Bachelier PhD seminar

March-May 2025, IHP, Paris.

Friday 21th March

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9h-9h20 **Edouard MOTTE**, Catholic University of Louvain.

Title : The Volterra Stein-Stein model with stochastic interest rates

Abstract : We introduce the Volterra Stein-Stein model with stochastic interest rates, where both volatility and interest rates are driven by correlated Gaussian Volterra processes. This framework unifies various well-known Markovian and non-Markovian models while preserving analytical tractability for pricing and hedging financial derivatives. We derive explicit formulas for pricing zero-coupon bond and interest rate cap or floor, along with a semi-explicit expression for the characteristic function of the log-forward index using Fredholm resolvents and determinants. This allows for fast and efficient derivative pricing and calibration via Fourier methods. We calibrate our model to market data and observe that our framework is flexible enough to capture key empirical features, such as the humped-shaped term structure of ATM implied volatilities for cap options and the concave ATM implied volatility skew term structure (in log-log scale) of the S&P 500 options. Finally, we establish connections between our characteristic function formula and expressions that depend on infinite-dimensional Riccati equations, thereby making the link with conventional linear-quadratic models. Joint work with Eduardo Abi Jaber and Donatien Hainaut.

9h20-9h40 **Othmane ZARHALI**, Université Paris Dauphine - CNRS.

Title : From rough to multifractal volatility, topics around the Log S-fBM model.

Abstract : The Log Stationary Fractional Brownian Motion (Log S-fBM) model, introduced by *Peng, Bacry,* and *Muzy* , describes a log-volatility process driven by a stationary fractional Brownian motion (S-fBM). This model is characterized by three key parameters: the intermittency parameter λ, the correlation scale T, and the Hurst exponent H. Notably, as H approaches zero, the model?s multifractal random measure (volatility measure) converges to that of the multifractal random walk introduced by *Bacry et al.*. In contrast, when $H \approx 0.1$, the model captures rough volatility dynamics. A multidimensional extension of the Log S-fBM model, referred to as the m-Log S-fBM was also developed. In this framework, the log-volatilities of multiple assets are correlated, with dependencies governed by both the cointermittency matrix and the co-Hurst matrix. These matrices ensure that the marginal distributions of the model retain the one-dimensional Log S-fBM dynamic. A key analytical tool for studying this model is the small intermittency approximation,

which allows to approximate the generalized moments of the normalized log-volatility over a time period $\Delta > 0$ using the moments of the integrated S-fBM process over the same period when λ^2 is small. This approximation is particularly relevant given the empirical findings of Wu et al., who observed that for various assets, $\lambda^2 \approx 0.02$. Besides, the Log S-fBM model can be used in the Nested factor model, introduced by *Bouchaud et al.*, where the asset return fluctuations are explained by common factors representing the market economic sectors and residuals (noises). These residuals share with the factors a common dominant volatility mode in addition to the idiosyncratic mode unique to each residual. Here, we consider the case of a single factor, where the only dominant common mode is a S-fBM process with Hurst exponent $H \simeq 0.11$, while the residuals, in addition to the previous common mode, contain idiosyncratic components with Hurst exponents $H \simeq 0$. Furthermore, we propose a statistical procedure to estimate the Hurst factor exponent from stock return dynamics, providing theoretical guarantees. The method performs well in the limit where the number of stocks N tends to infinity. In this talk, we introduce the Log S-fBM model in its one-dimensional and multidimensional forms, present the calibration procedure based on the small intermittency approximation, and discuss the Nested Log S-fBM factor model. This is a joint work with Cécilia Aubrun, Emmanuel Bacry, Jean-Philippe Bouchaud, Jean-François Muzy.

9h40-10h **Yadh HAFSI**, Université Paris-Saclay, LaMME.

Title : Optimal Execution under Incomplete Information

Abstract : We study optimal liquidation strategies under partial information for a single asset within a finite time horizon. We propose a model tailored for high-frequency trading, capturing price formation driven solely by order flow through mutually stimulating marked Hawkes processes. The model assumes a limit order book framework, accounting for both permanent price impact and transient market impact. Importantly, we incorporate liquidity as a hidden Markov process, influencing the intensities of the point processes governing bid and ask prices. Within this setting, we formulate the optimal liquidation problem as an impulse control problem. We elucidate the dynamics of the hidden Markov chain's filter and determine the related normalized filtering equations. We then express the value function as the limit of a sequence of auxiliary continuous functions, defined recursively. This characterization enables the use of a dynamic programming principle for optimal stopping problems and the determination of an optimal strategy. It also facilitates the development of an implementable algorithm to approximate the original liquidation problem. We enrich our analysis with numerical results and visualizations of candidate optimal strategies.

10h-10h20 **Break**

10h20-10h40 **Fallou NIAKH** , ENSAE IP Paris, CREST

Title : P2P Risk Basis management for renewable production parametric insurance

Abstract : This work presents a framework for peer-to-peer (P2P) risk basis management applied to solar electricity generation. The approach leverages physically based simulation models to estimate the day-ahead production forecasts and the actual realized production at the solar farm level. We quantify the financial loss from mismatches between forecasted and actual production using the outputs of these simulations. The framework then implements a parametric insurance mechanism to mitigate these financial losses and combines it with a P2P market structure to enhance participant risk sharing. By integrating day-ahead forecasts

and actual production data with physical modeling, this method provides a comprehensive solution to manage production variability, offering practical insights for improving financial resilience in renewable energy systems. The results highlight the potential of combining parametric insurance with P2P mechanisms to foster reliability and collaboration in renewable energy markets

10h40-11h **Hamza BODOR**, Centre d'économie de la Sorbonne.

Title : Deep Learning Meets Queue-Reactive: A Framework for Realistic Limit Order Book Simulation.

Abstract : The Queue-Reactive model introduced by Huang et al. (2015) has become a standard tool for limit order book modeling, widely adopted by both researchers and practitioners for its simplicity and effectiveness. We present the Multidimensional Deep Queue-Reactive (MDQR) model, which extends this framework in three ways: it relaxes the assumption of queue independence, enriches the state space with market features, and models the distribution of order sizes. Through a neural network architecture, the model learns complex dependencies between different price levels and adapts to varying market conditions, while preserving the interpretable point-process foundation of the original framework. Using data from the Bund futures market, we show that MDQR captures key market properties including the square-root law of market impact, cross-queue correlations, and realistic order size patterns. The model demonstrates particular strength in reproducing both conditional and stationary distributions of order sizes, as well as various stylized facts of market microstructure. The model achieves this while maintaining the computational efficiency needed for practical applications such as strategy development through reinforcement learning or realistic backtesting.

Friday 28th March

9h-9h20 **Antoine LOTZ**, Université Paris Dauphine & EDF Lab

Title: A central limit theorem for locally stationary Hawkes processes

Abstract : We prove a law of large numbers and functional central limit theorem for a class of multivariate Hawkes processes with time-dependent reproduction rate. We address the difficulties induced by the use of non-convolutive Volterra processes by recombining classical martingale methods introduced in Bacry et al. (2013) with novel ideas proposed by Kwan, Chen and Dunsmuir (2024). The asymptotic theory we obtain yields useful applications in financial statistics. As an illustration, we derive closed-form expressions for price distortions under liquidity constraints, and present some first estimations of the model on order book data from intraday power markets.

9h20-9h40 **Elie ATTAL**, CMAP, Ecole Polytechnique.

Title: From Hyper Rougness to Jumps as $H \to -1/2$.

Abstract: We investigate the weak limit of the hyper-rough square-root process as the Hurst index H goes to $-1/2$. This limit corresponds to the fractional kernel $t^{H-1/2}$ losing integrability. We establish the joint convergence of the couple (X, M), where X is the hyper-rough process and M the associated martingale, to a fully correlated Inverse Gaussian Lévy jump process. This unveils the existence of a continuum between hyper-rough continuous models and jump processes, as a function of the Hurst index. Since we prove a convergence of continuous to discontinuous processes, the usual Skorokhod J_1 topology is not suitable for our problem. Instead, we obtain the weak convergence in the Skorokhod M_1 topology for X and in the non-Skorokhod S topology for M.
Based on a joint work with Eduardo Abi Jaber (CMAP) and Mathieu Rosenbaum (CMAP).

9h40-10h **Lamia LAMRANI**, Université Paris-Saclay, CentraleSupélec.

Title : Holdout method error and optimal split for large covariance matrix estimation

Abstract : Covariance matrix estimation is an important topic for financial applications such as risk management or portfolio selection. Cross-validation, one of the most widely used methods for model selection and evaluation, can be used to improve large covariance matrix estimation. However, although its efficiency is recognized for financial applications, little is known about the theoretical behavior of its error. In this talk, we discuss the expected Frobenius error of the holdout method, a particular cross-validation procedure that involves a single train and test split, for a generic rotationally invariant multiplicative noise in the high dimension limit. When the population covariance matrix follows an inverse Wishart distribution, we find a closed form for the expected holdout error. Furthermore, we find that the optimal train-test split ratio is proportional to the square root of the order of the matrix to estimate.

10h20-10h40 **Thomas PEYRAT**, CREST-IMT-Exiom Partners.

Title : A Multivariate Self-Exciting Processes with Dependencies for actuarial applications

Abstract : The compound Poisson process is commonly used to model the loss process associated to a certain risk. This process relies on the assumption of independence between the counting process (a Poisson

process) and the claim sizes (independent and identically distributed random variables), making the calculation of the expectation and correlation straightforward. However, these assumptions limit its applicability to more complex risk structures. To overcome these limitations, we propose a similar framework in which the counting process is replaced by a self-exciting process whose intensity is influenced by the amount of the claims. Introducing dependency between the counting process and the claims, however, induces theoretical challenges in the computations of the first two moments of the loss process. To this end, we introduce the class of Multidimensional Self-Exciting Processes with Dependencies (MSPD), for which we derive closed-form expressions for the expectation and correlation.

10h40-11h **Benoît ORIOL**, CEREMADE and Société Générale.

Title : Non-linear shrinkage of weighted sample covariances.

Abstract : Covariance estimation is a central topic in multivariate analysis, and the weighted sample covariance emerges as a natural candidate to estimate it in finance. However, in high dimension, due to spectral deformation, the eigenvalues of the weighted sample covariance need to be unbiased in order to make the estimation optimal. We compute the asymptotic non-linear shrinkage formulas that correct the spectrum of weighted sample covariance, in the spirit of Ledoit and Péché. We detail explicitly the formulas for exponentially-weighted sample covariances, and propose an algorithm to compute them.

Friday 11th April

9h-9h20 **Mathieu TRUC**, R&D Milliman, LPSM.

Title : Multi-level Monte Carlo for economic capital estimation in insurance.

Abstract : The Solvency II directive has posed a major challenge to European insurers by requiring a market-consistent evaluation of the distribution of their future own-funds. Insurers using "internal models" must undertake a complex nested Monte Carlo procedure to estimate an extreme quantile, involving Real-World distributions, Risk-Neutral distributions, and asset-liability management models. This resource-intensive calculation is being performed increasingly often to meet regulatory and management demands. In this talk we formalize the computational challenges faced by European insurer in this context. Traditional solutions such as nested simulations and Least Square Monte Carlo proxies are explosive in computational cost and complex to apply in the presence of many risk factors, respectively. To optimize computing resources and improve the efficiency of economic capital estimation we introduce the Weighted Multi-Level Monte Carlo method that we adapt and illustrate in the insurance context of extreme quantile estimation. Using different weighted levels of Monte Carlo estimators, the method reduces the bias while controlling variance through antithetic variables. We demonstrate in a case study that this results, both theoretically and practically, provide an efficient alternative to traditional methods.

9h20-9h40 **Kaixin YAN**, Ecole polytechnique, CMAP

Title : Optimal consumption under relaxed benchmark tracking and consumption drawdown constraint

Abstract : This paper studies an optimal consumption problem with both relaxed benchmark tracking and consumption drawdown constraint, leading to a stochastic control problem with dynamic state-control constraints. In our relaxed tracking formulation, the fund manager strategically injects capital to ensure the total capital process outperforms a benchmark modeled as a geometric Brownian motion. We transform the original regular-singular control problem with state-control constraints into an equivalent regular control problem involving a reflected state process and consumption drawdown. Utilizing dual transforms and optimal consumption behavior, we analyze a linear dual PDE with Neumann and free boundary conditions across distinct regions. By applying the smooth-fit principle and super-contact conditions, we derive closed-form solutions for the dual PDE and obtain feedback-form optimal investment and consumption policies. A verification theorem is proven using novel arguments, supported by an auxiliary reflected dual process and technical estimates. Numerical examples and financial insights are also discussed.

9h40-10h **Ruben HAALEBOS** CREST/ENSAE/EDF

Title : Reconstructing Economic Network Structures for Enhanced Climate Alignment Estimation

Abstract : The transition to a low-carbon economy necessitates profound structural changes, particularly within carbon-intensive sectors. While climate scenarios, such as those produced by the Network for Greening the Financial System (NGFS), offer projections of emission reductions and output changes, they often lack granular insights into the evolving structures of economic networks and are influenced by the variability of

economic model assumptions. This paper presents a novel methodology for rebalancing sectoral input-output matrices to ensure alignment with the macroeconomic assumptions embedded in various climate scenarios. By integrating publicly available climate data with input-output analysis, we derive robust direct and indirect emission trajectories, which are essential for accurate corporate and portfolio climate alignment assessments. This research advances the existing body of literature by providing a transparent and scenario-consistent framework for developing sector-level carbon emission benchmarks, thereby enhancing the capabilities of existing methodologies. The practical application of this methodology demonstrates its potential to enhance the reliability and comparability of portfolio alignment metrics, thereby improving the robustness and fitness for use of climate alignment assessments.

10h-10h20 **Break**

10h20-10h40 **Paulin AUBERT**, LaMME, Université Paris-Saclay, UEVE, Exiom Partners, France.
Title : Market making in option markets with hedging-induced market impact
Abstract : In this work, we study a market making problem in the options market formulated as an impulse control problem. We suppose that a market maker is mandated to provide liquidity on an option backed by an underlying asset whose mid and spread are observed. This problem requires the modeling of two distinct markets: that of the underlying and that of the options. The underlying market is represented by modeling the mid-price and the spread, both of which are impacted by the consumption of the order book, represented by functions f_A and f_B. In addition to exogenous orders, the market for the underlying asset is impacted by the market maker adjusting his hedge. In the options market, the market maker sets the bid and ask prices, and the market reacts accordingly. The supply and demand intensities for options are assumed to be governed by functions λ^b and λ^a, which depend on the market maker's bid and ask, as well as on the time and value of the underlying's mid-price. Finally, the market maker's objective is to maximize his total gain at maturity by providing liquidity in the options market and hedging his options position. In the first part, we present the problem and discuss the assumptions made. Then, a reinforcement-type numerical method is developed and some numerical results are shown.

10h40-11h **Amal OMRANI**, CEREMADE, Paris Dauphine-PSL.
Title: Beyond the Leland Strategy.
Abstract: In the Black-Scholes model with small transaction costs, Leland proposed an asymptotic super-hedging strategy for the call option as the number of revision dates tends to $+\infty$. The idea is to use a delta-hedging strategy with an adjusted volatility to compensate for transaction costs. A natural question is how to solve the same problem in a general model where the number of discrete dates is fixed, the proportional transaction cost coefficient does not tend to 0, and no martingale measure is assumed. We propose a new, easily computable method to address this problem.

Friday 2ond May

9h-9h20 **Dimitri SOTNIKOV**, CMAP, Ecole Polytechnique & Engie Global Markets.
Title : Martingale property and moment explosions in signature volatility models
Abstract : We study the martingale property and moment explosions of a signature volatility model, where the volatility process of the log-price is given by a linear form of the signature of a time-extended Brownian motion. Excluding trivial cases, we demonstrate that the price process is a true martingale if and only if the order of the linear form is odd and a correlation parameter is negative. The proof involves a fine analysis of the explosion time of a signature stochastic differential equation. This result is of key practical relevance, as it highlights that, when used for approximation purposes, the linear combination of signature elements must be taken of odd order to preserve the martingale property. Once martingality is established, we also characterize the existence of higher moments of the price process in terms of a condition on a correlation parameter. This is joint work with Eduardo Abi Jaber and Paul Gassiat.

9h20-9h40 **Xiaozhen WANG**, Université Paris-Dauphine PSL.
Title : Convergence of Sinkhorn's Algorithm for Entropic Martingale Optimal Transport Problem.
Abstract : We study the Entropic Martingale Optimal Transport (EMOT) problem on R. We begin by introducing the dual formulation and prove the exponential convergence of Sinkhorn's algorithm on the dual potential coefficients. Our analysis does not require prior knowledge of the optimal potential and confirms that there is no primal-dual gap. Our findings provide a theoretical guarantee for solving the EMOT problem using Sinkhorn's algorithm. In applications, our result provides insight into the calibration of stochastic volatility models, as proposed by Henry-Labordere.

9h40-10h **Break**

10h-10h20 **Zakaria BENSAID**, LMM, Université du Mans.
Title : Deep learning algorithms for FBSDEs with jumps: Applications to option pricing and a MFG model for smart grid
Abstract : In this paper, we introduce various new machine learning solvers for (coupled) forward-backward systems of stochastic differential equations (FBSDEs) driven by a Brownian motion and a Poisson random measure. We provide a rigorous comparison of the new algorithms developed in the paper by applying them to cases derived from pricing and mean-field games with jumps. In particular, these algorithms are also used in a more general setting involving a coupled multi-dimensional FBSDE system driven by a time-inhomogeneous jump process with stochastic intensity, which describes the Nash equilibria for a specific mean-field game (MFG) problem for smart grids for which we also provide the complete theoretical resolution. To the best of our knowledge, this is the first paper which proposes a new tailor-made scheme appropriate to the use of deep-learning solvers for FBSDEs in the case with jumps. Finally, this article also brings important improvements to the existing literature on deep-learning solvers for FBSDEs with and without jumps (talk based on the paper https://arxiv.org/abs/2401.03245).

10h20-10h40 **Maxime GUELLIL**, CMAP, LPSM.

Title : Complex discontinuities of $\sqrt{\text{Fredholm determinants}}$ in the Volterra Stein-Stein model

Abstract : We study complex discontinuities arising from the miscomputation of the Fourier-Laplace transform in the Volterra Stein-Stein model, which involves the complex square root of a Fredholm determinant. Discontinuities occur when the determinant crosses the negative real axis. We characterize these crossings for the joint Fourier-Laplace transform of the integrated variance and log-price. Additionally, we derive a corrected formula for the Fourier-Laplace transform and develop efficient numerical techniques to detect and compute these crossings. Applying our algorithms to Fourier-based pricing in the rough Stein-Stein model, we achieve a significant increase in accuracy while drastically reducing computational cost compared to existing methods.