16 Bachelier Colloquium

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Ruin probabilities with investments in random environment: smoothness

Victor Antipov * [1], Yuri Kabanov [2]

[1] Lomonosov Moscow State University – Russia
[2] Université de Franche-Comté – Université Bourgogne Franche-Comté [COMUE] – France

The paper deals with the ruin problem of an insurance company investing its capital reserve in a risky asset with the price dynamics given by a conditional geometric Brownian motion whose parameters depend on a Markov process describing a random variations in the economic and financial environments. We prove smoothness of the ruin probability as a function of the initial capital and obtain for it an integro-differential equation.

*Speaker

Path-regularity and martingale properties of set-valued stochastic integrals

Çağın Ararat * [1], Jin Ma [2]

[1] Bilkent University – Turkey
[2] University of Southern California – United States

We study the path-regularity and martingale properties of set-valued stochastic integrals defined in our previous work A., Ma, Wu (AAP, 2023). Such integrals are fundamentally different from the well-known Aumann-Itô stochastic integrals and more suitable for representing set-valued martingales. However, like the Aumann-Itô integral, the new integral is only a set-valued submartingale in general, and there is very limited knowledge about its path-regularity. We first establish the existence of right- and left-continuous modifications of set-valued submartingales in continuous time and apply these results to set-valued stochastic integrals. We also show that a set-valued stochastic integral yields a martingale if and only if the set of terminal values of the stochastic integrals associated to the integrand is closed and decomposable. As a special case, we study the set-valued martingale in the form of the conditional expectation of a convex set-valued random variable. When this random variable is a convex random polytope, we show that the conditional expectation of a vertex stays as a vertex of the set-valued conditional expectation if and only if the random polytope has a deterministic normal fan.

*Speaker

Homogenization of a multivariate diffusion with semipermeable reflecting interfaces

Olga Aryasova * [1]

[1] Institute of Geophysics, National Academy of Sciences of Ukraine – Ukraine

The mathematical problem of homogenization typically involves studying the effective parameters of a system that exhibits rapid variations in its spatial characteristics. However, we focus on a stochastic multivariate homogenization problem of a different kind: the diffusion in the presence of narrowly located semipermeable interfaces.
In simple words, our model reminds of a foiled composite material consisting of a media interlaced with
very thin plates of different permeability. In material science such models are referred to as reinforced materials like a glass wool reinforced by aluminium foil. Usually, one is interested in the effective parameters of such a system.
By combining the study of stochastic differential equations with local times and homogenization, we explore how the presence of interfaces can alter the diffusion behavior of the limit process.
As a byproduct of our research, we obtain theorems for the existence and uniqueness of solutions to SDEs for multidimensional diffusion processes with membranes. Uniqueness is a problem of particular interest because it implies the strong Markov property of the solution, which is essential for the proof of convergence.

*Speaker

Decentralized exchange liquidity provision

Rostislav Berezovskii * [1]

[1] Vyssaja škola èkonomiki = National Research University Higher School of Economics [Moscow] – Russia

In this talk a model is introduced to calculate the liquidity provider's payoff on a decentralized exchange taking into account the accumulated swap fees. The results are applied to estimate the value for a range option position derived from the liquidity accumulated in a decentralized exchange pool.

*Speaker

Nonconcave Robust Utility Maximization under Projective Determinacy

Laurence Carassus * [1]

[1] Université de Reims Champagne-Ardenne – CNRS : UMR9008 – France

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

*Speaker

Uniform-in-time propagation of chaos for mean field Langevin dynamics

Fan Chen * [1,2]

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[2] Université Paris Dauphine - PSL – UMR 7534, CEREMADE – France

We study the mean field Langevin dynamics and the associated particle system.
By assuming the functional convexity of the energy,we obtain the L^p-convergence of the marginal distributions towards the unique invariant measure for the mean field dynamics.
Furthermore, we prove the uniform-in-time propagation of chaos in both the L^2-Wasserstein metric and relative entropy.

*Speaker

Equilibria in incomplete markets - an FBSDE approach

Nikolaos Constantinou * [1], Martin Herdegen [1]

[1] Department of Statistics, University of Warwick – United Kingdom

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

*Speaker

On NUPBR and NFLVR for general 1D diffusion models

David Criens * [1], Mikhail Urusov [2]

[1] University of Freiburg – Germany
[2] University of Duisburg-Essen – Germany

In this talk, I will discuss the absence of arbitarge in the sense of NUPBR and NFLVR for general 1D regular diffusion models. More precisely, we consider a single asset market whose asset is modeled as a general 1D regular strong Markov process that is characterized by its scale function and its speed measure. This includes classical so-called Ito diffusion models given as solutions to SDEs with drift and volatility, but we also allow local time effects such as stickiness (such cannot be described by an SDE in general). I present precise deterministic characterizations of NUPBR and NFLVR in terms of scale and speed. Moreover, I highlight the interesting structural observaton that NUPBR forces the scale function to be of the same type as for Ito diffusion models, i.e., of class C^1 with absolutely continuous derivative, and the surprising observation that NUPBR and NFLVR are quite often equivalent, namely in all cases where finite bounary points are attainable.
The talk is based in joint work with Mikhail Urusov (University of Duisburg-Essen).
arXiv: https://doi.org/10.48550/arXiv.2306.11470

*Speaker

McKean-Vlasov SDEs: New results on existence of weak solutions and on propagation of chaos

Robert Crowell * [1]

[1] ETH Zurich – Switzerland

We consider weak solutions of McKean-Vlasov SDEs with common noise. The aim of this overview talk is to discuss the main steps to prove weak existence and identify more nuanced assumptions under which chaos propagates. The results are obtained through a marriage of probabilistic and analytic techniques for general non-linear but uniformly elliptic coefficients that posses only low spatial regularity.

*Speaker

The Recalibration Conundrum: Darwinian model risk and HVA

Stéphane Crépey * [1,2]

[1] Université Paris Cité – Université de Paris / LPSM, Batiment Sophie Germain, 8 Place Aurélie Nemours 75013 France, France
[2] Université Paris Cité – LPSM – France

Based on joint works with Claudio Albanese, Cyril Benezet, Dounia Essaket, and Stefano Iabichino.

The dynamic hedging theory only makes sense in the setup of one given model, whereas the practice of dynamic hedging is just the opposite, with models fleeing after the data through daily recalibration. In this paper we revisit Burnett (2021) & Burnett and Williams (2021)'s notion of hedging valuation adjustment (HVA), originally intended to deal with dynamic hedging frictions, in the direction of model risk. We formalize and quantify Darwinian model risk as introduced in Albanese, Crépey, and Iabichino (2021), in which traders select models producing short to medium term gains at the cost of large but distant losses. The corresponding HVA can be seen as the bridge between a global fair valuation model and the local models used by the different desks of the bank. Importantly, model risk and dynamic hedging frictions indeed deserve a reserve, but a risk-adjusted one, so not only an HVA, but also a contribution to the KVA of the bank. Further adjustments are required to deal with possibly suboptimal stopping by the bank on callable claims. The orders of magnitude of the effects involved suggest that bad models should not so much be managed via reserves, as excluded altogether.

*Speaker

Capitalization distribution curve modeling and conditional polynomial McKean-Vlasov equations

Christa Cuchiero * [1]

[1] University of Vienna – Austria

Motivated by the robustness of the market capitalization curves, we study the behavior of a certain polynomial equity market model as the number of companies goes to infinity. Indeed, we extend volatility stabilized market models introduced by Fernholz et al. by allowing for a common noise term. As the number of companies approaches infinity, we show that the limit of the empirical measure of the N-company system converges to the unique solution of a degenerate, non-linear SPDE. The obtained limit also has a representation as a conditional probability of the solution to a certain McKean-Vlasov SDE. Together with its conditional expectation this is again a polynomial process. This intriguing property can be extended to other more general McKean-Vlasov SDEs. The talk is based on joint works with Florian Huber and Janka Möller.

*Speaker

Order routing and market quality: Who benefits from internalization?

Albina Danilova * [1], Umut Cetin

[1] LSE – United Kingdom

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

*Speaker

The disorder problem. An approach based on Partially Observable Markov Decision Proccesses.

Doncho Donchev * [1]

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The discrete time disorder problem has been stated by A.N. Shiryev as follows. On some probability space are given a non-observable random variable θ and a sequence of observable random variables $\xi_n,\ n = 1, 2, ...$ The distribution of θ is a mixture of Bernulli(π) and Geometric(p) distributions, that is, $P(\theta = 0) = \pi,\ P(\theta = n) = (1-\pi)p(1-p)^{n-1},\ n = 1, 2, ...,\ 0 < \pi, p < 1$. The distribution of ξ_n has a density $p_1(x)$ if $n > \theta$ and a density $p_0(x)$ otherwise. Let $\mathcal{F}_n$ be a filtration generated by the observations ξ_n. The problem is to find a $\mathcal{F}_n$-stopping time τ which minimizes the risk

$$\rho^\tau(\pi) = P^\pi(\theta > \tau) + cE^\pi(\tau - \theta)^+,\ c > 0,$$

where P^π is a measure that corresponds to the initial distribution π.
In this note, instead of $\rho^\tau(\pi)$, we consider the criterion

$$J^\tau(\pi) = E^\pi(\theta \wedge \tau - c(\tau - \theta)^+).$$

Our goal is to maximize $J^\tau(\pi)$ over all stopping times τ. We include this problem into the framework of the Partially Observable Markov Decision Processes which improves the quality of detection, and allows, in some cases, to find solutions to Bellman's equation.

*Speaker

Time changes, Fourier transforms and the joint calibration to the S&P500/VIX smiles.

Ernst Eberlein * [1], Laura Ballotta [2], Grégory Rayée [3]

[1] University of Freiburg – Germany
[2] Bayes Business School (formerly Cass), City, University of London – United Kingdom
[3] Belfius Banque & Assurances – Belgium

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

*Speaker

Design risk: the curse of CPPIs

Raquel Gaspar * [1], João Beleza Sousa

[1] ISEG and REM - CEMAPRE, Universidade de Lisboa – Portugal

This study underscores the notion that inadequately designed structured products or investment strategies have the potential to expose investors to unintended risks. Within this context, we introduce the concept of "design risk" into the portfolio insurance literature.
Specifically, our analysis focuses on Constant Proportion Portfolio Insurance (CPPI) structures and draws comparisons with classical Option-Based Portfolio Insurance (OBPI) as well as naive strategies like Stop-Loss Portfolio Insurance (SLPI) or CPPI with a multiplier set at one.
To assess the effectiveness of these strategies, we employ conditional Monte Carlo simulations to control the terminal value of the underlying asset. Our findings reveal a noteworthy phenomenon: even in scenarios where the terminal value of the underlying asset exceeds several times its initial value, CPPI strategies can lead to a cash-lock situation. The probability of getting cash-locked is influenced more by the multiplier's magnitude and the investment horizon than by the dynamics of the underlying asset.

*Speaker

From elephant to goldfish (and back): memory in stochastic Volterra processes

Martino Grasselli * [1,2]

[1] École Supérieure d'Ingénierie Léonard de Vinci – Devinci Research Center – France
[2] Università degli Studi di Padova = University of Padua – Italy

We propose a new theoretical framework that exploits convolution kernels to transform a Volterra path-dependent (non-Markovian) stochastic process into a standard (Markovian) diffusion process. This transformation is achieved by embedding a Markovian "memory process" within the dynamics of the non-Markovian process. We discuss existence and path-wise regularity of solutions for the stochastic Volterra equations introduced and we provide a financial application to volatility modeling. We also propose a numerical scheme for simulating the processes. The numerical scheme exhibits a strong convergence rate of 1/2, which is independent of the roughness parameter of the volatility process. This is a significant improvement compared to Euler schemes used in similar models.
We propose a new theoretical framework that exploits convolution kernels to transform a Volterra path-dependent (non-Markovian) stochastic process into a standard (Markovian) diffusion process. This transformation is achieved by embedding a Markovian "memory process" (the goldfish) within the dynamics of the non-Markovian process (the elephant). Most notably, it is also possible to go back, i.e., the transformation is reversible. We discuss existence and path-wise regularity of solutions for the stochastic Volterra equations introduced and we propose a numerical scheme for simulating the processes, which exhibits a remarkable convergence rate of 1/2. In particular, in the fractional kernel case, the strong convergence rate is independent of the roughness parameter, which is a positive novelty in contrast with what happens in the available Euler schemes in the literature in rough volatility models. (Joint work with O. Bonesini, G Callegaro, G. Pagès)

*Speaker

Lightning Network Economics: Channels and Topology

Paulo Guasoni * [1]

[1] Dublin City University, Dublin–Ireland

Designed to address Bitcoin's scalability challenge, the Lightning Network (LN) is a protocol allowing two parties to secure bitcoin payments and escrow holdings between them. In a lightning channel, each party commits collateral towards future payments to the counterparty and payments are cryptographically secured updates of collaterals. First, we identify conditions for two parties to optimally establish a channel, find explicit formulas for channel costs and optimal collaterals, and derive the implied reduction in congestion of the blockchain. Then we obtain necessary conditions for cost-minimizing topologies and bounds on the cost of the optimal topology, showing the unusual circumstances in which it is a hub that connects all other nodes.

*Speaker

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

Justin Gwee * [1], Mihail Zervos [1]

[1] London School of Economics and Political Science – United Kingdom

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

The talk is based on joint work with Mihail Zervos.

*Speaker

Signature stochastic volatility models: pricing and hedging with Fourier

Louis-Amand Gérard * [1]

[1] Centre d'Economie de la Sorbonne – Université Paris I - Panthéon-Sorbonne, Université Paris I Panthéon-Sorbonne – France

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

This is a joint work with Eduardo Abi Jaber.

(1) Lyons, T., Nejad, S., & Perez Arribas, I. (2020). Non-parametric pricing and hedging of exotic derivatives. *Applied Mathematical Finance*, *27*(6), 457-494.

(2) Arribas, I. P., Salvi, C., & Szpruch, L. (2020, October). Sig-SDEs model for quantitative finance. In *Proceedings of the First ACM International Conference on AI in Finance* (pp. 1-8).
(3) Christa Cuchiero, Guido Gazzani, and Sara Svaluto-Ferro. Signature-based models: theory and calibration. arXiv preprint arXiv:2207.13136, 2022.

*Speaker

Stochastic Impulse Control with Delay and Random Coefficients

Said Hamadene * [1]

[1] Laboratoire Manceau de Mathématiques – Le Mans Université – France

In this talk we discuss an infinite horizon impulse control problem with execution delay when the dynamics of the system is described by a general stochastic process adapted to the Brownian filtration. The problem is solved by means of probabilistic tools relying on the notion of Snell envelope and infinite horizon reflected backward stochastic differential equations. This allows us to establish the existence of an optimal strategy over all admissible strategies. We consider also the case of exponential utilities. The talk is based on (1). (1) Djehiche, B., Hamadene, S., Hdhiri, I. and Zaatra, H.: Infinite horizon stochastic impulse control with delay and random coefficients. Mathematics of Operations Research, 2022, 47(1), 665-689.

*Speaker

Common Noise by Poisson Random Measures: Mean-Field Equilibria in Relative Utility Maximization

Dirk Becherer [1], Stefanie Hesse * [1]

[1] Humboldt University of Berlin – Germany

This talk is about mean-field games with common noise, where the common noise incorporates Poisson random measures in addition to Brownian noises, instead of solely the latter as usual in the literature. We will characterize mean-field equilibria of mean-field games based on the problem of relative utility maximization via McKean-Vlasov Jump-Forward-Backward Stochastic Differential Equations (McKean-Vlasov JFBSDEs).

*Speaker

Supermartingales et densités conditionnelles

Monique Jeanblanc * [1], Pavel Gapeev * [2]

[1] Laboratoire de Mathématiques et Modélisation d'Evry – Ecole Nationale Supérieure d'Informatique pour l'Industrie et l'Entreprise, Université d'Évry-Val-d'Essonne, Université Paris-Saclay, Centre National de la Recherche Scientifique, Institut National de Recherche pour l'Agriculture, l'Alimentation et l'Environnement, Université Parais saclay – France
[2] LSE – United Kingdom

Dans cette présentation,je vais donner des caractérisations de supermartingales à valeur dans (0,1) et donner le type d'EDS qu'elles suivent et montrer comment on peut leur associer (sous conditions) une densité conditionnelle

*Speaker

Optimal pair trading: consumption-investment problem

Youri Kabanov * [1]

[1] Lomonosov Moscow State University and Université de France-Comté

We expose a simple solution of the consumption-investment problem in pair trading recently considered by Albosaily and Pergamenchtchikov. The proof is based on the remark that the HJB equation can be reduced to a linear parabolic equation solvable explicitly. The talk is based on a joint work with Aleksei Kozhevnikov.

*Speaker

Should I invest in the market portfolio? - A parametric approach

Jan Kallsen * [1]

[1] Mathematisches Seminar [Kiel] – Germany

This study suggests a parsimonious stationary diffusion model for the dynamics of stock prices relative to the entire market. Its aim is to contribute to the questions how to choose the relative weights in a diversified portfolio and, in particular, whether the market portfolio behaves close to optimally in terms of the long-term growth rate. Specifically, we introduce the elasticity bias as a measure of the market portfolio's suboptimality. We heavily rely on the observed long-term stability of the capital distribution curve, which also served as a starting point for the *Stochastic Portfolio Theory* in the sense of Fernholz.

*Speaker

Neural Jump ODEs and their Application to Stochastic Filtering

Florian Krach * [1]

[1] ETH Zurich – Switzerland

In this talk we study the problem of (online) forecasting general stochastic processes using a path-dependent extension of the Neural Jump ODE (NJ-ODE) framework. While NJ-ODE was the first framework to establish convergence guarantees for the prediction of irregularly observed time series, these results were limited to data stemming from Itô-diffusions with complete observations, in particular Markov processes, where all coordinates are observed simultaneously. In this work, we generalise these results to generic, possibly non-Markovian or discontinuous, stochastic processes with incomplete observations, by utilising the reconstruction properties of the signature transform. These theoretical results are supported by empirical studies. Moreover, these generalised results now allow us to apply the PD-NJ-ODE to stochastic filtering problems, which we will discuss in detail. This is joint work with Marc Nübel and Josef Teichmann.

*Speaker

Pathwise convergence of the Euler scheme for rough and stochastic differential equations

Andrew L. Allan [1], Anna P. Kwossek * [2], Chong Liu [3], David J. Prömel [2]

[1] Durham University – United Kingdom
[2] University of Mannheim – Germany
[3] ShanghaiTech University – China

First and higher order Euler schemes play a central role in the numerical approximations of stochastic differential equations. While the pathwise convergence of higher order Euler schemes can be adequately explained by rough path theory, the first order Euler scheme seems to be outside of its scope, at least at first glance.
In this talk, we show the convergence of the first order Euler scheme for differential equations driven by càdlàg rough paths satisfying a suitable criterion, namely the so-called Property (RIE) along time discretizations with mesh size going to zero. This property is verified for almost all sample paths of various stochastic processes and time discretizations. Consequently, we obtain the pathwise convergence of the first order Euler scheme for rough stochastic differential equations driven by these stochastic processes.
The talk is based on joint work with A. L. Allan, C. Liu, and D. J. Prömel.

*Speaker

The fundamental theorem of asset pricing with and without transaction costs

Christoph Kühn * [1]

[1] Goethe-University Frankfurt – Germany

We prove a version of the fundamental theorem of asset pricing (FTAP) in continuous time that is based on the strict no-arbitrage condition and that is applicable to both frictionless markets and markets with proportional transaction costs. We consider a market with a single risky asset whose ask price process is higher than or equal to its bid price process. Neither the concatenation property of the set of wealth processes, that is used in the proof of the frictionless FTAP, nor some boundedness property of the trading volume of admissible strategies usually argued with in models with a nonvanishing bid-ask spread need to be satisfied in our model.

(2307.00571) The fundamental theorem of asset pricing with and without transaction costs (arxiv.org)

*Speaker

An Explicit Scheme for Pathwise XVA Computations

Lokman Abbas-Turki [1], Stéphane Crépey [1], Botao Li * [1], Bouazza Saadeddine [1,2,3]

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[2] Laboratoire de Mathématiques et Modélisation d'Evry – Ecole Nationale Supérieure d'Informatique pour l'Industrie et l'Entreprise, Université d'Évry-Val-d'Essonne, Université Paris-Saclay, Centre National de la Recherche Scientifique, Institut National de Recherche pour l'Agriculture, l'Alimentation et l'Environnement – France

[3] Quantitative Research GMD/GMT Crédit Agricole CIB – Credit Agricole – France

Motivated by the equations of cross valuation adjustments (XVAs) in the realistic case where capital is deemed fungible as a source of funding for variation margin, we introduce a simulation/regression scheme for a class of anticipated BSDEs, where the coefficient entails a conditional expected shortfall of the martingale part of the solution. The scheme is explicit in time and uses neural network least-squares and quantile regressions for the embedded conditional expectations and expected shortfall computations. An a posteriori Monte Carlo validation procedure allows assessing the regression error of the scheme at each time step. The superiority of this scheme with respect to Picard iterations is illustrated in a high-dimensional and hybrid market/default risks XVA use-case.

*Speaker

Volatility Models in Practice: Rough, Path-Dependent or Markovian?

Eduardo Abi Jaber [1], Shaun Li * [2]

[1] Ecole polytechnique –CMAP–France

[2] Université Paris 1 Panthéon Sorbonne – CES–France

An extensive empirical study of the class of Volterra Bergomi models using SPX options data between 2011 to 2022 reveals the following fact-check on two fundamental claims echoed in the rough volatility literature:

1) Do rough volatility models really capture well SPX implied volatility surface with very few parameters? No, rough volatility models are inconsistent with the global shape of SPX smiles. They suffer from severe structural limitations imposed by the roughness component, with the Hurst parameter H controlling the smile in a poor way. In particular, the SPX at-the-money skew is incompatible with the power-law shape generated by rough volatility models. The skew of rough volatility models increases too fast on the short end, and decays too slow on the longer end where negative H is sometimes needed.

2) Do rough volatility models really outperform consistently their classical Markovian counterparts? No, for short maturities they underperform their one-factor Markovian counterpart with the same number of parameters. For longer maturities, they do not systematically outperform the one-factor model and significantly underperform when compared to an under-parametrized two-factor Markovian model with only one additional calibratable parameter.

On the positive side, our study identifies a (non-rough) path-dependent Bergomi model and an under-parametrized two-factor Markovian Bergomi model that consistently outperform their rough counterpart in capturing SPX smiles between one week and three years with only 3 to 4 calibratable parameters.

*Speaker

Impulse Control of a Linear Diffusion: an Explicitly Solvable Problem

Zhesheng Liu * [1], Mihail Zervos [2]

[1] Department Mathematics [London](LSE) – United Kingdom
[2] Department Mathematics [London](LSE) – United Kingdom

We consider a stochastic impulse control problem that is motivated by applications such as the optimal exploitation of a natural resource. In particular, we consider a stochastic system whose uncontrolled state dynamics are modeled by a non-explosive positive linear diffusion. The control that can be applied to this system takes the form of one-sided impulsive action. The objective of the control problem is to maximize a discounted performance criterion that rewards the effect of control action but involves a fixed cost at each time of a control intervention. We derive the complete solution to this problem under general assumptions. It turns out that the solution can take four qualitatively different forms, several of which have not been observed in the literature. In two of the four cases, there exist only ε-optimal control strategies. We also show that the boundary classification of 0 may play a critical role in the solution of the problem. Furthermore, we develop a way for establishing the strong solution to a stochastic impulse control problem's optimally controlled SDE.

*Speaker

Transition of Alpha-Mixing in Random Iterations

Attila Lovas * [1,2]

[1] Alfréd Rényi Institute of Mathematics – Hungary
[2] Budapest University of Technology and Economics [Budapest] – Hungary

The exploration and analysis of non-linear autoregressive processes incorporating exogenous covariates constitutes a recent and actively developing area of research. Notable examples include time series models in econometrics, specific queuing models, and stochastic optimization algorithms such as stochastic gradient Langevin dynamics, which play a pivotal role in machine learning applications. The influence of exogenous covariates can create dependencies in time series that persist over time. Therefore, understanding how the sequence of iterates inherits the mixing properties of the exogenous regressor is important. Using a coupling approach, we have established an upper bound on the mixing coefficient, which is particularly valuable because several significant results have been established for weakly dependent sequences exhibiting favorable mixing properties. For instance, it is well known that strong mixing and stationarity together imply ergodicity. Furthermore, Hansen showed that the law of large numbers holds in weak and L^p senses for heterogeneous dependent processes and arrays under weak mixing. Additionally, Herrndorf established that if the sequence of mixing coefficients decays to zero rapidly enough, then the functional central limit theorem holds for certain measurable functionals of the process.

*Speaker

Estimation and Inference for Multivariate Continuous-time Autoregressive Processes

Lorenzo Lucchese * [1], Mikko S. Pakkanen [1], Almut E. D. Veraart [1]

[1] Department of Mathematics [Imperial College London] – United Kingdom

The aim of this talk is to develop estimation and inference methods for the drift parameters of multivariate Lévy-driven continuous-time autoregressive processes of order p$\in$ N. Starting from a continuous-time observation of the process, we develop consistent and asymptotically normal maximum likelihood estimators. We then relax the unrealistic assumption of continuous-time observation by considering natural discretizations based on a combination of Riemann-sum, finite difference, and thresholding approximations. The resulting estimators are also proven to be consistent and asymptotically normal under a general set of conditions, allowing for both finite and infinite jump activity in the driving Lévy process. When discretizing the estimators, allowing for irregularly spaced observations is of great practical importance. In this respect, CAR(p) models are not just relevant for "true" continuous-time processes: a CAR(p) specification provides a natural continuous-time interpolation for modeling irregularly spaced data - even if the observed process is inherently discrete. The finite sample behavior of all theoretical asymptotic results is empirically assessed by extensive simulation experiments.

*Speaker

Maximum Principle For McKean-Vlasov Type Stochastic Optimal Singular Control Problems

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In this presentation, first we consider a general characterization of the optimal stochastic combined control for mean-field jump-systems which is derived by applying mixed convex-spike perturbation method. The diffusion coefficient depends on the continuous control variable and the control domain is not necessary convex. In our combined mean-field control problem, we discuss two classes of jumps for the state processes, the inaccessible jumps which caused by Poisson martingale measure and the predictable ones which caused by the singularity of the control variable. Markowitz's mean-variance portfolio selection problem with intervention control is discussed as an application.
Secondly, the work to be discussed is as follows: Stochastic singular control for mean-field forward-backward stochastic differential equations, driven by orthogonal Teugels martingales associated with some Lévy processes heaving moments of all orders and an independent Brownian motion. Under partial information, necessary and sufficient conditions for optimality in the form of maximum principle for this mean-field system are established by means of convex variation methods and duality techniques. As an illustration, this paper studies a partial information mean-variance portfolio selection problem driven by orthogonal Teugels martingales associated with Gamma process as Lévy process of bounded variation.

Main work of this presentation is to be considered as: Necessary and sufficient conditions for optimal singular control for systems governed by general controlled McKean-Vlasov differential equations, in which the coefficients depend on the state of the solution process as well as of its law and the control. The control domain is assumed to be convex. The control variable has two components, the first being absolutely continuous and the second singular. The proof of our result is based on the derivative of the solution process with respect to the probability law and a corresponding Itô formula. Finally, an example is given to illustrate the theoretical results.

Keywords: Singular stochastic control, stochastic maximum principle, mean-field stochastic systems, McKean-Vlasov differential equations, probability measure.

*Speaker

Computing convex conjugates with neural networks

Aleksei Minabutdinov * [1], Patrick Cheridito [1]

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The paper introduces a novel approach to computing dual/conjugate functions in high-dimensional settings, addressing the limitations of previous methods. Traditional techniques, primarily based on grid methods, have shown effectiveness in low-dimensional scenarios but struggle with scalability to higher dimensions. Our work pivots from these grid-based methods to harness the potential of Deep Learning. We propose a scalable solution for multidimensional cases, significantly expanding the computational capacity beyond the constraints of the earlier algorithms.

*Speaker

Sensitivity of robust optimization problems and nonlinear Kolmogorov equations

Daniel Bartl [1], Ariel Neufeld [2], Kyunghyun Park * [2]

[1] University of Vienna – Austria
[2] NTU Singapore – Singapore

In this talk we provide a sensitivity analysis of the portfolio optimization and pricing problem under drift and volatility uncertainty. In the first optimization problem an investor has the opportunity to trade in a stock with the goal of maximizing her worst-case cost of cumulative gains and losses. Here, worst-case refers to taking into account all possible drift and volatility processes for the stock that fall within a ε-neighbourhood of predefined baseline processes. We show that it can be approximated as $\varepsilon \to 0$ by the baseline problem (computed using the baseline processes) in the following sense: Firstly, the value of the worst-case problem is equal to the value of the baseline problem plus ε times a correction term. This correction term can be computed explicitly and quantifies how sensitive a given optimization problem is to model uncertainty.

Next we examine nonlinear Kolmogorov partial differential equations. Here the nonlinearity comes from maximization over all possible coefficients of first/second order partial derivatives in the equations which fall within a ε-neighbourhood of predefined baseline coefficients. This hence corresponds to the pricing problem under drift and volatility uncertainty where the financial agent has a candidate for drift and volatility coefficients but prefers to price robustly. Similarly, we show that the solution of the nonlinear PDEs can be approximated as the solution of the linear PDE (under the baseline coefficients) plus a correction term. In particular, the correction term can be characterized by the solution of another linear PDE under the baseline coefficients. This talk is based on joint works with Daniel Bartl and Ariel Neufeld.

*Speaker

Nonparametric generative modeling for time series via Schrödinger bridge

Huyên Pham * [1]

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We propose a novel generative model for time series based on Schrödinger bridge (SB) approach. This consists in the entropic interpolation via optimal transport between a reference probability measure on path space and a target measure consistent with the joint data distribution of the time series. The solution is characterized by a stochastic differential equation on finite horizon with a path-dependent drift function, hence respecting the temporal dynamics of the time series distribution. We estimate the drift function from data samples by nonparametric, e.g. kernel regression methods, and the simulation of the SB diffusion yields new synthetic data samples of the time series.

The performance of our generative model is evaluated through a series of numerical experiments. First, we test with autoregressive models, a GARCH Model, and the example of fractional Brownian motion, and measure the accuracy of our algorithm with marginal, temporal dependencies metrics, and predictive scores. Next, we use our SB generated synthetic samples for the application to deep hedging on real-data sets.

*Speaker

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

Francesca Primavera * [1], Christa Cuchiero [1], Xin Guo [2]

[1] University of Vienna [Vienna] – Austria
[2] UC Berkeley – United States

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

*Speaker

Ruin probabilities for a Sparre Andersen model with investments: the case of annuity payments

Platon Promyslov * [1,2]

[1] Université d'État Lomonossov de Moscou = Lomonosov Moscow State University – Russia
[2] Vega Institute Foundation – Russia

In recent studies, the Sparre Andersen model of insurance company was enriched by the assumption that the capital reserve of the insurance company is fully invested in a risky asset. In this model, for the case of non–life insurance, under fairly moderate hypotheses, the asymptotic behavior of the probability of ruin is the same as for generalizations of the Kramer-Lundberg model. The report will consider the Sparre Andersen model in the case when the price of a risky asset is set by a geometric Levy process, and the jumps in the business process are positive.

*Speaker

Optimal investment in markets with transaction costs for behavioural investors

Miklos Rasonyi * [1]

[1] HUN-REN Alfred Renyi Institute of Mathematics – Hungary

We investigate how the existence of optimal portfolios can be established for investors with behavioural preferences. As the latter involve probability distortion functions and fail to be convex, the usual compactness substitutes based on convex combinations cannot be used. One has to work with weak convergence instead. However, this leads to the appearance of randomized strategies which, indeed, enhance performance. We survey available results in the context of markets with proportional transaction costs and discuss open problems. Based on joint work with Ngoc Huy Chau (Manchester University).

*Speaker

Epic Math Battles: Nash vs Pareto

Birgit Rudloff * [1]

[1] Vienna University of Economics and Business – Austria

Nash equilibria and Pareto optimization are two distinct concepts in multi-criteria decision making. It is well known that the two concepts do not coincide. However, in this work we show that it is possible to characterize the set of all Nash equilibria for any non-cooperative game as the set of all Pareto optimal solutions of a certain vector optimization problem. This characterization opens a new way of computing Nash equilibria. It allows to use algorithms from vector optimization to compute resp. to approximate the set of all Nash equilibria, which is in contrast to the classical fixed point iterations that find just a single Nash equilibrium. Examples are given, first in the linear case. Then, the convex case is considered and an algorithm is proposed that computes a subset of the set of epsilon-Nash equilibria such that it contains the set of all (true) Nash equilibria for convex games with either independent convex constraint sets for each player, or polyhedral joint constraints. Furthermore, the computation of the set of Nash equilibria of bi-matrix games is discussed. This is joint work with Zachary Feinstein, Niklas Hey, and Andreas Löhne

*Speaker

Term structure modelling with overnight rates beyond stochastic continuity

Thorsten Schmidt * [1]

[1] University of Freiburg [Freiburg]

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

*Speaker

Universal Approximation Property of Random Neural Networks

Ariel Neufeld [1], Philipp Schmocker * [1]

[1] Nanyang Technological University – Singapore

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

*Speaker

Stochastic Fubini theorems: a new perspective

Martin Schweizer * [1]

[1] ETH Zurich – Switzerland

We present a new stochastic Fubini theorem which is based on the idea of using stochastic integrals of measure-valued processes. One application is to study the behaviour of a stochastic Volterra-type semimartingale.
This is based on joint work with T. Choulli and J. Chen.

*Speaker

An axiomatic viewpoint on the Rogers–Veraart and Suzuki–Elsinger models of systemic risk

Yuri Kabanov [1], Artur Sidorenko * [1,2]

[1] Lomonosov Moscow State University – Russia
[2] Vega Institute Foundation – Russia

We study a model of clearing in an interbank network with crossholdings and default charges. Following the Eisenberg–Noe approach, the authors define the model via a set of natural financial regulations including those related to eventual default charges and derive a finite family of fixpoint problems. These problems are parameterized by vectors of binary variables. The model combines features of the Ararat–Meimanjanov, Rogers–Veraart, and Suzuki–Elsinger networks. The authors develop methods of computing the maximal and minimal clearing pairs using the mixed integer-linear programming and a Gaussian elimination algorithm

*Speaker

A stochastic control perspective on term structure models with roll-over risk

Simone Pavarana * [1], Claudio Fontana [2], Wolfgang J. Runggaldier [2]

[1] Abteilung für Mathematische Stochastik, Albert-Ludwigs-Universität Freiburg – Germany
[2] Dipartimento di Matematica [padova] – Italy

In this paper, we consider a generic interest rate market in the presence of roll-over risk, which generates spreads in spot/forward term rates. We do not require classical absence of arbitrage and rely instead on a minimal market viability assumption, which enables us to work in the context of the benchmark approach. In a Markovian setting, we extend the control-theoretic approach of Gombani and Runggaldier (Math. Finance 23 (2013) 659–686) and derive representations of spot/forward spreads as value functions of suitable stochastic optimal control problems, formulated under the real-world probability and with power-type objective functionals. We determine endogenously the funding–liquidity spread by relating it to the risk-sensitive optimisation problem of a representative investor.

*Speaker

Self-interacting approximation to McKean–Vlasov long-time limit: a Markov chain Monte Carlo method

Florin Suciu * [1], Kai Du [2], Zhenjie Ren [1], Songbo Wang [3]

[1] CEREMADE – Université Paris Dauphine-PSL – France
[2] Fudan University [Shanghai] – China
[3] Centre de Mathématiques Appliquées - Ecole Polytechnique – Ecole Polytechnique, Centre National de la Recherche Scientifique, Centre National de la Recherche Scientifique : UMR7641 – France

For a certain class of McKean–Vlasov processes, we introduce proxy processes that substitute the mean-field interaction with self-interaction, employing a weighted occupation measure. Our study encompasses two key achievements. First, we demonstrate the ergodicity of the self-interacting dynamics, under broad conditions, by applying the reflection coupling method. Second, in scenarios where the drifts are negative intrinsic gradients of convex mean-field potential functionals, we use entropy and functional inequalities to demonstrate that the stationary measures of the self-interacting processes approximate the invariant measures of the corresponding McKean–Vlasov processes. As an application, we show how to learn the optimal weights of a two-layer neural network by training a single neuron. Joint work with Kai Du, Zhenjie Ren and Songbo Wang.

*Speaker

Inter-temporal DC Pension Management

Ho Man Tai * [1], Paolo Guasoni [2], Bohan Li [3], Tak Kwong Wong [4], Sheung Chi Phillip Yam [5]

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The objective of this article is to resolve the pension management problem with constant contribution from fund holders in the perspective of the manager who aims to maximize the expectation of generic running and terminal utilities of the management fees collected. Research on the existing literature largely neglects the impacts of inter-temporal reward for the manager. With the aim of the Dynamic Programming Principle, the problem is associated with a singular, fully non-linear HJB equation. We develop a direct mathematical primal analysis to establish the unique existence of its classical solution by transforming the problem into a non-canonical variational inequality problem and then solving it in a trailer Sobolev space. In addition, an efficient numerical scheme has been introduced to compute the optimal trading strategy and the value function numerically.

*Speaker

A partial rough path space for rough volatility

Ryoji Takano * [1], Masaaki Fukasawa [1]

[1] Osaka University – Japan

We develop a variant of rough path theory tailor-made for analyzing a class of financial asset price models known as rough volatility models. As an application, we prove a pathwise large deviation principle (LDP) for a certain class of rough volatility models, which in turn describes the limiting behavior of implied volatility for short maturity under those models. First, we introduce a partial rough path space and an integration map on it and then investigate several fundamental properties including local Lipschitz continuity of the integration map from the partial rough path space to a rough path space. Second, we construct a rough path lift of a rough volatility model. Finally, we prove an LDP on the partial rough path space, and the LDP for rough volatility then follows by the continuity of the solution map of rough differential equations. This work is a joint work with Masaaki Fukasawa.

*Speaker

Real analyticity in signature theory and mathematical finance

Josef Teichmann * [1]

[1] ETH – Zürich

We explore several recent instances of real analyticity with relations to mathematical finance. We are motivated by a extending several theories with a polynomial flavor, like affine or polynomial processes or signature approximations, towards their real analytic version.

*Speaker

Reducing Obizhaeva-Wang type trade execution problems to LQ stochastic control problems

Mikhail Urusov * [1]

[1] University of Duisburg-Essen – Germany

We start with a stochastic control problem where the control process is a process of finite variation with jumps and acts as integrator both in the state dynamics and in the target functional. Problems of such type arise in the stream of literature on optimal trade execution pioneered by Obizhaeva and Wang (models with finite resilience).
We consider a general framework where the price impact and the resilience are stochastic processes. Both are allowed to have diffusive components.

First we continuously extend the problem from processes of finite variation to progressively measurable processes. While semimartingales seem to be a very natural class of processes for such an extension, in our generality it is necessary to go beyond semimartingales (cf. (1)). With the help of a certain nonlinear change of variables we are able to reduce the extended problem to a linear quadratic (LQ) stochastic control problem. Using well-developed theory of LQ problems we describe the solution to the obtained LQ problem and trace it back up to the solution to the (extended) initial trade execution problem. Finally, we discuss several examples.

Among other things the examples show the Obizhaeva-Wang model with random terminal and moving targets, the necessity to extend the initial trade execution problem to a reasonably large class of progressively measurable processes and the effects of diffusive components in the price impact process and/or in the resilience process.

This is a joint work with Julia Ackermann and Thomas Kruse ((2)).

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Reducing Obizhaeva-Wang type trade execution problems to LQ stochastic control problems.
Accepted in Finance and Stochastics, 2023.
arXiv: https://arxiv.org/abs/2206.03772

*Speaker

Utility maximization of the exponential Levy switching models

Lioudmila Vostrikova * [1]

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This article is devoted to maximization of HARA utilities of the exponential Levy switching processes on a finite time interval via the dual method. The description of all f -divergence minimal martingale measures and the expression of their Radon-Nikodym densities involving the Hellinger and the Kulback- Leibler processes are given. The optimal strategies in progressively enlarged filtration for the maximization of HARA utilities as well as the values of the corresponding maximal expected utilities are derived. As an example, the Brownian switching model is presented with financial interpretations of the results via value process.

*Speaker

Uniform-in-time propagation of chaos for kinetic mean field Langevin dynamics

Songbo Wang * [1]

[1] Centre de Mathématiques Appliquées - Ecole Polytechnique – Ecole Polytechnique, Centre National de la Recherche Scientifique, Centre National de la Recherche Scientifique : UMR7641 – France

We study the kinetic mean field Langevin dynamics under the functional convexity assumption of the mean field energy functional. Using hypocoercivity, we first establish the exponential convergence of the mean field dynamics and then show the corresponding N-particle system converges exponentially in a rate uniform in N modulo a small error. Finally we study the short-time regularization effects of the dynamics and prove its uniform-in-time propagation of chaos property in both the Wasserstein and entropic sense. Our results can be applied to the training of two-layer neural networks with momentum and we include the numerical experiments. Joint work with Fan Chen, Yiqing Lin, Zhenjie Ren.

*Speaker

Detecting Momentum Turning Points in High-Frequency Data

Zhan Yaosong * [1], Zhenya Liu [2]

[1] Sun Yat-Sen University – China
[2] Renmin University of China – China

Momentum turning points are important in investment strategies. We simultaneously consider the error rate and time lag caused by market noise and propose a turning point detection model in a high-frequency market based on stochastic optimization methods. The numerical analyses demonstrate that our model can rapidly respond to turning points at a low error rate. The parameters of the price process influence the model's detection performance. The empirical tests show that our model effectively reduces the error rate in detecting turning points. We further propose a trend-following strategy which outperforms the benchmark and yields higher returns and lower risks.

*Speaker

When will China overtake the US in GDP?

Zhenya Liu [1,2], Yaosong Zhan * [3]

[1] EM Normandie Business School, Metis Lab – EM Normandie Business School, Metis Lab., EM Normandie Business School, Métis Lab – France
[2] Renmin University of China = Université Renmin de Chine – China
[3] Sun Yat-Sen University [Guangzhou] – China

As the world's two largest economies, the competition between China and the United States will profoundly impact the international economic order. This paper first conducts stochastic process modeling of the two countries' gross domestic product (GDP). Then, based on the first arrival time theory and historical data trends, this article predicts that China's GDP and per capita GDP will surpass the United States. According to theoretical model results, China's GDP and per capita GDP are expected to reach those of the United States in 2028 and 2048, respectively. At the same time, taking into account changes in the economic environment, this paper also applies a change point analysis of model parameters to obtain more robust prediction results.

*Speaker

Optimal monotone mean-variance portfolio selection

Aleš Černý * [1], Christoph Czichowsky [2], Martin Schweizer [3]

[1] Bayes Business School, City, University of London – United Kingdom
[2] LSE Mathematics – United Kingdom
[3] ETH Zurich – Switzerland

We study monotone mean-variance portfolio allocation by embedding the monotone mean-variance preferences in the class of divergence preferences generated by monotone HARA utility functions. Explicit results for optimal portfolios and minimax measures are obtained via the stochastic calculus of predictable variations.

*Speaker

List of participants

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- Ararat Cagin
- Aryasova Olga
- Awad Alaa
- Berezovskii Rostislav
- Carassus Laurence
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