued martingales (MVMs). We establish the classical results of stochastic control for these problems: specifically, we prove that the value function for the problem can be characterised as the unique solution to the Hamilton-Jacobi-Bellman equation in the sense of viscosity solutions. In order to prove this result, we exploit structural properties of the MVM processes. Our results also include an appropriate version of Its lemma for controlled MVMs. We also show how problems of this type arise in a number of applications, including model-independent derivatives pricing, the optimal Skorokhod embedding problem, and two player games with asymmetric information.

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MS36

Optimizing Intra-Day Battery Storage Dispatch

The topic of my talk is about electric battery storage for intra-day use in electricity grids. These can be operated independently or coupled to a renewable generator. I will be talking about different ways to formulate an optimization problem (for example to maximize revenue, or to minimize the variability of a given generators output) and the respective solution approach given a stochastic model for locational marginal prices and/or generation output.

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MS37

Ergodic Robust Maximization of Asymptotic Growth under Stochastic Volatility

We consider an asymptotic robust growth problem under model uncertainty and in the presence of (non-Markovian) stochastic covariance. Building on the previous work of Kardaras Robertson we fix two inputs representing the instantaneous covariation and invariant density for the asset process X, but additionally allow these quantities to depend on a stochastic factor process Y. Under mild technical assumptions we are able to show that the robust growth optimal strategy is functionally generated and, unexpectedly, does not depend on the factor process Y. We present two financial interpretations for this result and consider some examples. The technical tools used to establish the main result rely on a combination of PDE and generalized Dirichlet form techniques.

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MS37

Arbitrage Theory in a Market of Stochastic Dimension

This talk presents an equity market of stochastic dimension, where the number of assets changes over time. In such a market, we develop the fundamental theorem of asset pricing, which provides the equivalences between the following statements; (i) there exists a supermartingale numraire portfolio; (ii) each dissected market, which is of a fixed dimension between dimensional jumps, has locally finite growth; (iii) there is no arbitrage of the first kind; (iv) there exists a local martingale deflator; (v) the market is viable. We also present the Optional decomposition theorem, which characterizes a given nonnegative process as a wealth process of some investment-consumption strategy. These results are developed in an equity market model where the price process is given by a piecewise continuous semimartingale of stochastic dimension. Without the continuity assumption on the price process, we present similar results but without explicit characterization of the numraire portfolio.

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MS37

How Fast Can One Beat the Market?

We study the largest time horizon for any sufficiently volatile market to admit relative arbitrage opportunities. The latter is characterized as the extinction time of a simplex under the minimum curvature flow [Larsson and Ruf, 2021]. However, only few explicit estimates on the latter are available so far, and the talk will focus on new such estimates.

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MS37

Mean field formulation in stochastic portfolio theory

This paper studies portfolio optimization with infinitely many interacting investors. The optimal arbitrage is characterized by the equilibrium of extended mean field games, which is then solved by a Cauchy problem with probability measure flows. We show the propagation of chaos results for the multi-player game and its approximate Nash equilibrium. We discuss a class of non-unique Cauchy problems by looking at the associated Fichera drift and reflected BSDEs.

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MS38

Joint Calibration of SPX and VIX Options with Signature-Based Models

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, whose signature serves as linear regression basis of the volatility process. Under the assumption that this primary process is of polynomial type, we obtain closed form expressions for the squared VIX by 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 squared VIX as linear functions of the signature of the augmented process. This linearity can then be efficiently used for pricing and calibration as signature samples can be easily precomputed offline. 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, but just path-dependence via the signature process.

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MS38

Fast Exact Joint SP 500/VIX Smile Calibration in Discrete and Continuous Time

We introduce the Newton-Sinkhorn and implied Newton algorithms which significantly speed up the Sinkhorn algorithm that [Guyon, The joint S&P 500/VIX smile calibration puzzle solved, 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 show how to build a continuous-time extension of the previous discrete-time model. We also compute model-free bounds on S&P 500 options that show the importance of taking VIX smile information into account. Extensive numerical tests are conducted.

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MS38

Grey Rough Bergomi for SPX-VIX Calibration

Rough volatility models have recently been developed in the context of Equity markets. They have showed to outperform most existing models under the historical measure (characterising the dynamics of volatility) and under the pricing measure (for option pricing purposes). Among this new class of models, rough Bergomi has been featured as combining desired characteristics with relative simplicity. However, one of its main drawbacks is that the instantaneous variance is Log-Normal, which is not consistent with observed data for the VIX (and options on the VIX). We investigate here a generalised family, preserving self-similarity and stationary increments, deviating from the log-normality constraint. We develop semi-closed form option pricing formulae, asymptotics and calibration procedure, and show that this tractable new model is a serious contender for the race to joint SPX-VIX calibration.

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MS38

Neural Joint SPX/VIX Smile Calibration

We calibrate neural stochastic differential equations jointly to S&P 500 smiles, VIX futures, and VIX smiles. Drifts and volatilities are modeled as neural networks. Minimizing a suitable loss allows us to fit market data for multiple S&P 500 and VIX maturities. A one-factor Markovian stochastic local volatility model is shown to fit both smiles and VIX futures within bid-ask spreads. The joint calibration actually makes it a pure path-dependent volatility model, confirming the findings in [Guyon, 2022, The VIX Future in Bergomi Models: Fast Approximation Formulas and Joint Calibration with S&P 500 Skew].

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MS39

Portfolio Optimization with Random Time in an Illiquid Market With Transaction Costs and Search Frictions

In this paper, we consider an optimal investment problem to maximize expected power-utility of the random terminal wealth in an market with two types of illiquidity: transaction costs and search frictions. In the market model, we suppose that an investor can trade only at arrival times of a Poisson process, and pays proportional transaction costs for purchasing or selling stocks. Furthermore, the random terminal time is exponentially distributed which is independent of the Poisson process and Brownian motion. We characterize a unique optimal trading strategy in terms of buy region, no-trade region, and sell region. Furthermore, we provide asymptotic expansions on small transaction costs and small search frictions for boundaries of the no-trade region and value function. The asymptotic expansions on small transaction costs and small search frictions show that the width of no-trade region widens and the diminishing effect of the value function increases as the transaction costs increase and the search frictions decrease. Moreover, the first order of the width of no-trade region and value reduction are represented by transaction costs parameter times search frictions parameter and transaction costs parameter times square root of search frictions parameter, respectively.

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MS39

Short Term Approximation for Optimal Portfolio Liquidation

This paper studies a short time approximation of optimal portfolio execution. We consider the Almgren-Chriss optimal execution problem with linear permanent and temporary impacts where the stock price is a bounded time-homogeneous Markov diffusion satisfying an SDE. For the CARA utility function, the first-order approximation formula for the logarithm of the optimal expected benefit is provided for short terminal time. We also provide an approximate strategy which gives a first-order approximation of the logarithm of the optimal expected benefit. To achieve this, applying stochastic control theory, we compute the upper bound and lower bound of the expected benefit through supermartingale and submartingale arguments, respectively.

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MS39

The Convergence Rate of the Equilibrium Measure for the Log Mean Field Game with a Common Noise

The convergence rate of equilibrium measures of N-player Games with Brownian common noise to its asymptotic Mean Field Game system is known as 1/9 with respect to 1-Wasserstein distance, obtained by the monograph [Cardaliaguet, Delarue, Lasry, Lions (2019)]. In this work, we study the convergence rate of the N-player LQG game with a Markov chain common noise towards its asymptotic Mean Field Game. The approach relies on an explicit coupling of the optimal trajectory of the N-player game driven by N-dimensional Brownian motion and the Mean Field Game counterpart driven by one-dimensional Brownian motion. As a result, the convergence rate is 1/2 with respect to the 2-Wasserstein distance. This is a joint work with Jiamin Jian, Peiyao Lai, Jiaxuan Ye.

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MS39

Optimally Terminated Contract with Asymmetric Information

We investigate the optimal contract which can be terminated by the principal and specifies the compensation to the agent at the termination. The jump-diffusion model we consider features asymmetric information so that the true status of the project is only observed by the agent and is reported to the principal. By considering an auxiliary optimal control/stopping problem of the agent, we first characterize the incentive compatible contracts under which the agent does not lie about the progress. The optimal contracts are then found within this smaller set, which reduces the optimal choice of contract to an optimal control problem to the principal.

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MS40

The Adoption of Blockchain-Based Decentralized Exchanges

We show that pricing curves implemented by automated market makers allow arbitrageurs to extract profits from liquidity providers. This raises the cost of liquidity provision, and may lead to a liquidity freeze if token pairs are too volatile. A more convex pricing curve results in higher price impact, which inhibits arbitrage but also reduces investors' surplus. The convexity of the socially optimal pricing curve is higher for more volatile token pairs. Our empirical analysis reveals that gas price volatility is 60% lower for stable-coin pairs, and that deposit inflows are negatively correlated with volatility, and positively correlated with trading volume.

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MS40

Decentralised Finance and Automated Market Making: Predictable Loss and Optimal Liquidity Provision

We introduce a new comprehensive metric of predictable loss (PL) for liquidity providers in constant function automated market makers and derive an optimal liquidity provision strategy. PL compares the value of the LP's holdings in the liquidity pool (assuming no fee revenue) with that of a self-financing portfolio that replicates the LP's holdings and invests in a risk-free account. We provide closed-form formulae for PL, and show that the losses stem from two sources: the convexity cost, which depends on liquidity taking activity and the convexity of the pool's trading function; the opportunity cost, which is due to locking the LP's assets in the pool. For LPs in constant product market makers with concentrated liquidity, we derive a closed-form strategy that dynamically adjusts the range around the exchange rate as a function of market trend, volatility, and liquidity taking activity in the pool. We prove that the profitability of liquidity provision depends on the tradeoff between PL and fee income. Finally, we use Uniswap v3 data to show that LPs have traded at a significant loss, and to show that the out-of-sample performance of our strategy is considerably superior to the historical performance of LPs in the pool we consider.

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MS40

Optimal Execution in Automatic Market Making Pools: Deep Reinforcement Learning and Galerkin Approaches

Automatic market markers (AMM) allow traders to post liquidity and trade between two cryptocurrencies. Currently, most AMMs set prices by setting the input-output of tokens by forcing a specific function of reserves to be constant before and after a trade is made. Traders may also use centralized exchanges, such as Binance or Gemini, to swap tokens. Both markets are tied to one another as arbitrageurs take advantage of mispricing. In this work, we develop a "model based and a "model agnostic approach to modeling events in AMMs and derive optimal strategies for a trader who wishes to liquidate one token in exchange for another. In the model based approach, we employ deep Galerkin methods and in the model agnostic approach we develop a deep reinforcement learning approach.

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MS40

A Mean Field Games Model for Cryptocurrency Mining

We propose a mean field game model to study the question of how centralization of reward and computational power occur in Bitcoin-like cryptocurrencies. Miners compete against each other for mining rewards by increasing their computational power. This leads to a novel mean field game of jump intensity control, which we solve explicitly for miners maximizing exponential utility, and handle numerically in the case of miners with power utilities. We show that the heterogeneity of their initial wealth distribution leads to greater imbalance of the reward distribution, and increased wealth heterogeneity over time, or a "rich get richer" effect. This concentration phenomenon is aggravated by a higher bitcoin mining reward, and reduced by competition. Additionally, an advantaged miner with cost advantages such as access to cheaper electricity, contributes a significant amount of computational power in equilibrium, unaffected by competition from less efficient miners. Hence, cost efficiency can also result in the type of centralization seen among miners of cryptocurrencies.

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MS41

Harry Markowitz Meets James Stein: How Two Influential But Wildly Disparate Theories from the 1950s Combine to Create Better Portfolios

Recent research identifies and corrects bias, such as excess dispersion, in the leading sample eigenvector of a factor-based covariance matrix estimated from a high dimension low sample size (HL) data set. We show that eigenvector bias can have a substantial impact on variance-minimizing optimization in the HL regime, while bias in estimated eigenvalues may have little effect. We describe a data-driven eigenvector shrinkage estimator in the HL regime called "James-Stein for Eigenvectors" (JSE) and its close relationship to the James-Stein (JS) estimator for a collection of averages. We show, both theoretically and with numerical experiments, that, for certain variance-minimizing problems of practical importance, efforts to correct eigenvalues have little value in comparison to the JSE correction of the leading eigenvector.

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MS41

Neutralizing Optimization Bias in Multi Constrained Optimized Portfolios

Estimation error in a covariance matrix distorts optimized portfolios, and the effect is pronounced when the number of securities p exceeds the number of observations n. In the HL regime where $p >> n$, we show that a material component of the distortion can be attributed to optimization specific biases that correspond to the constraints used to construct the portfolio. Using Multiple Anchor Point Shrinkage (MAPS) for eigenvectors developed in Gurdogan and Kercheval (2021), we materially eliminate these optimization specific biases for large p, and zero them out asymptotically, leading to more accurate portfolios. This work extends the correction of the dispersion bias in Goldberg, Papanicolaou and Shkolnik (2022).

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Direction-Regularized PCA and Its Applications to Asset Pricing

We propose a new regularization method and its fast machine learning algorithm called direction-regularized principal component analysis (drPCA). The regularization method solves the PCA problem that seeks the direction of maximum variance of the data subject to some prior target direction. An asymptotic analysis of the solution by the high-dimensional low-sample size framework gives an optimal tuning parameter that minimizes an asymptotic loss function, and the data quickly learns the corresponding estimator to the optimal tuning parameter. We can also show that our estimator is equivalent to the Ledoit-Wolf constant correlation shrinkage estimator and a recently proposed James-Stein estimator for the first principal component under some specific covariance structures. Finally, our estimator significantly improves risk measures in asset pricing when an investor constructs a portfolio under the mean-variance scheme.

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MS41

Subspace Shrinkage for PCA and Applications to Portfolio Theory

We analyze the interplay between risk factors and the accuracy of minimum variance portfolios constructed from p risky securities. We show that estimation error in any (risk) factor with loadings that have a non-zero mean materializes in a large gap between the estimated and actual porfolio risks. Moreover, this "gap" grows with the dimension p, a phenomenon sometimes referred to as the Markowitz enigma. The latter alludes to the fact that "variance minimizers are excellent error maximizers". Building on recent work on this problem in the setting of a single risk factor (i.e., the market), we construct a principal component analysis (PCA) model that optimally corrects any number of estimated risk factors (i.e., principal components). The approach involves a subspace shrinkage formula in terms of a matrix-valued parameter that is computed from the sample eigenvalues of the security returns covariance matrix. We prove that this correction of the principal components leads to minimum variance portfolios for which the risk vanishes asymptotically in p almost surely. Numerical simulations of risk models calibrated to the US equity market confirm our theoretical findings.

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MS43

SOFR Term Structure Dynamics Discontinuous Short Rates and Stochastic Volatility Forward Rates

As more and more jurisdictions transition from LIBOR-type interest rate benchmarks to new riskfree rate (RFR) benchmarks based on overnight rates, such as SOFR in the US, it is important to adapt interest rate term structure models to reflect this. In particular, overnight rates are largely driven by monetary policy and thus display dynamics that are (at least to first order) piecewise constant between central bank rate decisions, while forward rates continue to evolve in a more diffusive fashion. We construct a tractable multifactor, stochastic volatility term structure model which incorporates these features. Calibrating to prices for options on SOFR futures, we achieve a good fit to the market across available maturities and strikes in a single, consistent model. The model also provides novel insights into SOFR term rate behaviour (and implied volatilities) within the SOFR term rate accrual periods, as well as into empirical mean reversion dynamics.

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MS43

Expected and Unexpected Jumps in the Overnight Rate: Consistent Management of the Libor Transition

Interest-rate benchmark reform has revived short-rate modelling. One reason is that short-rate models provide a consistent framework in which different benchmarks, and contracts linked to them, can be compared. Another reason is that new benchmarks can be directly dependent on very short-term rates; the key example is a backward-looking compounding of overnight rates, a prominent alternative to forward-looking Libor. Indeed, under Libor, one can often safely ignore aspects of short-rate behaviour, especially jumps. At least partially for this reason, jumps are inadequately treated in the interest-rate literature, particularly expected jumps (jumps with known timing). We estimate a model with expected and unexpected jumps, which involves separating their effect on term rates. We then price forward- and backward-looking caplets, quantifying the spread exhibited by the latter over the former. Expected jumps lead to significantly time-inhomogeneous option behaviour, particularly for short-term options linked to a backward-looking benchmark.

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MS43

Cross Currency HJM Models in the Multiple Curve Framework

The aim of the present talk is to discuss HJM cross currency models that can serve as the basis for the simulation of exposure profiles in the xVA context. Such models need to take into account the asymmetries that arise in the different currency denominations in view of the benchmark reform: for example, while in the EUR area Euribor is still the dominant interest rate benchmark, the situation in the US is much more complex due to the introduction of SOFR and alternative forward looking unsecured rates such as the Bloomberg BSBY or the Ameribor 90T. The impact of the Libor transition on the structure of cross currency swap is also an aspect we would like to address. In summary we would like to: - Provide, in a HJM setting, a unified treatment of forward looking and backward looking rates with and without a credit/liquidity component, i.e. consider a HJM setting for a general underlying index in each currency area. - Properly link such general single currency HJM models by means of cross currency processes that capture the cross currency basis. - Analyze cross currency swaps with arbitrary combinations of interest rate indexes and collateral rates in the different currency areas i.e. with and without Libor discontinuation.

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MS43

The Generalized Forward Market Model: Genesis and Extensions

In this paper, we show how the generalized Forward Market Model (FMM) introduced by Lyashenko and Mercurio (2019) can be extended to make it a complete term-structure model describing the evolution of all points on a yield curve, as well as of the bank account, and not just of a spanning set of forward term rates. The extended model is both theoretically sound and computationally efficient. The FMM is an extension of the popular Libor Market Model (LMM), so it can be also used to complete the yield curve evolution under existing LMM implementations.

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MS44

Impermanent Loss in Automated Market Making

As DeFi increased in popularity, it quickly became necessary to find tools that could play the same role as Limit Order Books in traditional finance, so that actors could easily exchange crypto assets. This has led to the design of Automated Market Makers (AMMs), which are protocols that permit the automated execution of buy and sell orders in a blockchain. The principle of an AMM is simple: any user can deposit their tokens in a so-called liquidity pool, where other actors can then use them for their trading activities. Impermanent loss (IL) is the difference in value (at some time horizon) between providing liquidity by adding tokens to a pool and keeping the tokens outside. Multiple AMM protocols lead to different ILs; the latter are also impacted by the trading fees offered to liquidity providers. In this work, we compare the distribution of Impermanent losses according to the different AMMs.

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MS44

Automated Market Making and Loss-Versus-

Rebalancing

We consider the market microstructure of AMM and, specifically, constant function market makers (CFMMs), from the economic perspective of passive liquidity providers (LPs). In a frictionless, continuous-time Black-Scholes setting and in the absence of trading fees, we decompose the return of an LP into a instantaneous market risk component and a non-negative, non-decreasing, and predictable component which we call "loss-versus-rebalancing". Market risk can be fully hedged, but once eliminated, LVR remains as a running cost that must be offset by trading fee income in order for liquidity provision to be profitable. LVR is distinct from the more commonly known metric of "impermanent loss" or "divergence loss"; this latter metric is more fundamentally described as "loss-versus-holding" and is not a true running cost. We express LVR simply and in closed-form: instantaneously, it is the scaled product of the variance of prices and the marginal liquidity available in the pool, i.e., LVR is the floating leg of a generalized variance swap. As such, LVR is easily calibrated to market data and specific CFMM structure. LVR provides tradeable insight in both the ex ante and ex post assessment of CFMM LP investment decisions, and can also inform the design of CFMM protocols.

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MS44

Decentralised Finance and Automated Market Making: Execution and Speculation

Automated market makers (AMMs) are a new prototype of trading venues which are revolutionising the way market participants interact. At present, the majority of AMMs are constant function market makers (CFMMs) where a deterministic trading function determines how markets are cleared. A distinctive characteristic of CFMMs is that execution costs are given by a closed-form function of price, liquidity, and transaction size. This gives rise to a new class of trading problems. We focus on constant product market makers and show how to optimally trade a large position in an asset and how to execute statistical arbitrages based on market signals. We employ stochastic optimal control tools to devise two strategies. One strategy is based on the dynamics of prices in competing venues and assumes constant liquidity in the AMM. The other strategy assumes that AMM prices are efficient and liquidity is stochastic. We use Uniswap v3 data to study price, liquidity, and trading cost dynamics, and to motivate the models. Finally, we perform consecutive runs of in-sample estimation of model parameters and out-of-sample liquidation and arbitrage strategies to showcase the performance of the strategies.

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MS44

Credible Decentralized Exchange Design via Verifiable Sequencing Rules

Trading on DEX has been one of the primary use cases for permissionless blockchains with daily trading volume exceeding billions of U.S. dollars. In the status quo, users broadcast transactions and miners are responsible for composing a block of transactions and picking an execution ordering. Due to the lack of a regulatory framework, it is common to observe miners exploiting their privileged position by front-running transactions and obtaining risk-fee profits. We propose to modify the interaction between miners and users and initiate the study of verifiable sequencing rules. As in the status quo, miners can determine the content of a block; however, they commit to respecting a sequencing rule that constrains the execution ordering and is verifiable. Thus in the event a miner deviates from the sequencing rule, anyone can generate a proof of non-compliance. We ask if there are sequencing rules that limit price manipulation from miners in a two-token liquidity pool exchange. Our first result is an impossibility theorem: for any sequencing rule, there is an instance of user transactions where the miner can obtain non-zero risk-free profits. In light of this impossibility result, our main result is a verifiable sequencing rule that provides execution price guarantees for users.

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MS45

Multidimensional Singular Control and Related Skorokhod Problem: Sufficient Conditions for the Characterization of Optimal Controls

We characterize the optimal control for a class of singular stochastic control problems as the unique solution to a related Skorokhod reflection problem. The considered optimization problems concern the minimization of a discounted cost functional over an infinite time-horizon through a process of bounded variation affecting an It-diffusion. In a multidimensional setting, we prove that the optimal control acts only when the underlying diffusion attempts to exit the so-called waiting region, and that the direction of this action is prescribed by the derivative of the value function. Our approach is based on the study of a suitable monotonicity property of the derivative of the value function through its interpretation as the value of an optimal stopping game. Such a monotonicity allows to construct nearly optimal policies which reflect the underlying diffusion at the boundary of approximating waiting regions. The limit of this approximation scheme then provides the desired characterization. Our result applies to a relevant class of linear-quadratic models, among others. Furthermore, it allows to construct the optimal control in degenerate and non-degenerate settings considered in the literature, where this important aspect was only partially addressed. This talk is based on a joint work with Giorgio Ferrari.

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MS45

Learning Equilibrium Mean-Variance Strategy

We study a dynamic mean-variance portfolio optimization problem under the reinforcement learning framework, where an entropy regularizer is introduced to induce exploration. Due to the time–inconsistency involved in a mean-variance criterion; we aim to learn an equilibrium policy. Under an incomplete market setting, we obtain a semi-analytical, exploratory, equilibrium mean-variance policy that turns out to follow a Gaussian distribution. We then focus on a Gaussian mean return model and propose a reinforcement learning algorithm to find the equilibrium policy. Thanks to a thoroughly designed policy iteration procedure in our algorithm, we prove the convergence of our algorithm under mild conditions, despite that dynamic programming principle and the usual policy improvement theorem failing to hold for an equilibrium policy. Numerical experiments are given to demonstrate our algorithm. The design and implementation of our reinforcement learning algorithm apply to a general market setup.

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MS45

Agency Problem and Mean Field System of Agents with Moral Hazard, Synergistic Effects and Accidents

We investigate the existence of an optimal policy to monitor a mean-field system of agents managing a risky project under moral hazard with accidents modeled by Lvy processes magnified by the law of the project. We provide a general method to find both a mean field equilibrium for the agents and the optimal compensation policy under general, sufficient and necessary assumptions on all the parameters. We formalize the problem as a bilevel optimization with the probabilistic version of mean-field games which can be reduced to a controlled McKean-Vlasov SDE with jumps. We apply our results to an optimal energy demand-response problem with a crowd of consumers subjected to power cut/shortage when the variability of the energy consumption is too high under endogenous or exogenous strains. In this example, we get an explicit solution to the mean-field game and to the McKean-Vlasov equation with jumps.

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MS46

Convergence Rates for Backward Sdes Driven by Lvy Processes

We consider a Backward SDEs driven by infinite activity pure-jump Lvy process $X = (X_t)_{0\leq t\leq T}$. Our aim is to give an explicit convergence rate in L^2 and Wasserstein distance when the solution of the BSDEs is approximated by a solution to a BSDE driven by a compound Poisson process or more general. The starting point is the convergence result of [Papapantoleon et al., Stability of backward differential equations: the general case]. When the generators are matched, the rate will be $1/(n^{1-\frac{\beta}{2}})$, where β is bigger than the Blumenthal–Getoor index β_*. We will consider two different settings in order to derive convergence rates for BSDEs driven by Lvy processes. In the first setting, the terminal condition will be a "Markovian' function of the terminal random variable X_T, while the approximating sequence $(X^n)_{n\in\mathbb{N}}$ will be general. In the second setting, the terminal condition will be general, while the approximating sequence will have the form $X^n_t = \int_0^t \int_{\|x\|\geq n^{-1}} \quad x\widetilde{\mu}^n(ds, dx)$; in that case, the Lvy measure may not necessarily have the "canonical' form.

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MS46

One Step Malliavin Schemes: a BSDE Approach for the Pricing and Delta-Gamma Hedging of Multi-Asset European and Bermudan Options

In this talk, our recent works on the One Step Malliavin (OSM) scheme are presented for both standard and discretely reflected FBSDE systems. Such equations naturally appear in the pricing and hedging of European and Bermudan options. Our novel discretization schemes exploit a linear BSDE representation for the Z process stemming from Malliavin calculus, and imply the need to provide accurate Γ estimates corresponding to second-order Greeks of the associated option prices. Therefore, the resulting schemes give a robust and efficient way to perform delta-gamma hedging which is a fundamental task in risk management. Two fully-implementable schemes are considered using Fourier cosine expansions, and neural network Monte Carlo regressions in case of high-dimensional problems, similarly to the recently emerging class of Deep BSDE methods. Theoretical analyses are given showing optimal convergence rates. Numerical experiments are provided up to 50 dimensions, exhibiting accurate solutions of the FBSDE systems and demonstrating that the resulting hedging strategies significantly outperform benchmark methods both in case of standard delta and delta-gamma hedging.

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MS46

Convergence of a Robust Deep Fbsde Method for Stochastic Control

In this presentation, we present a deep learning based numerical scheme for strongly coupled FBSDEs, stemming from stochastic control. It is a modification of the deep BSDE method in which the initial value to the backward equation is not a free parameter, and with a new loss function being the weighted sum of the cost of the control problem, and a variance term which coincides with the mean squared error in the terminal condition. Under regularity and boundedness assumptions on the exact controls of time continuous and time discrete control problems, we provide an error analysis for our method. We show empirically that the method converges for three different problems, one being the one that failed for a direct extension of the deep BSDE method.

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MS46

A Posteriori Error Estimates for Fully Coupled McKean-Vlasov Forward-Backward SDEs

Fully coupled McKeanVlasov forward-backward stochastic differential equations (MV-FBSDEs) arise naturally from large population optimization problems. Judging the quality of given numerical solutions for MV-FBSDEs, which usually require Picard iterations and approximations of nested conditional expectations, is typically difficult. In this talk, we discuss an a posteriori error estimator to quantify the L_2-approximation error of an arbitrarily generated approximation on a time grid. We establish that the error estimator is equivalent to the global approximation error between the given numerical solution and the solution of a forward Euler discretized MV-FBSDE. A crucial and challenging step in the analysis is the proof of stability of this Euler approximation to the MV-FBSDE, which is of independent interest. We further demonstrate that, for sufficiently fine time grids, the accuracy of numerical solutions for solving the continuous MV-FBSDE can also be measured by the error estimator. The error estimates justify the use of residual-based algorithms for solving MV-FBSDEs. Numerical experiments for a MV-FBSDE arising from a mean field game confirm the effectiveness and practical applicability of the error estimator.

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MS47

A Mean-Field Version of Bank-El Karoui's Representation of Stochastic Processes

We study a mean-field version of Bank-El Karouis representation theorem of stochastic processes. Under different technical conditions, we establish some existence and uniqueness results. In particular, we derive a stability result on the classical Bank-El Karouis representation theorem, which would have its own interests. Finally, as motivation and applications, our mean-field representation results provide a unified approach to study different Mean-Field Games (MFGs) in a setting with common noise and multiple populations, including the MFG of timing, the MFG with singular control, etc.

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MS47

Moral Hazard for Time-Inconsistent Agents

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.

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MS47

A Mean Field Game Approach to Equilibrium Consumption under External Habit Formation

This paper studies the equilibrium consumption under external habit formation in a large population of agents. We first formulate problems under two types of conventional habit formation preferences, namely linear and multiplicative external habit formation, in a mean field game framework. In a log-normal market model with the asset specialization, we characterize one mean field equilibrium in analytical form in each problem, allowing us to understand some quantitative properties of the equilibrium strategy and conclude distinct financial implications caused by different consumption habits from a mean field perspective. In each problem with n agents, we then construct an approximate Nash equilibrium for the n-player game using the obtained mean field equilibrium when n is sufficiently large. The explicit convergence order in each problem can also be obtained.

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MS47

Time Consistent HJB Equation and Deep Learning for General Mean Variance Models

We consider an equilibrium strategy for investment and consumption in a general mean-variance model, which covers many well-known models in portfolio selection literature, including expected-utility, mean-variance, log-mean-variance. We derive the time-consistent HJB equation for the equilibrium value function and provide the verification theorem. We find the equilibrium investment and consumption strategies for the complete market model and the Heston stochastic volatility model. We solve numerically for the general model with the physics informed neural network (PINN) and compare our model with others to illustrate the impact of consumption and variance on portfolio selection.

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MS48

Feature-Based Time Series Generator with GANs

Identifying features from non-stationary time series is a challenging problem since the features are covered by noise and features may vary across time. How- ever, in real world, non-stationary time series are more general and contain more information. Here, we design an algorithm to solve this problem. The resulting algorithm can identify not only static features, but also capture the dynamic features which are the nature of time series dataset. In theory, we prove this algorithm is sound and complete, hence deep features can be obtained. Based on those features, Generative adversarial network can be used to generate various samples. The algorithm outperforms other state-of-the-art methods, including Quant-Gan and Time Series Gan, on simulated stochastic process. Our method also performs well on real data. The solid theory foundation and competitive performance make it a suitable method for discovering features from time series and further generating samples.

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MS48

Learning by Neural Directed Chain Stochastic Equations

We shall discuss data generation via the system of the neural stochastic equations with distributional constraints on the directed network. Here, each node on the graph represents a stochastic process with common distribution in the sample path space and has interactions only with its neighborhood nodes on some filtered probability space. Based on the probabilistic understanding of the evolution of the measure, the sequential data are generated from the the inputs that are treated as the neighborhood processes of the target in the system. The advantage of this approach is to learn and generate the sequential data that might come from evolutions of distributions which are not necessarily unimodal, and capture the multi-modal property of the marginal distributions. We discuss financial applications including portfolios and electricity uses.

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MS48

Attention-Based Reading, Highlighting, and Forecasting of the Limit Order Book

Managing high-frequency market data has been a challenging task in finance. A limit order book is a collection of orders that a trader intends to place, either to buy or sell at a certain price. Traditional approaches often fall short in forecasting future limit orders because of their high frequency and volume. In this study, we propose a modified attention algorithm to analyze the movement patterns in a limit order book. The enormous amount of data with millisecond time stamps are efficiently examined and processed using an attention module, which highlights important aspects of limit orders. We demonstrate that our modified attention algorithm improves the forecasting accuracy of limit orders.

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MS48

Algorithmic Trading in a Hawkes Flocking LOB Model

In this work, we model the dynamics of the Best Bid and Ask price of a financial asset using the Hawkes-flocking model and study the optimal placement problem under the model. The Hawkes flocking model is modified version of multivariate Hawkes process with flocking mechanism, derived from a stochastic cucker-smale flocking system. Under this price process model, we study the optimal order placement problem: the trader makes its decision at discrete time points until time T to maximize its cash flow under restrictions. We derive the solution under different market regimes.

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MS49

Calculation of Enterprise Capital via Least-squares Monte Carlo Regress Now or Later?

The difficulty of estimating risk capital arises from characterizing the distribution of the companys available capital. One prevalent approach, referred to as regression-now, projects the companys realized cash flows and regresses resulting discounted values against a set of basis functions of the Markov states at the risk horizon. Another approach seeks to approximate the cash-flows based on functions of realizations of a class of tractable processes, and in a second step calculates the conditional expected value of the approximating functional combination at the risk horizon. This approach is referred to as regression-later. Different authors documented advantages and disadvantages to both approaches in specific situations. This paper makes two contributions. The first is theoretical. We show that the left and right singular functions of the valuation operator mapping cash flows to capital present robust approximating functions for the regress-now and regress-later approach, respectively. We show superior performance of the approaches when relying on these functions. The second contribution is applied. We characterize situations in which either of the approaches results in a superior performance. In essence, the regress-later approach performs better when underlying theoretical conditions are met, whereas the regress-now approach is the more robust approach.

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MS49

Optimal Consumption, Investment, and Insurance Under State-Dependent Risk Aversion

We formalize a consumption-investment-insurance problem with the distinction of a state-dependent relative risk aversion. The state-dependence refers to the state of the finite state Markov chain that also formalizes insurable risks such as health and lifetime uncertainty. We derive and analyze the implicit solution to the problem, compare it with special cases in the literature, and illustrate the range of results in a disability model where the relative risk aversion is preserved, decreases, or increases upon disability. We also discuss whether the approach is appropriate to deal with uncertainty in relative risk aversion and consider some alternative ideas.

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MS49

Stackelberg Reinsurance Chain under Model Ambiguity

In this paper, we consider a continuous-time version of a reinsurance chain, which is sequentially formed by n+1 companies, with the first company being the primary insurer and the rest being reinsurers. Because of possible model misspecification, all companies are ambiguous about the original risk of the primary insurer. We model each reinsurance contracting problem as a Stackelberg game, in which the assuming reinsurer acts as the leader while the ceding company is the follower. Reinsurance is priced using the mean-variance premium principle and all companies are risk neutral under their own beliefs. We obtain equilibrium indemnities, premium loadings, and distortions in closed form, all of which are proportional to the original risk, with the corresponding proportions decreasing along the chain. We also show that the reinsurance chain with ambiguity aversions in increasing order is optimal from the perspectives of both selfish individual companies and an unselfish central planner.

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MS50

Double Data Piling for Heterogeneous Covariance Models

In this work, we characterize two data piling phenomena for a high-dimensional binary classification problem with heterogeneous covariance models. The data piling refers to the phenomenon where projections of the training data onto a direction vector have exactly two distinct values, one for each class. This first data piling phenomenon occurs for any data when the dimension p is larger than the sample size n. We show that the second data piling phenomenon, which refers to a data piling of independent test data, can occur in an asymptotic context where p grows while n is fixed. We further show that a second maximal data piling direction, which gives an asymptotic maximal distance between the two piles of independent test data, can be obtained by projecting the first maximal data piling direction onto the nullspace of the common leading eigenspace. This observation provides a theoretical explanation for the phenomenon where the optimal ridge parameter can be negative in the context of high-dimensional linear classification.

Based on the second data piling phenomenon, we propose various linear classification rules which ensure perfect classification of high-dimensional low-sample-size data under generalized heterogeneous spiked covariance models.

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MS50
On Graphical Models and Convex Geometry

We introduce a mixture-model of beta distributions to identify significant correlations among P predictors when P is large. The method relies on theorems in convex geometry, which we use to show how to control the error rate of edge detection in graphical models. Our betaMix method does not require any assumptions about the network structure, nor does it assume that the network is sparse. The results hold for a wide class of data generating distributions that include light-tailed and heavy-tailed spherically symmetric distributions.

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MS50
Large Covariance Matrix Estimation for Portfolio Risk Prediction

Most covariance matrix estimation studies consider portfolio optimization applications, ultimately mitigating the "error maximization" property of optimizers. It has been found that estimators such as those based on the spiked covariance model may dramatically improve the robustness of optimized portfolios and reduce their out-of-sample risk. However, correcting one kind of error might lead to introducing errors in other applications, such as portfolio risk measurement. This talk is focused on covariance estimation issues which arise in the application of risk prediction for different portfolios, especially in the high-dimension low-sample-size regime. A spiked covariance model is considered, and the effects of eigenstructure shrinkage methods on the risk prediction errors are analyzed. An experimental study is presented, for a range of dimensionality scenarios and various portfolios, together with some insights for practitioners and directions for future work.

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MS50
Adjusting Systematic Bias in High Dimensional Principal Component Scores

Principal component analysis continues to be a powerful tool in dimension reduction of high dimensional data. We assume a variance-diverging model and use the high-dimension, low-sample-size asymptotics to show that even though the principal component directions are not consistent, the sample and prediction principal component scores can be useful in revealing the population structure. We further show that these scores are biased, and the bias is asymptotically decomposed into rotation and scaling parts. We propose methods of bias-adjustment that are shown to be consistent and work well in the high dimensional situations with small sample sizes. The potential advantage of bias-adjustment is demonstrated in a classification setting.

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MS51
Dynamic Inventory Management with Mean-Field Competition

Agents attempt to maximize expected profits earned by selling multiple units of a perishable product where their revenue streams are affected by the prices they quote as well as the distribution of other prices quoted in the market by other agents. We propose a model which captures this competitive effect and directly analyze the model in the mean-field limit as the number of agents is very large. We classify mean-field Nash equilibrium in terms of the solution to a Hamilton-Jacobi-Bellman equation and a consistency condition and use this to motivate an iterative numerical algorithm to compute equilibrium. Properties of the equilibrium pricing strategies and overall market dynamics are then investigated, in particular how they depend on the strength of the competitive interaction and the ability to oversell the product.

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MS51
Data-Driven Modeling of Limit Order Markets

For many applications, market participants are more interested in time series of limit order book (LOB) snapshots rather than the precise event stream. One reason for this is sufficient amount of information in the evolution of such snapshots. One interesting problem, when modeling LOBs and generating synthetic data is to reflect market impact which is non-observable in the market. This study leverages generative adversarial networks (GANs) to model and simulate time series of LOB snapshot. More precisely, we learn the conditional probability distribution of future LOB snapshots based on past states. Our results show GANs are able to learn LOB transitions and capture a variety of stylized facts when properly tuned. Recurrent simulation allows to generate entire time series of order book data. Finally, we show that the trained generator can reflect stylized properties from market impact studies. In particular, the model shows a decaying marginal impact of trade size, higher impact of liquidity extraction than liquidity provision as well as decreasing impact with increasing depths. These results are even more interesting as the model learns these properties despite not being trained to do so and a very reduced state space. Our research opens plenty of avenues which can be pursued in this direction. These are the inclusion of longer history, more state variables as well as an improved training procedure amongst others.

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MS51

Brokers and Informed Traders: Dealing with Toxic Flow and Extracting Trading Signals

We derive closed-form strategies for a broker who provides liquidity to an informed trader and to a noise trader over a finite-time and infinite-time trading horizon. The flow of the noise trader is uninformative and the broker trades with the noise trader at a profit, on average. On the other hand, the informed trader has privileged information about the trend in the price of the asset, so the broker trades with the informed trader at a loss, on average. These losses are payment for toxic flow from which the broker extracts the trend signal. The signal is one of the key ingredients in the broker's trading strategy to internalise (i.e., how much of the flow she keeps in her books), to externalise (i.e., how much she unwinds in a lit exchange), and to speculate in the lit market. The broker's dynamic strategy is a linear combination of four variables: the broker's inventory, the informed trader's inventory, the trend signal, and the uninformed trader's rate of trading with the broker. When the trading horizon is infinite (resp. finite), the coefficients of the four terms are constants (resp. deterministic functions of time). Finally, in the infinite horizon case, we show how the broker uses the flow of her clients to estimate the constant coefficients of the optimal strategy.

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MT1

Decentralized Finance and Blockchain Technology

Decentralized finance has soared in popularity since 2020, accounting for hundreds of billions of dollars in trade volume over the past two years. During this tutorial, we will begin by overviewing the core differences between centralized and decentralized finance, with a focus on those platforms underlying infrastructure (Blockchain), their design, their microstructure (Order books and Automated Market Makers), and what impact those differences have in the methodology used to value cryptocurrencies in a hybrid (on-chain and off-chain) world. Topics that will be talked about deeply include the impact of the blockchains inherent latency to design choices (AMMs vs Orderbooks or Hybrid DeFi Derivatives platforms), and similarities between high-frequency trading attacks and attacks observed on DeFi protocols. The DeFi protocols categories we will go through include decentralized exchanges, lending protocols, and DeFi derivatives. This tutorial will address these topics from a descriptive point of view to understand how it works in reality and from a quantitative point of view to model them. The presentation will also include open problems and future perspectives.

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MT1

Decentralized Finance and Blockchain Technology

Input your abstract, including TeX commands, here. The abstract should be no longer than 1500 characters, including spaces. Only input the abstract text. Don't include title or author information here.

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MT2

Signature Methods in Finance

The signature of a path provides a faithful, non-parametric way to extract characteristic features from data streams evolving in time. In recent years, data-driven methods based on signatures have been successfully applied to various areas of stochastic modeling and mathematical finance, such as the pricing of European and American options, optimal execution problems, and Sig-SDE models for financial markets. The signature can be understood as an enhancement of a path with its iterated integrals, and constitutes a central object in the theory of rough paths, which offers a pathwise approach to stochastic integration and differential equations. This minitutorial aims to provide a gentle introduction to the concept of signatures and to the theory of rough paths, whilst keeping their applications to mathematical finance in mind. In particular, we study theoretical and numerical results underpinning the suitability of the signature transform as a feature map, and present the general underlying ideas behind signature methods. Some recent applications of signature methods and rough paths to challenges in mathematical finance will also be discussed.

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PP1

Multiperiod Static Hedging of European Options

We consider the hedging of options when the price of the underlying asset is determined by the Black-Scholes framework and the Heston stochastic volatility model. By working in a single-factor Markovian setting, Carr and Wu derived a spanning relation between a given option and a continuum of shorter-term options written on the same asset. In the constructed portfolio of shorter-term options, the portfolio weights do not vary with the underlying asset price or calendar time. While they had only considered the case of using options with a single short maturity and over an infinite range of strike points, we have modified their approach to simultaneously include options with two short maturities over any bounded range of strikes, that can be readily extended to any finite number of short maturities. We then implement this static relation using a finite set of shorter-term options to determine the hedging error using a Gaussian quadrature(GQ) method. We perform a wide range of experiments for both the Black-Scholes and the Heston models, to do a comparative study illustrating the performance of the two methods. For the Heston models dynamics, the portfolio weights and strikes are calculated using two different approaches: 1. computing the portfolio weights and strikes assuming Black-Scholes volatility; 2. computing the portfolio weights and strikes by using a Black-Scholes implied volatility.

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PP1

Stochastic Algorithms for Advanced Risk Budgeting

Modern portfolio theory has provided for decades the main framework for optimizing portfolios. Because of its sensitivity to small changes in input parameters, especially expected returns, the mean-variance framework proposed by Markowitz (1952) has however been challenged by new construction methods that are purely based on risk. Among risk-based methods, the most popular ones are Minimum Variance, Maximum Diversification, and Risk Budgeting (especially Equal Risk Contribution) portfolios. Despite some drawbacks, Risk Budgeting is particularly attracting because of its versatility: based on Euler's homogeneous function theorem, it can indeed be used with a wide range of risk measures. This paper presents sound mathematical results regarding the existence and the uniqueness of Risk Budgeting portfolios for a very wide spectrum of risk measures and shows that, for many of them, computing the weights of Risk Budgeting portfolios only requires a standard stochastic algorithm.

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PP1

Global Gauge Symmetries, Risk-Free Portfolios, and the Risk-Free Rate

We define risk-free portfolios using three gauge invariant differential operators that require such portfolios to be insensitive to price changes, to be self-financing, and to produce a zero real return so there are no risk-free profits. This definition identifies the risk-free rate as the return of an infinitely diversified portfolio rather than as an arbitrary external parameter. The risk-free rate measures the rate of global price rescaling, which is a gauge symmetry of economies. We explore the properties of risk-free rates, rederive the Black Scholes equation with a new interpretation of the risk-free rate parameter as a that background gauge field, and discuss gauge invariant discounting of cash flows.

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PP1

On Decomposition of the Last Passage Time of Diffusions

For a regular transient diffusion X on $(\ell, r) \subset \mathbb{R}$, we decompose the Laplace transform of its last passage time to a certain state α into a simple formula based on Green functions. This formula is convenient for further investigations of diffusions with switching parameters which, for example, have applications in stochastic control problems. The last passage time $\lambda_\alpha := \sup\{t : X_t = \alpha\}$ is not a stopping time because it looks into the future path of the process. Such times have a wide range of applications in financial modeling such as the analysis of default risk, insider trading, and option valuation. We first transform the original diffusion into two processes X^A and X^B using the occupation time of the region above and below α. The final decomposition formula is expressed as

$$\mathbb{E}^\alpha[e^{-q\lambda_\alpha}] = \frac{G_q^A(\alpha,\alpha)}{G_q^A(\alpha,\alpha) + G_q^B(\alpha,\alpha)} \cdot \frac{G_q^B(\alpha,\alpha)}{G_0^B(\alpha,\alpha)}$$

where $G_\cdot^A(\cdot,\cdot)$ and $G_\cdot^B(\cdot,\cdot)$ are the Green functions of X^A and X^B, respectively. Our results allow us to bypass (often) hard calculations related to diffusions with switching parameters because we can reduce the problem to two processes with no switching parameters. We demonstrate this in the case of a diffusion with two-valued drift.

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PP1

Gradient-Based Estimation of Linear Hawkes Processes With General Kernels

Linear multivariate Hawkes processes (MHP) are a fundamental class of point processes with self-excitation. When estimating parameters for these processes, a difficulty is that the two main error functionals, the log-likelihood and the least squares error (LSE), as well as the evaluation of their gradients, have a quadratic complexity in the number of observed events. In practice, this prohibits the use of exact gradient-based algorithms for parameter estimation. We construct an adaptive stratified sampling estimator of the gradient of the LSE. This results in a fast parametric estimation method for MHP with general kernels, applicable to large datasets, which compares favourably with existing methods.

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PP1

Irreversible Investment Decision Problem with

Regime-Switching Jump-Diffusion Models on a Finite Time Horizon

An irreversible investment decision problem on a finite time horizon is considered where an underlying cash flow follows a regime-switching jump-diffusion model. When new projects are launched, the investor is faced with the situation to determine an optimal irreversible investment time to maximize the discounted payoff on the finite time horizon. The value of a project is evaluated by solving a partial integro-differential equation (PIDE) and it can be expressed as a closed-form solution. The value function with a finite expiration date is computed by using a finite difference mehod combined with an operator spliting method. A variety of numerical simulation under the regime-switching jump-diffusion model are performed to determine the optimal investment time in a project and show that the proposed method has the second-order convergence rate in the time and spatial variables.

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PP1

The Forecasting of Crude Oil Prices Using Particle Filters

The fluctuations in oil prices are one of the critical issues in South Korea as an energy-importing country. Due to the sensitivity of oil-related events, it is important to predict the oil price changes in the Korean economy for stable operation. Particle filters are one of the data assimilation methods, which are called sequential Monte-Carlo methods and commonly used in various fields such as manufacturing, producer services and distribution services. Particularly, in finance, particle filters have been used mainly in stochastic models and help to estimate unobservable latent variables in the observed market. To forecaste the price of crude oil more accurately and efficiently, we apply the method of particle filters to financial market. In this study, WTI (West Texas Intermediate) oil price data from January 2007 to March 2023 is used to predict the future of the crude oil market by applying particle filters. Compared to LSTM (Long Short Term Memory) and ARIMA (Autoregressive Integrated Moving Average), which are widely used in price prediction models, the particle filters demonstrates the performance of predicting the crude oil price market.

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PP1

SPDE-Net A Neural Network Way to Solve Singularly Perturbed Partial Differential Equations

Numerical techniques and neural network-based PDE solvers are inadequate to solve singularly perturbed differential equations(SPDE). These techniques give spurious oscillation in the numerical solution in the presence of boundary layers. Stabilization techniques are often employed to reduce spurious oscillations, but the accuracy of the stabilization technique is limited by the availability of a user-chosen stabilization parameter(τ). We introduce SPDE-Net- a neural network cum finite element technique to solve singularly perturbed partial differential equations. In this talk, we will explain our contributions to learning stabilization parameters for Streamline Upwind Petrov Galerkin technique using deep learning. The prediction task is solved in a regression setup. All of the proposed techniques perform better than state-of-the-art neural network-based PDE solvers such as Physics Informed Neural Networks (PINNs)

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