QUANTITATIVE FINANCE
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BOOK OF ABSTRACTS

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CVA in fractional and rough volatility models

Fabio Antonelli (University of L'Aquila)

In recent years, the interest in including correctly the effects due to default risks in the derivatives' evaluation has grown immensely, generating a whole new field in mathematical finance. Considering stochastic volatility models for derivatives subject to credit risks is an important modeling feature, even more so under volatility roughness that better reflects the market behavior, as much of the recent literature shows. Here, we focus our attention on vulnerable European options, that is options subject to some default event concerning the solvability of the issuer, and we provide a general representation formula for the price and the required Credit Value Adjustment (CVA) for stochastic (either rough or not) volatility market models, when correlations among the driving processes are present.

Keywords: CVA, fractional and rough volatility models, numerical methods

Optimal installation of renewable electricity sources: the case of Italy

Awerkin Almendra (University of Padova)

The aim of this work is to validate empirically the theoretical model which assume the existence of a one large energy producer company, whose increments in the current installed power influence negatively the electricity price. The company's optimal choice of increment the current installed power to maximize the utility of selling the energy produced in the market, net installation costs, is model by means of a singular control problem. We extend this model to the case of several power producers. We investigate and compare the solution of both cooperative and competitive situation when there are two producers.

Keywords: Singular control, Irreversible investment, Pareto optimality, Nash equilibria, Market impact

Short-time implied volatility of additive normal tempered stable processes

Azzone Michele (Polytechnic of Milan)

Empirical studies have emphasized that the equity implied volatility is characterized by a negative skew inversely proportional to the square root of the time-to-maturity. We examine the short-time-to-maturity behavior of the implied volatility smile for pure jump exponential additive processes. An excellent calibration of the equity volatility surfaces has been achieved by a class of these additive processes with power-law scaling. The two power-law scaling parameters are beta, related to the variance of jumps, and delta, related to the smile asymmetry. It has been observed, in option market data, that beta=1 and delta=-1/2. In this paper, we prove that the implied volatility of these additive processes is consistent, in the short-time, with the equity market empirical characteristics if and only if beta=1 and delta=-1/2.

Keywords: Additive process, volatility surface, skew, small-time, calibration

A fast Monte Carlo scheme for additive processes and option pricing

Roberto Baviera (Polytechnic of Milan)

In this paper, we present a fast Monte Carlo scheme for additive processes. We analyze in detail numerical error sources and propose a technique that reduces the two major sources of error. We also compare our results with a benchmark method: the jump simulation with Gaussian approximation. We show an application to additive normal tempered stable processes, a class of additive processes that calibrates ``exactly'' the

implied volatility surface. Numerical results are relevant. The algorithm is an accurate tool for pricing path-dependent discretely-monitoring options with errors of one bp or below. The scheme is also fast: the computational time is of the same order of magnitude of standard algorithms for Brownian motions.

Keywords: Additive process, simulation, fast Fourier transform, Lewis formula

Algorithmic market making in foreign exchange cash markets with hedging and market impact

Philippe Bergault (Ecole Polytechnique)

In OTC markets, one of the main tasks of market makers consists in providing prices at which they agree to buy and sell the assets they have in their scope. With ever increasing trading volume, this quoting task has to be done algorithmically. Over the last ten years, many models have been designed that can be the basis of quoting algorithms in OTC markets. Nevertheless, in most models, the market maker is a pure internalizer, setting quotes and waiting for clients. However, on many markets such as FX cash markets, market makers have access to liquidity pools where they can hedge part of their inventory. In this paper, we propose a model taking this possibility into account, therefore allowing market makers to externalize part of their risk by trading in a liquidity pool. The model displays an important feature that within a certain inventory range, the market maker internalizes the flow by appropriately adjusting the quotes, and externalizes outside of that range.

Keywords: Market making, Algorithmic trading, Stochastic optimal control, Viscosity solutions

Mean-reversion and Production Flexibility: Effects on Firms' Operational Strategy

Bertolosi Cristina (Bayes Business School, UCL)

Production flexibility allows a firm to temporarily stop and eventually restart its operational activity to react to changes in market conditions. Mainly based on the previous contributions of Sarkar (2003), Tsekrekos (2010, 2013), and Wong and Yi (2013), this work investigates the impact of mean-reversion on the strategic decisions of a firm when real options to temporarily suspend and to permanently abandon production co-exist. Findings reveal a non-negligible effect of mean-reversion, reinforced by a moderate degree of production flexibility, which might lead to exercising the suspension option more – or less – often than optimal. As such, results confirm the inappropriateness of using geometric Brownian motion as a proxy for mean-reverting processes in real options models.

Keywords: flexibility; mean-reversion; real options

Dynamic regulation of carbon market

Sara Biagini (Luiss)

We consider the problem of reducing the carbon emissions of a set of firms over a finite horizon. A regulator dynamically allocates emission allowances to each firm. Firms face idiosyncratic as well as common economic shocks on emissions, and have linear quadratic abatement costs. Firms can trade allowances so to minimise total expected costs, from abatement and trading plus a quadratic terminal penalty. Using variational methods, we exhibit in closed-form the market equilibrium in function of regulator's dynamic allocation. We then solve the Stackelberg game between the regulator and the firms. Again, we obtain a closed-form expression of the

dynamic allocation policies that allow a desired expected emission reduction. Optimal policies are not unique but share common properties. Surprisingly, all optimal policies induce a constant abatement effort and a constant price of allowances.

Keywords: Stochastic optimization, environmental economics, cap and trade, linear quadratic problem, Fréchet differentiability, market equilibrium, social cost minimisation.

Extracting implied volatilities from bank bonds

Bianchi Michele Leonardo (Banca d'Italia)

In this work we explore the information content of senior, subordinated and additional tier 1 (or contingent convertible) bonds issued by euro area banks. We analyze both the asset volatility implied in senior and subordinated bonds and credit default swap market spreads, and the CET1 ratio volatility extracted from additional tier 1 bonds secondary market spreads in the period from December 31, 2012 to March 31, 2021. Furthermore, we jointly consider the following important bank variables: asset, equity and CET1 ratio volatilities. In doing so, we can obtain the market view on credit spreads, banks balance sheet and capital ratio dynamics on a daily basis even if bank data are released quarterly. The approach can be used to monitor the risk of each bank, as perceived by the market, and to investigate banking fragility at a stand-alone or at a country level.

Keywords: subordinated bonds; AT1 bonds; CoCo bonds; credit default swaps; capital requirements; CET1 ratio; implied CET1 volatility; firm value models

Insurance valuation: A two-step generalized regression approach

Bignozzi Valeria (University of Milan Bicocca)

Current approaches to fair valuation in insurance often follow a two-step approach, combining quadratic hedging with application of a risk measure on the residual liability, to obtain a cost-of-capital margin. In such approaches, the preferences represented by the regulatory risk measure are not reflected in the hedging process. We address this issue by an alternative two-step hedging procedure, based on eneralized regression arguments, which leads to portfolios that are neutral with respect to a risk measure, such as Value-at-Risk or the expectile. First, a portfolio of traded assets aimed at replicating the liability is determined by local quadratic hedging. Second, the residual liability is hedged using an alternative objective function. The risk margin is then defined as the cost of the capital required to hedge the residual liability. In the case quantile regression is used in the second step, yearly solvency constraints are naturally satisfied.

Keywords: Market-consistent valuation, Quantile regression, Solvency II, Cost-of-capital, Dynamic risk measurement.

A McKean-Vlasov Game of Commodity Production, Consumption and Trading

Ofelia Bonesini (University of Padova)

We propose a model where a producer and a consumer affect the price dynamics of a commodity controlling drift and volatility of production and consumption rate, respectively. The producer has a short position in a forward contract on λ units of the underlying at a fixed price F, while the consumer has the corresponding long position. Moreover, both players are risk-averse. Thus, we are dealing with a two-player linear-quadratic McKean-Vlasov stochastic differential game. Using methods based on the martingale optimality principle and

BSDEs, we find a Nash equilibrium and characterize the corresponding strategies and payoffs in semi-explicit form. Then, we compute the two indifference prices induced by that equilibrium and we determine the quantity λ such that the players agree on the price. Finally, we illustrate our results with some numerics, focusing on how the risk aversions and the volatility control costs of the players affect the derivative price.

Keywords: price manipulation, indifference pricing, linear-quadratic stochastic differential games, weak martingale optimality principle, mean-field BSDEs.

A Lucas Critique Compliant SVAR model with Observation-driven Time-varying Parameters

Giacomo Bormetti (University of Bologna)

We propose an observation-driven time-varying SVAR model where, in agreement with the Lucas Critique, structural shocks drive both the evolution of the macro variables and the dynamics of the VAR parameters. Contrary to existing approaches where parameters follow a stochastic process with random and exogenous shocks, our observation-driven specification allows the evolution of the parameters to be driven by realized past structural shocks, thus opening the possibility to gauge the impact of observed shocks and hypothetical policy interventions on the future evolution of the economic system.

Keywords: Time-varying VAR models; Independent Component Analysis; Score-driven models.

A Stochastic Control Approach to Public Debt Management

Matteo Brachetta (Polytechnic of Milan)

Public debt management is one of the most relevant topics in Economics, especially after economic crises due to wars, pandemics or economic recession. We discuss a class of debt management problems in a stochastic environment model. We propose a model for the Debt-to-GDP ratio where the government interventions (via fiscal policies) affect the public debt and the GDP growth rate at the same time. We allow for a stochastic interest rate on debt and possible correlation with the GDP growth rate. Indeed, both the interest rate and the GDP growth depend on a stochastic factor, which may represent any relevant macroeconomic variable, such as economic conditions. We tackle the problem of a government whose goal is to determine the fiscal policy in order to minimize a general functional cost. We prove that the value function is a viscosity solution to the Hamilton-Jacobi-Bellman equation and provide a Verification Theorem based on classical solutions. Then we discuss two specific problems.

Keywords: Optimal stochastic control; government debt management; optimal fiscal policy; Hamilton-Jacobi-Bellman equation.

Portfolio returns and tracking error optimization in presence of skew-normal distributions

Michele Bufalo (University of Rome - Sapienza)

The gist of this work is to propose a minimum tracking error portfolio that could be adopted not only as an automated alternative to ETFs but, it could also be potentially used to anticipate market changes in the target index. This goal has been achieved by adopting a skew Brownian motion as a general framework. The proposed solution has been declined in two versions: the case in which the constituents (i.e., in our case the sub-indices)

of the objective portfolio are uncorrelated among each other, and the case in which correlation should be taken into account. Our tests, carried out on the S&P 500, as an example of a developed market, and Bovespa, as an example of an emerging market, shows that the proposed solutions replicate the index with a much smaller tracking error than that of the ETFs considered.

Keywords: Forecasting, Portfolio optimization, Tracking error, Skew-normal Brownian motions.

On a class of partially observed systems arising in singular optimal control

Alessandro Calvia (Luiss)

Partially observed systems in continuous-time model phenomena that appear in various disciplines where some quantity of interest, described by a stochastic process called signal, is not directly measurable and affects an observed process. The latter process allows to compute an estimate of the unobserved state, given by the filtering process. This is required to study optimal control problems with partial observation, where an agent aims at optimizing some functional, depending on the unobserved state and on the observation, by means of a control process. In the singular control case, these problems have been studied only in specific cases, despite possible interesting applications. The aim of this talk is to introduce a class of singular control problems with partial information, to provide an application to a pollution control problem, and to give the explicit filtering equation (an SPDE) together with a uniqueness result. Joint work with Giorgio Ferrari, Bielefeld University.

Keywords: Singularly controlled systems; pollution control; stochastic filtering; Zakai equation; Kushner-Stratonovich equation.

Living on the Edge: An Unified Approach to Antithetic Sampling

Roberto Casarin (Ca' Foscari University of Venice)

We identify recurrent ingredients in the antithetic sampling literature leading to a unified sampling framework. We introduce a new class of antithetic schemes that include the most used antithetic proposals. This perspective enables the derivation of new properties of the sampling schemes: i) optimality in the Kullback-Leibler sense; ii) closed-form multivariate Kendall's τ and Spearman's ρ; iii)ranking in concordance order and iv) a central limit theorem that characterizes stochastic behavior of Monte Carlo estimators when the sample size tends to infinity. Finally, we provide applications to Monte Carlo integration and Markov Chain Monte Carlo Bayesian estimation.

Keywords: Antithetic variables; Countermonotonicity; Monte Carlo; Negative dependence; Variance reduction

The Leverage Effect and Propagation

Leopoldo Catania (Aarhus BSS and CREATES)

This paper proposes a new way to measure the leverage effect and its propagation over time. We also show that, with respect to the newly proposed measure, common volatility models like the GJRGARCH, the Exponential GARCH, and the asymmetric SV can be inaccurate to correctly represent the leverage effect and its propagation for financial time series. We propose to modify the variance recursion of common volatility models by including an auxiliary leverage process which allows for a proper representation of the leverage effect and its propagation over time. Empirical results indicate that the inclusion of the auxiliary leverage process is required for both in sample and out of sample analyses.

Keywords: Leverage effect, volatility modelling, asymmetric GARCH

AI and Adversarial AI in insurance: Background, examples and future implications

Matteo Cattaneo (Reale Mutua)

This paper describes the rapid and dynamic pace of Artificial Intelligence (AI) and Machine Learning (ML) developments that have revolutionized the insurance sector. AI content-based processing of information includes image and video analysis, facial recognition and automated decision making for claims management and fraud detection. The paper focuses on adversarial AI, namely on the creation of input data slightly altered to mislead a machine learning system and make it produce incorrect predictions. It provides a case study of the impact of adversarial AI in health insurance. Not only can the model be fooled for detecting the malignancy of patients, but a higher level of perturbation can increase the success rate of the attack by lowering the accuracy of the system. We deem important, for insurance companies ready to adopt AI technologies, to be aware of the consequences of adversarial attacks. We conclude with policy recommendations, consistent with the current regulatory framework

Keywords: Artificial Intelligence, Neural Networks, Insurance sector

Optimal Reinsurance and Investment under common shock dependence between the financial and the actuarial market

Claudia Ceci (University of Chieti-Pescara)

We study optimal proportional reinsurance and investment strategies for an insurance company which experiences both ordinary and catastrophic claims and wishes to maximize the expected exponential utility of its terminal wealth. We propose a model where the insurance framework is affected by environmental factors, and aggregate claims and stock prices are subject to common shocks, i.e. drastic events such as earthquakes, extreme weather conditions, or even pandemics, that have an immediate impact on the financial market and simultaneously induce insurance claims. Using the classical stochastic control approach based on the Hamilton-Jacobi- Bellman equation, we provide a verification result for the value function via classical solutions to two backward partial differential equations and characterize the optimal reinsurance and investment strategies. Finally, we discuss the effect of the common shock dependence via a comparison analysis.

Keywords: Optimal proportional reinsurance; optimal investment; common shock dependence; environmental factors; Hamilton-Jacobi-Bellman equation

Maximum risk diversification for portfolio selection

Francesco Cesarone (University of Roma Tre)

In this paper, we address the problem of finding portfolios with maximum diversification, possibly with the addition of return constraints. The diversification measure is based on a convexity ratio between the risk of a convex combination of assets and the convex combination of their risks. Our contribution is manifold: we extend the maximum diversification approach for volatility to general subadditive and positive homogeneous risk measures; we create a bridge between Risk Parity and the most diversified portfolios; we add a target return to the maximum diversification approaches in the Gain-Risk analysis style. Finally, we provide an extensive empirical analysis based on seven real-world datasets, highlighting encouraging out-of-sample performances of our approach compared to the classical ones.

Keywords: Risk Diversification; Portfolio Selection; Convex Risk Measures; Subadditivity.

Measure-valued affine and polynomial diffusions for energy modeling

Christa Cuchiero (University of Vienna)

We introduce a class of measure-valued processes, which we call in analogy to their finite dimensional counterparts measure-valued polynomial diffusions. We show the so-called moment formula, i.e. a representation of the conditional marginal moments via a system of finite dimensional linear PDEs. We also characterize the corresponding infinitesimal generators and obtain a representation analogous to polynomial diffusions on $\mathbb{R}_+^m$. From a mathematical finance point of view this polynomial framework is particularly attractive as it allows to transfer the most famous finite dimensional models, such as the Black-Scholes model or the Cox-Ingersoll-Ross process, to an infinite dimensional measure-valued setting. Our focus here lies on electricity and gas market modeling with the goal to establish a Heath-Jarrow-Morton approach based on measure-valued processes and to identify tractable polynomial models whose function-valued characteristics are parametrized via neural networks.

Keywords: measure-valued processes ; polynomial and affine processes ; energy modeling; HJM approach; neural SPDEs

Cumulative Prospect Theory portfolio selection

Marco Corazza (Ca' Foscari University of Venice)

We introduce elements of Cumulative Prospect Theory into the portfolio selection problem and then compare stock portfolios selected under the behavioral approach with those selected according to classical approaches, such as Mean Variance and Mean Absolute Deviation ones. The mathematical programming problem associated to the behavioral portfolio selection is highly non-linear and non-differentiable; for these reasons it is solved using a Particle Swarm Optimization approach. An application to the STOXX Europe 600 equity market is performed.

Keywords: Cumulative Prospect Theory; Portfolio Selection; Particle Swarm Optimization.

Herding and Anti-Herding Across ESG Funds

Ambrogio Dalò (University of Groningen)

We investigate to what extent ESG funds present a herding/anti-herding behavior, and the consequences of their investment strategies in terms of both systematic risk exposure and risk-adjusted returns. Our findings document that ESG funds pursue an anti-herding strategy that leads to higher risk-adjusted returns. Specifically, a one standard deviation increase in ESG score at the fund-level is associated with an increase in fund performance of about 3.74 basis points per year. Moreover, we document that such an enhanced performance does not come at the cost of higher systematic risk exposure but instead reduces it. A possible explanation behind our findings is that after the catching-up phase previously documented by the literature, ESG funds are now able to put to good use enhanced stock-picking skills built over the years.

Keywords: ESG investing, Equity Funds, Herding, Anti-Herding, Risk-Adjusted Returns.

Filtering and Parameter Estimation in a Rough Volatility Model

Camilla Damian (TU Vienna)

We focus on the estimation of historical volatility of asset prices from high-frequency data. Stochastic volatility models pose a major statistical challenge: since in reality historical volatility is not observable, its current level and, possibly, the parameters governing its dynamics have to be estimated from the observable time series of asset prices. To complicate matters further, recent research has analyzed the rough behavior of volatility time series to challenge the common assumption that the volatility process is a Brownian semimartingale. In order to tackle the arising inferential task efficiently in this setting, we use the fact that a fractional Brownian motion can be represented as a superposition of Markovian semimartingales (Ornstein-Uhlenbeck processes) and we solve the filtering (and parameter estimation) problem by resorting to more 'standard' techniques, such as particle methods.

Keywords: high-frequency data; rough volatility; nested particle filter

Directional Signal and Momentum

Luca Del Viva (ESADE Business School)

We document the existence of exploitable directional predictability in equity returns. We find that that the conditional probability of observing positive returns after a sequence of k consecutive negative (positive) returns is increasing (decreasing) with k. We propose a number of strategies to profit from this finding and compare them with momentum. We show that the proposed strategies (i) generate positive alphas and higher Sharpe ratios relative to momentum; (ii) generate positively skewed returns and have very low probability of crashes; (iii) when combined with momentum, our strategies generate substantially higher returns and Sharpe ratios; and (iv) correlate with momentum during bull markets, but substantially outperform momentum strategies in bear markets thus reducing momentum crashes.

Keywords: Return sign dependence, prediction, market timing, momentum

Portfolio Optimization Under Solvency II: a Multi-objective Approach Incorporating Market Views and Real World Constraints

Marco Di Francesco (UnipolSai Assicurazioni S.p.A.)

We propose a new approach to handle the problem of portfolio optimization for non-life insurance company incorporating the Solvency Capital Requirement (SCR), market views and their confident levels, several equality and inequality real world constraints and transaction costs. We analyze two case studies: first, we consider a tri-objective optimization problem in which we minimize the Mar- ket SCR, the variance of the so called Basic Own Funds (BOF) and maximize the return of portfolio; secondly we consider bi-objective optimization problem in which we minimize the variance of BOF and maximize the return of portfolio while considering the Market SCR as a constraint. We introduce a scenario-based framework in which the reference model is given by an internal model. By Entropy Pooling approach we blended market views and their confident levels with the reference model to build the posterior distribution. The latter is used to compute the variance of BOF and the portfolio return.

Keywords: Portfolio Theory, Solvency II, Multi-objective evolution algorithm, real world constraints, non-life insurance company

Conditional Systemic Risk Measures

Alessandro Doldi (University of Milan)

We investigate to which extent the relevant features of (static) Systemic Risk Measures can be extended to a conditional setting. After providing a general dual representation result, we analyze in greater detail Conditional Shortfall Systemic Risk Measures. In the particular case of exponential preferences, we provide explicit formulas that also allow us to show a time consistency property. Finally, we provide an interpretation of the allocations associated to Conditional Shortfall Systemic Risk Measures as suitably defined equilibria. Conceptually, the generalization from static to conditional Systemic Risk Measures can be achieved in a natural way, even though the proofs become more technical than in the unconditional framework.

Keywords: Conditional Risk; Systemic Risk; Conditional Equilibrium; Dynamic Risk Measures.

A dynamic theory of spatial externalities: The case of transboundary pollutions

Salvatore Federico (University of Genova)

We characterize the shape of spatial externalities in a continuous time and space differential game with transboundary pollution. We posit a realistic spatiotemporal law of motion for pollution (diffusion and advection), and tackle spatiotemporal non-cooperative (and cooperative) differential games. Precisely, we consider a circle partitioned into several states where a local authority decides autonomously about its investment, production and depollution strategies over time knowing that investment/production generates pollution, and pollution is transboundary. The time horizon is infinite. We allow for a rich set of geographic heterogeneities across states. We solve analytically the induced non-cooperative differential game and characterize its long-term spatial distributions. In particular, we prove that there exist a Perfect Markov Equilibrium, unique among the class of the affine feedbacks. We further provide with a full exploration of the free riding problem and the associated

Keywords: Spatial externalities, spatial diffusion, differential games in continuous time and space, infinite dimensional optimal control problems, environmental federalism.

Generalized PELVE and applications to risk measures

Anna Maria Fiori (University of Milan Bicocca)

Recent revisions in Banking and Insurance Regulation have raised interest in the calibration between pairs of different risk measures. In particular, Li and Wang (2019) have introduced a probability equivalent level (called PELVE) for the replacement of Value at Risk with Conditional Value at Risk at suitable confidence levels. Extending their work, we here propose a new index (generalized PELVE, or g-PELVE) that permits the calibration between more general pairs of monotone risk measures. We state conditions for the existence and uniqueness of g-PELVE, and derive additional properties for specific families of risk measures. A study of Generalized Pareto Distributions reveals an interesting connection between PELVE and g-PELVE, and explores their relationship with the tail index. An empirical application illustrates the usefulness of (g-)PELVE in characterizing tail behavior of individual assets and portfolio combinations.

Keywords: Conditional Value at Risk; Heavy Tails; Generalized Pareto Distributions.

Graphical models for commodities: a quantile approach

Beatrice Foroni (University of Rome - Sapienza)

The high level of integration of international financial markets highlights the need to accurately assess contagion and systemic risk under different market conditions. To this end, we develop a quantile graphical model to identify the tail conditional dependence structure in multivariate data across different quantiles of the marginal distributions of the variables of interest. To implement the procedure, we consider the Multivariate Asymmetric Laplace distribution and exploit its location-scale mixture representation to build a penalized EM algorithm for estimating the sparse precision matrix of the distribution by means of an L_1 penalty. The empirical application is performed on a large set of commodities representative of the energy, agricultural and metal sectors.

Keywords: Financial Networks, Multivariate Asymmetric Laplace Distribution, Multiple Quantiles, EM Algorithm

Deep Neural Network Algorithms for Parabolic PIDEs and Applications in Finance and Insurance

Rüdiger Frey (WU Vienna)

In recent years a large literature on deep learning based methods for the numerical solution partial differential equations has emerged; results for integro-differential equations on the other hand are scarce. In this paper we study deep neural network algorithms for solving linear and semilinear parabolic partial integro-differential equations with boundary conditions in high dimension. To show the viability of our approach we discuss several case studies from insurance and finance.

Keywords: Deep Neural networks, parabolic partial integro differential equations, insurance models, stochastic control

Non-linear approximated value adjustments for derivatives under multiple risk factors

Ivan Gallo (University of L'Aquila)

In our work, we develop a framework for valuing the Value Adjustment of European contingent claims option on an underlying driven by a geometric Brownian motion correlated with two Cox-Ingersoll-Ross (CIR) default intensities. The valuation equation takes the form of an FBSDE and in a Markovian setting, we may associate a semi-linear PDE. Under appropriate conditions, it is possible to show the existence and uniqueness of the solution, in any case, the non-linearity prevents writing explicit solutions. Since the 3-dimensional process is Markov, the solution process to the FBSDE is a deterministic function in the state variables. Verifying a semi-linear PDE in R+ x R3+, which cannot the solved explicitly because of its nonlinearity and we resort to numerical methods. We apply the method of lines to numerically solve the PDE efficiently and we show that such method is much faster than Monte Carlo simulation.

Keywords: Valutation adjustments; Backword stochastic differential Equation; Nonlinear valuation; Credit risk; Defaultable Claims.

News Sentiment indicators and the Cross-Section of Stock Returns in the European Stock Market

Luca Gambarelli (University of Modena and Reggio Emilia)

This paper investigates whether the Bloomberg sentiment index can explain the cross-section of stock returns. Using a sample of listed European stocks from 2010 to 2021, we exploit portfolio strategies to assess whether and how long investor sentiment can affect future stock returns. Moreover, we aggregate the investor sentiment to monitor the overall sentiment level in the EU stock market. We find a positive relationship between sentiment and future stock returns, both statistically and economically significant and robust to the inclusion of common risk factors—stocks with high (low) sentiment exhibit high (low) returns on average. Stock return predictability using sentiment indicator hold for at least three months, and positive news are incorporated slower than negative news in the stock price, especially for small-cap stocks. Finally, aggregate sentiment is inversely related to future market returns: high (low) sentiment predicts negative (positive) future returns.

Keywords: Investor sentiment, Cross section, Portfolio strategies, Future returns, Stock size

The complex step method for financial Greeks

Anna Maria Gambaro (University of Piemonte Orientale)

The complex step approximation (CSA) is a well known numerical method for the calculus of derivatives of highly non linear functions. To te best of our knowledge, a complete discussion of the application of CSA to the calculus of financial Greeks is not presented in literature. This work aims to fill this gap. Firstly, we analyse both theoretically and empirically the CSA performance associated with Monte Carlo simulations. In particular, we study the statistical properties of the CSA estimators for first and second order Greeks. Moreover, in case of discontinuous payoff, we analyse the bias-variance trade-off problem. Furthermore, we compare the CSA method with the other most widespread methods for the calculus of financial Greeks, i.e. the finite difference and the algorithmic differentiation. Finally, we present an application of the CSA method for the Gamma-Delta approximation of the Value at Risk of a portfolio, containing digital and barrier options.

Keywords: complex step approximation, financial greeks, discontinuous payoff.

Reinforcement learning for investment strategies with transaction costs

Federico Giorgi (University of Roma - Tor Vergata)

We apply Reinforcement Learning (RL) to determine an optimal portfolio strategy in a dynamic setting with transaction costs. To evaluate the performance of our approach we consider the model proposed by Gârleanu and Pedersen, where it is possible to compute the theoretical optimum. Then, we consider a more general and realistic setting where an optimal solution is not known and the use of RL can be justified. In the first set of tests we use the same factor model as Gârleanu and Pedersen and we observe that in this case the RL algorithm produces a strategy whose performances are comparable to those of the theoretically optimal strategy. A second set of tests compares the performances of the three agents on nonlinear factor models and on cases where the factor are not directly observable by the agents; in this non-linear setting, RL is proven to obtain better results than the benchmark approaches.

Keywords: Dynamic strategies; Reinforcement learning; Intertemporal choice; Machine learning; Investment strategies

A Fully Quantization-based Scheme for FBSDEs

Alessandro Gnoatto (University of Verona)

We propose a quantization-based numerical scheme for a family of decoupled FBSDEs. We simplify the scheme for the control in Pagès and Sagna (2018) so that our approach is fully based on recursive marginal quantization and does not involve any Monte Carlo simulation for the computation of conditional expectations. We analyse in detail the numerical error of our scheme and we show through some examples the performance of the whole procedure, which proves to be very effective in view of financial applications. Paper available at: https://arxiv.org/abs/2105.09276

Keywords: FBSDEs, Quantization, Numerical Scheme

EU Post-COVID-19 Green Policy Announcements and Sectoral Stock Returns

Ivan Gufler (Luiss)

We explore the stock market response of green and brown stocks to green policy-related announcements (GPAs) in the post-COVID era (year 2020). Our main empirical findings indicate the presence of positive cumulative abnormal returns (CARs) both in the green and brown sectors following GPAs. However, the observed positive effect is stronger for more sustainable portfolios. A size effect in terms of the amount of resources announced to be allocated for a specific policy is also observed. In fact, we show that the observed positive benefits are mainly due to announcements of climate change mitigation-related policies, which account for 70% of the total allocated funds. At the sector level, positive and significant CARs due to GPAs are found in the i) energy, ii) financials and iii) industrials sectors. Once again, larger benefits from GPAs are found among more sustainable portfolios.

Keywords: Climate change, green policy announcements, green transition, green and brown stocks, event study

Sensitivity to large losses and ρ-arbitrage for convex risk measures

Nazem Khan (Warwick University)

We study mean-risk portfolio selection in a one-period financial market, where risk is quantified by a convex risk measure ρ. We introduce two new axioms: weak and strong sensitivity to large losses. We show that the first axiom is key to ensure the existence of optimal portfolios and the second one is key to ensure the absence of ρ -arbitrage. This leads to a new class of risk measures that are suitable for portfolio selection. We show that ρ belongs to this class if and only if ρ is real-valued and the smallest positively homogeneous risk measure dominating ρ is the worst-case risk measure. Finally, we introduce the new risk measure of Loss Sensitive Expected Shortfall, which is similar to and not more complicated to compute than Expected Shortfall but suitable for portfolio selection -- which Expected Shortfall is not.

Keywords: portfolio selection, ρ -arbitrage, convex risk measures, sensitivity to large losses, Expected Shortfall

Forward-looking Bandwidth Selection for the Kernel Density Estimator of the Physical Return Distribution

Maria Kosolapova (Free University of Bozen)

We consider a new rule for choosing the bandwidth (smoothing parameter) for the kernel density estimator of the physical return distribution. It aims at minimising its dissimilarity from the corresponding risk-neutral density, estimated from the option prices. We find that our bandwidth selection rule outperforms the rule of thumb one, especially in times of higher uncertainty (measured by expected volatility).

Keywords: Physical probabilities; Risk-neutral density; Kernel density; Relative entropy; Predicting returns.

Neural Jump Ordinary Differential Equations: Consistent Continuous-Time Prediction and Filtering

Florian Krach (ETH Zurich)

Combinations of neural ODEs with RNNs are well suited to model irregularly observed time series. While those models outperform existing discrete-time approaches, no theoretical guarantees for their predictive capabilities are available. Assuming that the irregularly-sampled time series data originates from a continuous stochastic process, the L^2-optimal online prediction is the conditional expectation given the currently available information. We introduce the Neural Jump ODE that provides a data-driven approach to learn, continuously in time, the conditional expectation of a stochastic process. Our approach models the conditional expectation between two observations with a neural ODE and jumps whenever a new observation is made. We show that the output of our model converges to the L^2-optimal prediction. This can be interpreted as solution to a special filtering problem. We provide experiments showing that the theoretical results also hold empirically.

Keywords: recurrent neural networks, continuously deep neural networks, neural ODEs, neural filtering, stochastic filtering, universal approximation, conditional expectation, time series prediction

Score Driven Generalized Fitness Model for Sparse Weighted Dynamical Networks

Fabrizio Lillo (University of Bologna and Scuola Normale Superiore)

We propose a novel time varying parameter model for sparse weighted temporal networks as a combination of the fitness model, appropriately extended to handle also the weights, and the score driven framework. While the vast majority of the literature on models for time varying networks focuses on binary graphs, i.e., graphs that are defined solely by a set of nodes and a set of links between pairs of nodes, often we can associate a weight to each link. In such cases the data is better described by a weighted, or valued, network. One important well-known fact is that real world valued networks are very often found to be sparse, i.e. their adjacency matrices have an abundance of zero entries. Our main contribution is a model for sparse weighted dynamical networks, that also accommodates for the dependency of the network dynamics on external variables, and its application to weighted temporal network data, describing overnight exposures in the European interbank market.

Keywords: Temporal Networks, Score Driven Models, Weighted Networks

Optimal withdrawal strategies in GLWB variable annuities

Rosario Maggistro (Università di Trieste)

We propose a discrete time model, based on dynamic programming, to price variable annuities with GLWB under the dynamic approach within a stochastic mortality framework. Although our set-up is very general and only requires the Markovian property for the mortality intensity and the asset price processes, in the numerical implementation of the model we shape the former as a non-mean reverting square root process, and the latter as an exponential Lévy process. In this way we get a tractable stochastic model for efficient pricing of the GLWB. We also provide the verification, through backward induction, of the bang-bang condition for the set of

discrete withdrawal strategies of the model.This result is particularly remarkable as in the insurance literature either the existence of optimal bang-bang controls is assumed, or it requires suitable conditions.In conclusion, we present numerical examples and compare the results obtained for different market parameters and policyholder behaviours.

Keywords: GLWB; Dynamic withdrawals; Bang-bang condition; Lévy processes; Stochastic mortality

A performance analysis of portfolio insurance strategies with guaranteed minimum equity exposure

Daniele Mancinelli (University of Roma - Sapienza)

In this paper we investigate the role played by the guaranteed minimum equity exposure (GMEE) in the Portfolio Insurance strategies, as a vehicle to test the efficiency of such methodologies. More precisely, we compare the Constant Proportion-Portfolio Insurance strategy (CPPI), with or without GMEE, and the Option Based-Portfolio Insurance (OBPI) one, where the risky asset is allocated in a European call option linked to a G-CPPI portfolio. We measure specific performance indicators, and draft the corresponding risk profiles by considering different market scenarios, and allowing for transaction costs. The performance analysis confirms the ability of the mixed strategy both to guarantee the equity market participation and to avoid the cash-in risk, regardless of market conditions. Moreover, we show that the presence of GMEE represents a further form of protection, as it ensures lower expected losses than the other strategies.

Keywords: Portfolio Insurance, CPPI, OBPI, Guaranteed minimum equity exposure, Risk-adjusted performance

Drift burst test statistic in a pure jump semimartingale model

Cecilia Mancini (University of Verona)

In a Ito semimartingale model we determine the asymptotic behavior of a statistic, used in Christensen, Oomen and Renò (2020), in the case where infinite variation jumps are present. We show that when there are no bursts in drift neither in volatility, explosion of the statistic only can occur when the jumps have finite variation. We also find that the statistic could be used for a variety of tests to investigate the nature of the data generating process of a discrete record of observations.

Keywords: test statistic; Ito semimartingale; infinite variation jumps; jump activity index; asymptotic behavior.

Pricing commodity index options

Alberto Pedro Manzano Herrero (Intesa Sanpaolo Group)

We present a stochastic local volatility model for derivative contracts on commodity futures. The aim of the model is to be able to recover the prices of derivative claims on commodity indices. Numerical examples for calibration and pricing are provided.

Keywords: Commodity markets; Index Options; Stochastic Local Volatility Models; Calibration.

A R-vine copula based model for multi-peril insurance ratemaking

Mario Marino (University of Rome - Sapienza)

Ratemaking is a crucial actuarial task in Non-Life insurance, and it is based on the probabilistic shaping about the claims distribution and the associated losses. In the case of multi-peril insurance contracts, losses derive from multiple types of coverage and dependencies among multiple types of claims could emerge under a single policy. Hence, a multivariate modeling accounting for claims dependence is necessary to determine the pure premium, the policy limits and risk capital charges associated with the contract. To this end, our proposal joins: (a) the Tweedie's compound Poisson regression model to marginally represent the aggregate claims for each peril, and (b) R-vine copula to take into account the dependence structure between pairs of perils. The resulting model provides a joint distribution for the overall loss embedding different dependency structures as well as coherent marginal behaviour.

From Zero-Intelligence to Queue-Reactive: Limit Order Book modeling for high-frequency volatility estimation and optimal execution

Tommaso Mariotti (Scuola Normale Superiore)

Many estimators have been proposed to deal with microstructure noise to estimate the integrated variance or the spot variance of high-frequency data, but the estimators might be sensitive to misspecification, especially in finite samples. Following Gatheral and Oomen (2010), we propose to use the “Queue-reactive model” for limit order book (Huang, LeHalle, Rosenbaum, 2015) to generate simulated data, which are calibrated on real data, to compare the performances in the estimation of integrated and spot variance of different estimators, such as Fourier, kernel-based, pre-averaging, multi-scale and maximum-likelihood estimators. The Queue-reactive model, introducing a correlation between intensities and state of the limit order book, should produce more realistic order book dynamics with respect to the zero-intelligence model used in Gatheral and Oomen (2010). The Hausman test for the presence of noise at different frequencies is also used to evaluate noise accumulation in the two model.

Keywords: Limit Order Book, Microstructure Noise, Volatility Estimation, Optimal Execution

A deep learning approach to manage the longevity risk

Antonio Luciano Martire (University of Rome - Sapienza)

Due to the 2007-2008 financial crisis, risk management has been playing a central role for those who operate in both the financial and life markets. Pertaining the latter, agents must confront themselves with some peculiar forms of risk, such as the Longevity risk. It is well known that in the financial/actuarial industry, stochastic models are used fo forecast mortality and that mean reversion models seem to be more suitable, in the reality, for mortality. The complexity of the stochastic integral/differential equations that this type of evolution models involve, makes it necessary to build dedicated methods to manage them. Under this perspective, deep neural network techniques may be applied to high-dimensional problems. In the present work, in a partial differential equation framework, starting form real data, we propose a deep learning architectures that, equipped with accurate predictions, permits to manage easily the longevity risk.

Keywords: longevity risk; deep neural network; partial differential equaiton; stochastic integral/differential equations.

A composite index for measuring stock market inefficiency

Raffaele Mattera (Università degli Studi di Napoli Federico II)

In this paper we develop a new time-varying measure of stock market inefficiency. The proposed measure, called Composite Efficency Index (CEI), is estimated as the synthesis of the most common efficiency measures such as the returns' Hurst exponent, autocorrelation, liquidity and volatility.

Keywords: multi-fractional Brownian motion, Hurst exponent, Composite indicator, Principal Component Analysis (PCA), Factor model

Realized Exponential Random Graphs, with an Application to the Interbank Network

Piero Mazzarisi (Scuola Normale Superiore)

Given a sequence of random graphs generated by an exponential family distribution, known as exponential random graphs (ERG), we define a realized ERG (RERG) as a single snapshot maximum-likelihood estimate of the ERG parameters. RERG's are noisy measurements of the latent state variables driving the evolution of the graph over time. They allow to transform a nonlinear state-space graph model into a linear time-series model, simplifying considerably the inference of a wide class of dynamic networks. Under the assumption that the random graph sequence is dense, and of a mixed membership stochastic blockmodel structure, we show that the model parameters and the latent state variables can be estimated at a super-consistent rate of convergence for increasing number of nodes. We corroborate our findings by using this novel framework to estimate and forecast the unobserved factors driving the evolution of the Italian electronic market of interbank deposits. Empirical evidences support the

Keywords: Exponential Random Graphs, Dynamic network models, Dynamic factors, Kalman filter, Interbank market.

Proxy-hedging with Integer Linear Programming in low-liquidity energy markets

Alexandru Melnic (University of Rome Sapienza)

We develop a method to reduce the risk given by the exposure in certain illiquid commodities markets. We formulate the proxy-hedging problem as an optimization problem. In order to reduce the risk of a mandatory instrument that must be hedged, we define the objective function as the total execution costs of the portfolio and we impose a limit on the maximum VaR of the solution, which is what defines the quality of the hedging. Since VaR does not have a closed-form expression, to be used in the optimization it is necessary to model it by introducing boolean variables to get at the end the problem as an Integer Linear Programming. We provide numerical results on the performances of the method and an analysis of the robustness.

Keywords: hedging; Portfolio-optimization; commodities

Determinism in corporate dynamics: The case of Android in the Operating System market

Giuseppe Orlando (University of Bari)

The aim of this paper is to model corporate dynamics in terms of the evolution of deterministic systems. Market competition is characterized by oscillations between periods of frenzy and quiescence development, swinging between periods of fierce competition and quieter periods when companies settle in a business niche.

Such behavior reminiscent of neuronal activity; we, therefore, use for the modeling of market competition a deterministic dynamical system approach that has successfully been applied in the later field. Our business example is the competition in the operating system (OS), where Android has managed to gain a substantial market share at the expense of MS Windows. In modeling this competition, our deterministic approach yields results that are on equal footing with the stochastic ARIMA-EGARCH approach. This implies that, behind a seemingly noisy activity, real-world business dynamics may have a strong low-dimensional deterministic components.

Keywords: Rulkov map, chaos, equilibrium, corporate dynamics

The Shapley Value and the Banzhaf Value as Instruments for Portfolio Selection

Arsen Palestini (University of Rome - Sapienza)

A novel approach is proposed to employ the solution concepts in Cooperative Game Theory in some Portfolio Optimization problems. Assets can be viewed as the players of a cooperative game which can be either a payoff or a cost game. We specifically focus on the payoff game to identify a new way of assessing the assets' marginal contributions to the overall return of the portfolio; in so doing, a payoff game can also be an efficient tool for portfolio selection. Solving a sequence of Markowitz problems yields the values of the game, and subsequently Shapley and Banzhaf values are found to be suitable to identify assets' marginal contributions to the overall payoff. A preference scheme is naturally induced by such a procedure.

Keywords: Cooperative Games; Portfolio Optimization; Shapley Value; Banzhaf Value; Markowitz.

Interpolating commodity futures prices with Kriging

Andrea Pallavicini (Intesa SanPaolo Group)

The shape of the futures term structure is essential to commodity hedgers and speculators as futures prices serve as a forecast of future spot prices. Commodity markets quotes futures prices on a selection of maturities and delivery periods. In this note we investigate a Bayesian technique known as Kriging to build a term structure of futures prices by embedding trends and seasonalities and by ensuring no-arbitrage conditions between different delivery periods.

Keywords: Kriging, Commodity Futures, Futures Term Structure, Natural Gas

When do investors go green? Evidence from a time-varying asset-pricing model

Roberto Panzica (European Commission, Joint Research Centre)

This paper studies the evolution of the greenium, i.e. a risk premium linked to firms' greenness and environmental transparency, based on individual stock returns. We estimate an asset pricing model with time-varying risk premia, where the greenium is associated to a priced `greenness and transparency' factor. We show that investors in the European equity market tend to accept lower returns, ceteris paribus, to hold greener and more transparent assets when the shift of the economy towards low-carbon becomes more credible. This happened after the Paris Agreement, the first Global Climate Strike and the announcement of the EU Green Deal, as well as when the price of critical raw materials for low-carbon technologies increased.

Signals going in the opposite direction, such as the US withdrawal from the Paris Agreement and more bad news about climate change, are associated with increases in the greenium.

Keywords: Climate risk, environmental disclosure, conditional factor models, asset pricing

An explorative analysis of sentiment impact on S&P 500 components returns, volatility and downside risk

Marco Patacca (University of Verona)

In this paper, we analyze the relative impact of sentiment measures either on the mean returns or on the variance of 150 components of the S&P 500 index by fitting nonlinear econometric models to the historical data of their returns. The overall effect of sentiment on downside risk measures, such as Value at Risk and Expected Shortfall, is also investigated. Sentiment is measured through two proprietary Bloomberg indicators based on media news and Twitter posts. Empirical results support the hypothesis that these indicators do have a positive impact on both returns and volatility. However, no clear effect is inherited in the downside risk measures assessment.

Keywords: Sentiment Analysis, Investor attention, GARCH time series model, Risk measures

Reinforcement Learning for Options on Target Volatility Funds

Stefano Polo (Illimity S.p.a.)

In this work we deal with the funding costs rising from hedging the risky securities underlying a target volatility strategy (TVS), a portfolio of risky assets and a risk-free one dynamically rebalanced in order to keep the realized volatility of the portfolio on a certain level. The uncertainty in the TVS risky portfolio composition along with the difference in hedging costs for each component requires to solve a control problem to evaluate the option prices. We derive an analytical solution of the problem in the Black and Scholes (BS) scenario. Then we use Reinforcement Learning (RL) techniques to determine the fund composition leading to the most conservative price under the local volatility (LV) model, for which an a priori solution is not available. We show how the performances of the RL agents are compatible with those obtained by applying path-wise the BS analytical strategy to the TVS dynamics, which therefore appears competitive also in the LV scenario.

Keywords: Reinforcement Learning; Target Volatility; Hedging Costs; Stochastic Control Problem; Asset Allocation.

Deep Learning Calibration of the SABR Model

Makar Pravosud (Pompeu Fabra University)

In this paper we investigate a two step procedure that formalizes the application of deep feed-forward neural nets in the problem of the calibration of the SABR option pricing model. The analysis is performed without the need of manually preparing the network topology, that is instead optimally choosen by means of a Bayesian algorithm. In particular, we show that the trained network possesses superior approximation and retrieval properties when compared to Hagan's fomula. Additionally, we show that calibrated Hagan's formula overfits the data giving a misleading impression of a perfect fit to the implied volatility surface. The analysis is based on an extensive numerical experiment.

Keywords: SABR model; Hyper-parameter optimization, Hagan's formula; Deep learning; Model calibration; implied volatility surface.

Universal approximation theorems for continuous functions of càdlàg paths and Lévy type signature models

Francesca Primavera (University of Vienna)

Signature-based models have recently entered the field of stochastic modeling, in particular in Mathematical Finance. The choice of the signature as the main building block is mostly explained by a universal approximation theorem (UAT) according to which continuous functionals of continuous paths can be approximated by linear functions of the time extended signature. This powerful result, however, leaves open the question of approximating continuous functionals of the more general set of càdlàg paths. Based on recent results on the signature of càdlàg paths, during the first part of the talk, we present UATs that solve this question. Next, as an application, we define signature-based models which include jumps, extending therefore the class of continuous signature models for asset prices proposed so far. This talk is based on ongoing joint work with Christa Cuchiero and Sara Svaluto-Ferro.

Keywords: Signature models in finance

Optimal Firm's Dividend and Capital Structure for Mean Reverting Profitability

Luca Regis (University of Torino)

We model a risk-averse firm owner who wants to maximize the inter-temporal expected utility of firm's dividends. The optimal dynamic control problem is characterized by two stochastic state variables: the equity value, and profitability (ROA) of the firm. According to the empirical evidence, we let profitability follow a mean reverting process. The problem is solved in a quasi-explicit form by computing both the optimal dividend and the optimal debt. Finally, we calibrate the model to actual US data and check both the properties of the solution and its sensitivity to the model parameters. In particular, our results show that the optimal dividend is smooth over time and that leverage is predominantly constant over time. Neither asymmetric information nor frictions are necessary to obtain these findings.

Keywords: dividend policy, capital structure, profit mean-reversion, closed-form, stochastic optimization

Portfolio selection with scenario filtering: A combinatorial optimization approach

Moisés Rodríguez-Madrena (Universidad de Sevilla)

Recent studies stressed the fact that covariance matrices computed from empirical financial time series appear to contain a high amount of noise. This makes the classical Mean-Variance Optimization model unable to correctly evaluate the performance associated to selected portfolios. Several filtering methods have been proposed in the literature to overcome the problem. The basic idea of these methods is to transform the estimated correlation matrix before applying the Mean-Variance Optimization model. However, experimental analysis shows that this strategy is not always effective when applied to real financial datasets. In this paper we propose a new filtering method: we develop a MIQP model which is able to filter those observations that may

affect the performance of the selected portfolio. We compare the out-of-sample performance of our portfolios with the one of the portfolios provided by alternative filtering methods giving evidence that our method outperforms them.

Keywords: Mean-Variance Optimization; Portfolio selection; Filtering methods; Mixed Integer Quadratic Programming.

The forecasting power of short-term options

Carlo Sala (ESADE Business School)

We propose option-implied measures of conditional asymmetry based upon quantiles and expectiles inferred from weekly options. All quantities are by construction forward-looking and estimated non-parametrically through a novel arbitrage-free natural smoothing spline technique that produces quick to estimate volatility smiles. We find that option-implied asymmetry indicators exhibit short, medium and long-term predictive ability for the U.S. equity risk premium and market volatility, both in- and out-of-sample, and out-perform equal indicators inferred from historical returns.

Keywords: Volatility smile, Quantiles, Expectiles, Weekly options, Forecasting.

Chebyshev Greeks: Smoothing Gamma without Bias

Stefano Scoleri (Be Management Consulting)

The computation of Greeks is a fundamental task for risk managing of financial instruments. The standard approach to their numerical evaluation is via finite differences. Most exotic derivatives are priced via Monte Carlo simulation: in these cases, it is hard to find a fast and accurate approximation of Greeks, mainly because of the need of a tradeoff between bias and variance. Recent improvements in Greeks computation, such as AAD, are unfortunately uneffective on second order Greeks (such as Gamma), which are plagued by the most significant instabilities, so that a viable alternative to standard finite differences is still lacking. We apply Chebyshev interpolation techniques to the computation of spot Greeks, showing how to improve the stability of finite difference Greeks of arbitrary order, in a simple and general way. The increased performance of the proposed technique is analyzed for a number of real payoffs commonly traded by financial institutions.

Keywords: Chebyshev interpolation, barycentric formula, finite differences, gamma, Monte Carlo

The impact of co-jumps on portfolio choice with recursive preferences

Ilaria Stefani (University of Rome - Sapienza)

In this paper we investigate a dynamic, continuous-time optimal consumption and portfolio allocation problem when the investor faces recursive utilities in an economy described through both diffusion and discontinuities in the state variable dynamics. By exploiting standard dynamic programming techniques we derive an approximated solution to optimal rules and study the role played by (co)jumps.

Keywords: Asset allocation, Consumption, Stochastic volatility, Co-jumps, Dynamic programming, Recursive preferences

Signature SDEs from an affine and polynomial perspective

Sara Svaluto-Ferro (University of Verona)

Already in the well studied finite dimensional framework, affine and polynomial processes are two fascinating classes of models. This is mostly due to the so-called affine transform formula and moment formula, respectively. In this paper we show that generic classes of diffusion models are projections of infinite dimensional affine processes (which in this setup coincide with polynomial processes). The second part of the paper is dedicated to applications. We first show how to apply the introduced mechanism to one-dimensional diffusion processes with analytic coefficients, and which type of formulas can be obtained in that framework. Then, we consider the so-called signature process and explain the advantages to use the obtained formulas in the context of the corresponding signature based models. The paper is based on ongoing joint works with Christa Cuchiero, Guido Gazzani, and Josef Teichmann.

Keywords: Stochastic processes, signatures, affine transform formula, affine processes, moment formula, polynomial processes, infinite dimensional lifts

CBI-time-changed Lévy processes for multi-currency modeling

Guillaume Szulda (University of Padova)

We develop a stochastic volatility framework for modeling multiple currencies based on CBI-time-changed Lévy processes. The proposed framework captures the typical risk characteristics of FX markets and is coherent with the symmetries of FX rates. Moreover, due to the self-exciting behavior of CBI processes, the volatilities of FX rates exhibit self-exciting dynamics. By relying on the theory of affine processes, we show that our approach is analytically tractable and that the model structure is invariant under a suitable class of risk-neutral measures. A semi-closed pricing formula for currency options is obtained by Fourier methods. We propose two calibration methods, also by relying on deep-learning techniques, and show that a simple specification of the model can achieve a good fit to market data on a currency triangle.

Keywords: FX market; multi-currency market; branching process; self-exciting process; time-change; stochastic volatility; deep calibration; affine process.

Energy Transition, Asset Price Fluctuations, and Dynamic Portfolio Decisions

Ibrahim Tahri (Potsdam Institut For Climate Impact Research)

This paper analyzes the implications of short-termism on portfolio decisions of investors, and its potential consequences on green investments. We first study a dynamic portfolio choice problem that contains two assets, one asset with fluctuating returns and another asset with a constant risk-free return. Fluctuating returns can arise from fossil or from clean energy related assets. Short-termism is seen to be driven by discount rates (exponential and hyperbolic) and the decision horizon of investors. We then introduce a portfolio of two risky asset returns, calibrated through harmonic estimations. For both model variants, we explore the impact of the fluctuating asset returns on the fate of the portfolio. We study deterministic and stochastic variants and the cases where innovation efforts are spent for fossil fuel or clean energy sources. Detailing dynamic portfolio decisions in such a way may allow us for better pathways to empirical tests.

Keywords: Short-termism, Decision horizon, Hyperbolic discounting

Optimal Stopping via Randomized Neural Networks

Josef Teichmann (ETH, Zurich)

This paper presents new machine learning approaches to approximate the solutions of optimal stopping problems. The key idea of these methods is to use neural networks, where the parameters of the hidden layers are generated randomly and only the last layer is trained, in order to approximate the continuation value. Our approaches are applicable to high dimensional problems where the existing approaches become increasingly impractical. In addition, since our approaches can be optimized using simple linear regression, they are easy to implement and theoretical guarantees can be provided. Our randomized reinforcement learning approach and randomized recurrent neural network approach outperform the state-of-the-art and other relevant machine learning approaches in Markovian and non- Markovian examples, respectively. In particular, we test the algorithm on data simulated from Black-Scholes, Heston, rough Heston and fractional Brownian motion.

Keywords: optimal stopping, least squares Monte Carlo, reinforcement learning, randomized neural networks, reservoir computing

Geometric Diversification in Portfolio Theory

Maria Laura Torrente (University of Genova)

In this paper we propose a novel asset allocation rule based on the intuitive idea of geometric diversification. The concept of diversification in portfolio theory is central and accountable of the popularity of Markowitz model where the idea has been first introduced. Despite its simplicity, no generally accepted unique definition of diversification is available in the literature, giving the rise to the production of many contributions on the topic. For an axiomatic approach to portfolio diversification measures we refer to [3], where the authors certify that single asset portfolios are the worst in terms of diversification assuming size degeneracy axiom. Regarding the axiomatic approach to risk measures, the literature dates back to the paper of [1], that proposes the desirable properties for a coherent risk measure. In this context, the importance of diversification is represented by the sub-additivity property, implying that the risk of a portfolio is less or equal than the sum of the risks of its constituents. To detail our proposal we start representing the set of long-only admissible portfolios with n risky components by means of the standard simplex of R n , a generalization of the notion of a triangle or tetrahedron to arbitrary dimensions. In this setting, the dimension of the space stands for the number of assets, while the vertices of the simplex are the single asset portfolios, which are considered the worst portfolios in terms of diversification, see again [3]. In order to differentiate from such maximum concentrated extreme cases, we propose to invest in the portfolio, called Geometric Diversified Portfolio (GDP), equally distant from the vertices of the simplex. Geometrically, the GDP is represented by the circumcenter of the simplex, whose position depends on the used distance. In order to take into account the specific risk of the assets, our approach is based on the Risk Adjusted Distances (RADs in the following) introduced in this paper and resulting in a deformation of the geometrical space. The RADs thus play a prominent role in our proposal. Though, from a strict mathematical point of view, a RAD is nothing but a weighted Euclidean distance, its use in the context of portfolio theory allows to compute the distance between investment portfolios not only in terms of difference in the allocation but also taking into account the risk undertaken. To the best of our knowledge, in the financial literature, this is the first attempt to conceive this kind of notion, in contrast to the case of risk adjusted performance measures which are well-known and widely accepted by the entire community. This evidence is a further argument supporting the intuition behind our proposal to adjust a distance for the risk. Investors are conscious that, when evaluating the overall performance of an investment, both the return and the risk undertaken to realize that return need to be considered. This is the reason why risk adjusted performance measures play a fundamental role in financial decision making. In the paper, given any RAD, we provide an explicit expression for the GDP strategy and prove interesting properties of the proposed approach, comparing it with alternative approaches to asset allocation.

The GDP shows the intuitive feature to underweight the allocation on the riskier asset classes while overweighting the allocation on the less risky ones. If the Euclidean distance is used, being the simplex a regular polytope, the circumcenter corresponds to the center of gravity, so that our proposal reduces to the Equally Weighted Portfolio (EWP), see [2]. In particular, if the variance is used, we show that the EWP is something more than a special case when the Euclidean distance is considered: indeed, it represents a limit case when the number n of assets is extremely large, that is $n \to +\infty$. We also compare the GDP with the Equally Risk Contribution model (ERC), see [4], showing the relations among the different approaches. The effectiveness of our proposal is finally highlighted through a real data out-of-sample experiment: empirical findings confirm and emphasize the goodness of our proposal, comparing its performance to the one of the very popular benchmark strategies. While the present paper focuses on the effective computation of the strategy and highlights its properties, in [5] the authors introduce an equivalent reformulation of the proposed asset allocation rule obtained through an optimization approach where the objective function can be interpreted as a diversification measure, providing an alternative and rigorous formalization in terms of maximum diversification.

References.

[1] Artzner, Delbaen, Eber, Heath (1990) Math Finance.

[2] DeMiguel, Garlappi, Uppal (2009) The Review of Financial Studies.

[3] Koumou, Dionne (2016) https://ssrn.com/abstract=2830516.

[4] Maillard, Roncalli, Teiletche (2010) The Journal of Portfolio Management.

[5] Torrente, Uberti (2021) https://www.researchgate.net/publication/355470977_On_a_Class_of_Portfolio_Diversification_Measures_Induced_by_Risk_Measures.

Keywords: Portfolio Diversification; Risk Adjusted Distance; Asset Allocation; Equally Weighted Portfolio; Equally Risk Contribution.

Convex duality in continuous option pricing models

Lorenzo Torricelli (University of Bologna)

We provide an alternative description of diffusive asset pricing models using the theory of convex duality. Instead of specifying an underlying martingale security process and deriving option price dynamics, we directly specify a stochastic differential equation for the dual delta, i.e. the option delta as a function of strike, and attain a process describing the option convex conjugate. For valuation, the convex conjugate of an option price is seen to satisfy a certain initial value problem dual to Dupire 1994 equation, and the option price can be derived by inverting the Legendre transform. We discuss in detail the primal and dual specifications of two known cases, the Normal Bachlier 1900 model and Carr and Torricelli 2021 logistic price model, and show that the dynamics of the latter retain a much simpler expression when the dual formulation is used.

Keywords: convex duality, option valuation, dual delta, convex conjugate, multiplicatively separable volatility, logistic model, Bachelier model

Linear transformation of multivariate AR processes in infinite dimension

Tiziano Vargiolu (University of Padova)

Our work aims to consider supply and demand curves of electricity day-ahead markets as stochastic processes with values in a functional space. We study linear transformations of multivariate stochastic processes. It is a known fact that a linear transformation of a vector ARMA process is again an ARMA process. However, in general, there are transformations of a finite order AR(p) process that do not admit a finite order AR representation, but just a mixed ARMA representation. We obtain a characterization result regarding the conditions that guarantees that a linear transformation of a vector AR process is again an AR process both in finite and in infinite dimension, and we apply these results to the model of Ziel and Steinert (2018).

Keywords: auto-regressive process in Hilbert spaces, electricity market, X-model, pseudo-inverse operators, variable selection models

Portfolio Optimization with self-exciting jump process

Andrea Veronese (University of Trento)

In the present work, we aim at generalizing the well-known portfolio optimization problem `a la Merton assuming the asset price evolution is described by a self-exciting jump-diffusion process. We consider the problem as firstly introduced by R. C. Merton in 1975, whose goal was to provide the investor the optimal consumption for a given portfolio with continuous dynamic. Thus, we generalize the original formulation assuming that the portfolio dynamic is steered by a stochastic point process that belongs to the class of self-exciting jump-diffusion process. To the best of our knowledge, this is the first work to consider an optimization problem in a self-exciting jump-diffusion setting. We first derive theoretical results needed to rigorously introduce the stochastic optimal control problem. Thus, after introducing a suitable Dynamic Programming Principle (DPP) to consider the general class of self-exciting processes under study, we derive the Hamilton-Jacobi-Bellman (HJB) equation, whose solution gives the value function for the associated optimal control problem. The resulting HJB equation is an Integro Partial Differential Equation (IPDE). It is worth stressing that, due to self-exciting process appearing in the asset dynamics, the HJB depends in general by an additional variable that does not appear in the standard setting. Such new variable accounts for the stochasticity due to the intensity of the jump process. Since the considered HJB does not fall in the classical setting, we prove existence and uniqueness for a solution to the HJB in the viscosity sense. We further derive a suitable numerical scheme to solve the HJB associated to the portfolio optimization problem, providing a detailed study on the solution and on its dependence on the parameters of the problem. The analysis is performed considering ENEL asset levels during the COVID-19 worldwide breakout. During this time period, asset prices showed extreme volatility and sudden jumps, so that the implementation of new approaches to describe extreme returns are necessary. Furthermore, the self-exciting model proposed requires sophisticated calibration procedure since the log-likelihood estimation is not sufficient to get a robust estimation, therefore we use a particular implementation of Sequential Monte Carlo algorithm, namely SMC. This family of Particle Filtering techniques relies on Bayesian statistical Inference and aim to compute the posterior distributions for some stochastic processes using a set of particles, whereas we are in presence of noisy observations. In particular, this filtering problem is high dimensional and the noisy part is given by several sources: this motivates a robust calibration procedure which acts simultaneously. The Sequential Monte Carlo proposed relies on the joint use of the iterated bath importance sampling (IBIS) algorithm, and the particle filters technique (PFs), whereas the priors distributions are centered on the calibration output of the log-likelihood routine.

Keywords: Portfolio optimization; self-exciting process; Hamilton-Jacobi-Bellman equation; viscosity solution; particle filtering.

Testing for Jumps in a Discretely Observed Price Process with Endogenous Sampling Times

Shifan Yu (Lancaster University)

We propose a new nonparametric test to determine whether finite-activity jumps are present in a discretely observed price process. For a univariate Itô semimartingale, we introduce the concept of censored increments for observations recursively sampled at exit times with a symmetric double barrier, and design a standardized test statistic to compare the sample moments of censored and uncensored increments. Simulation results show that our test has better finite-sample performance than other commonly used calendar time-based jump tests with a similar level of sampling sparseness, and is fairly robust to measurement errors including market microstructure noise and price staleness. Our empirical study provides strong evidence for the presence of jumps for 10 NYSE stocks in 2020, but the frequency of jumps are much less than that suggested by some existing tests.

Keywords: high-frequency data, jump test, market microstructure noise, stochastic sampling scheme, first exit time, price staleness

Optimal Dividends under Markov-Modulated Bankruptcy Level

Shihao Zhu (Bielefeld University)

This paper proposes and solves an optimal dividend problem in which a two-state regime-switching environment affects the dynamics of the company's cash surplus and, as a novel feature, also the bankruptcy level. The aim is to maximize the total expected profits from dividends until bankruptcy. The company's optimal dividend payout is influenced by four factors simultaneously: Brownian fluctuations in the cash surplus, as well as regime changes in drift, volatility and bankruptcy levels. In particular, the average profitability can assume different signs in the two regimes. We find a rich structure of the optimal strategy, which, depending on the interaction of the model's parameters, is either of barrier-type or of liquidation-barrier type. Furthermore, we provide explicit expressions of the optimal policies and value functions. Finally, we complement our theoretical results by a detailed numerical study, where also the sensitivities analysis of the optimal policy is performed.

Keywords: Optimal dividend policy; Regime-switching; Regime-dependent bankruptcy levels; HJB equation; Singular stochastic control.