mathematics & finance:

13th Edition

R:O

Research in Options

Búzios, Rio de Janeiro, Brazil - November 24th to 28th, 2018

Program & Abstracts

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Research in Options 2018

Búzios, Rio de Janeiro, November 24 – 28, 2018

Minicourses

Hour	Friday 23	Saturday 24	Sunday 25
9:00 - 10:30		**Part I** **Teemu Pennanen** (King´s College London, UK)	**Part I** **Jim Gatheral** (Baruch College, CUNY)
10:30 - 11:00		**Cofee Break**	
11:00 - 12:30		**Part II** **Teemu Pennanen** (King´s College London, UK)	**Part II** **Jim Gatheral** (Baruch College, CUNY)
12:30 - 14:00		**Lunch**	
14:00 - 15:30		**Part I** **Sebastian Jaimungal** (University of Toronto)	**14:00 - 17:00** **Free**
15:30 - 16:00		**Cofee Break**	
16:00 - 17:30	**ARRIVAL**	**Part II** **Sebastian Jaimungal** (University of Toronto)	**17:00 - 18:30** **Registration & Poster**
17:30 - 18:30			

Research in Options 2018

Búzios, Rio de Janeiro, November 24 – 28, 2018

Program

Hour	Monday 26	Tuesday 27	Wednesday 28	Thrusday 29
09:00 - 09:30	Opening: **Market Day** **Opening**		Panel 5: **Ernst Eberlein** (Universität Freiburg)	
09:30 - 10:00	Opening: **Jorge Zubelli** (IMPA)	Panel 3: **Carole Bernard** (Grenoble Ecole de Management)	Panel 5: **Giorgio Consigli** (Università degli Studi di Bergamo)	10:00 Bus Departure
10:00 - 10:30	Opening: **Yuri Saporito** (FGV)	Panel 3: **Lane Hughston** (Goldsmiths College, University of London)	Panel 5: **Stephane Crépey** (Université Evry Val d´Essonne)	
10:30 - 11:00	**Coffee Break**			
11:00 - 11:30	Mini course: **Bruno Dupire** (Bloomberg, NY)	Panel 4: **Teemu Pennanen** (King´s College London)	Panel 6: **Jan Obłoj** (University of Oxford)	
11:30 - 12:00		Panel 4: **Uwe Schmock** (Vienna University of Technology)	Panel 6: **Martin Schweizer** (ETH Zürich)	
12:00 - 12:30		Panel 4: **Lakshithe Wagalath** (IÉSEG)	Panel 6: **Josef Teichman** (ETH Zürich)	
12:30 - 14:00	**Lunch**			
14:00 - 14:30	Panel 1: **Guillaume Blacher** (Bank of America)	Contributed Talks: 14:00 - 14:20 **Julia Dupire** (NY University Stern School of Business)	Panel 7: **Martino Grasselli** (Padova University & Devinci Research Center)	
14:30 - 15:00	Panel 1: **Jim Gatheral** (Baruch College)	14:25 - 14:45 **Fernando A. L. Aiube** (Univ. do Estado do Rio de Janeiro) / **Marcos Costa Carreira** (École Polytechnique) 14:50 - 15:10 **Raquel M. Gaspar** (Universidade de Lisboa) / **Youngna Choi** (Montclair State University)	Panel 7: **Rodrigo Targino** (FGV)	
15:00 - 15:30	Panel 1: **Matheus Grasselli** (McMaster University)	15:15 - 15:35 **Diogo Duarte** (Florida International University) / **Jose Afonso Faias** (Universidade Católica Portuguesa) 15:40 - 16:10 **Bourgey Florian** (École Polytechnique) / **José Javier Cerda** (Univ. Nacional de Ingenieria)	Panel 7: **Julien Guyon** (Bloomberg)	
15:30 - 16:00	**Coffee Break**		**Coffee Break**	
16:00 - 16:30	Panel 2: **Sebastian Jaimungal** (Univ. of Toronto)	16:15 - 16:35 **Coffee Break**	Panel 8: **Alberto Pinto** (University of Porto)	
16:30 - 17:00	Panel 2: **Raphael Douady** (SUNY Stony Brook)	16:35 - 16:55 **Christopher Hofmann** (Chemnitz University of Technology) / **Sergio Maffra** (King's College London)	Panel 8: **Max Souza** (Universidade Federal Fluminense)	
17:00 - 17:30	Panel 2: **Jean Pierre Fouque** (Univ.of California S.B.)	17:00 - 17:20 **Eben Mare** (University of Pretoria) / **Konul Mustafayeva** (King´s College London) & **Babak Mahdavi-Damghani** (University of Oxford)	Panel 8: **Antoine Savine** (Danske Bank Copenhagen)	
17:30 - 19:00	**Poster Session**	17:25 - 17:45 **Juan Rodriguez Otazú** (LNCC) / **Ludger Overbeck** (University Giessen) 17:50 - 18:10 **Luca Parlamento** (Macquarie University) / **Gyorgy Varga** (FCE Consultoria)	**17:30 - 18:00** **Closing with Video by Marco Avellaneda**	
19:30 - 24:00	Conference Dinner			

Minicourses

Rough volatility

Jim Gatheral[1]

[1] Baruch College

The scaling properties of historical volatility time series, which now appear to be universal, together with the scaling properties of implied volatility smiles, motivate a new class of stochastic volatility models where paths of volatility are rougher than those of Brownian motion. Rough volatility connects the microstructure of financial markets with the large-scale behavior of volatility as encoded in the implied volatility surface. Rough volatility models are remarkably consistent with both econometric data and option prices and yet are typically very parsimonious. This mini-course will present an overview of rough volatility and its applications, including efficient forecasting of future integrated variance and option pricing.

Machine Learning in Algorithmic Trading

Sebastian Jaimungal[1]

[1] Univ. of Toronto

This mini course features studies in machine learning that are useful in algorithmic trading, including supervised and unsupervised learning and reinforcement learning. Specific topics include: multiclass logistic regression, Bayes classifiers, Gaussian mixture models, Hidden Markov Models, Q-learning, Deep Q-Learning, and Autoencoders. The course will provide an overview of the techniques and how they can be used in an algorithmic trading such as in statistical arbitrage strategies and optimal execution.

Incomplete markets

Teemu Pennanen[1]

[1] King's College London

The minicourse gives an introduction to financial economics in terms of basic optimization theory. We provide a unified treatment of financial risk management, accounting, and asset pricing in a simple discrete-time model that avoids many of the technicalities associated with traditional continuous-time models. This leaves room for practical considerations that are sometimes neglected in more mathematical texts. In particular, the approach allows for nonlinear illiquidity effects and portfolio constraints which are significant in practice but invalidate much of the classical theory of financial mathematics.

Invited Lectures

The influence of Bruno Dupire on derivatives markets

Antoine Savine[1]

[1] Danske Bank Copenhagen

30 minutes talk in 3 parts

1- Volatility and calibration
2- Variance swaps and the VIX index
3- Market risk, sensitivity and functional stochastic calculus

25 years of Local Volatility and 10 years of Functional Itô calculus

Bruno Dupire[1]

[1] Bloomberg & NYU

This talk visits a few milestones and anecdotes of my personal journey in mathematical finance.

Option Implied Dependence

Carole Bernard[1], Oleg Bondarenko[2], Steven Vanduffel[3]

[1] Grenoble Ecole de Management & Vrije Universiteit Brussel

Using forward-looking information from option prices, we propose a novel model-free approach to obtain the joint risk-neutral dependence among asset returns. As an application, we study the correlation risk premium. In previous literature, it is reported that the (unconditional) correlation risk premium is slightly negative. However, our methodology makes it possible to relate this risk premium to economic states. Specifically, using option data on the S&P 500 and its nine sectors, we estimate sector correlation risk premiums, conditional on the market going up or down. We show that the risk premium for the down correlation is strongly negative, whereas it is slightly positive for the up correlation. These findings confirm the economic intuition that the correlation premium is linked to the loss of diversification when financial markets fall.

Multiple curve Lévy forward price model allowing for negative interest rates

Ernst Eberlein [1]

[1] Freiburg, Germany

The global financial crisis which started in early August 2007 had a lasting effect on financial markets. In particular the fixed income markets changed in a fundamental way. As a consequence of a new perception of risk a number of interest rates, which until then had been roughly equivalent, drifted apart. The basic rates, which are relevant for the interbank market, became tenor-dependent after market participants became aware of credit, liquidity and funding risks in this market segment. These risks had been assumed to be negligible before. In the new reality classical modelling approaches which are based on arbitrage considerations assuming tenor-independence cannot reflect the market behaviour any more. More sophisticated approaches, so-called multiple curve models, are needed to take the increased diversity of risks into account.

We develop a multiple curve forward process model. Time-inhomogeneous Lévy processes are used as drivers. Negative interest rates are taken into account in a natural way. We derive valuation formulas for standard interest rate financial products such as caps and show how initial curves can be bootstrapped from rates which are quoted at the markets. Some calibration results are presented.

This project is joint work with Christoph Gerhart (Freiburg) and Zorana Grbac (Paris).

Fixed Point Method for Fast Smile Calibration of Hybrid Model

Guillaume Blacher[1]

[1] Bank of America

Highly efficient routines for calibrating complex exotic models to observable points on the market volatility smile, achieved by solving for a parametric local volatility component of the model. A Fixed Point Algorithm used to that effect is described in detail as are approximations for estimating implied volatilities from local volatilities.

Derivatives-based portfolio management via multistage stochastic programming

Giorgio Consigli[1], Diana Barro[2], Vivek Varun[3]

[1] Università degli Studi di Bergamo

[2] Università Ca' Foscari Venezia

[3] Università degli Studi di Bergamo

We extend a canonical dynamic asset management model to allow for nonlinear financial payoffs such as those carried by European call and put options. We present a generic optimization model, which is then applied to the US market to derive optimal hedging and speculative strategies over different time periods characterising recent financial history. From a modelling perspective we generalise previous efforts to allow for a comprehensive modelling approach based on a tree-based option pricing method and multistage stochastic optimization with recourse. The introduction of the derivative contracts by exploiting the asymmetric payoffs of options leads to a tight constraint on the underlying contracts price tails. Such underlying contract is indeed represented by a market portfolio such as the SPX500 in the US equity market. The talk will focus on a short term planning problem with 6 month horizon and monthly strategy revision, an objective function based on a shortfall minimization problem with respect to a return target and a set of constraints including options strategy constraints such as those induced by a covered call or a protective put strategy.

Keywords: asset management, hedging and speculative strategies, option pricing, multistage stochastic programming, stochastic linear programming.

Diamonds and the rough Heston model

Jim Gatheral[1]

[1] Baruch College

We use the Itô Decomposition Formula of Alòs to express certain conditional expectations as exponentials of forests of trees. Each tree represents iterated applications of a new diamond operator. As one application, we compute an exact formal expression for the leverage swap for any stochastic volatility model expressed in forward variance form. As another, we show how to extend the Bergomi-Guyon expansion to all orders in volatility of volatility. Finally, we compute exact expressions under rough volatility, obtaining in particular a closed-form expression for the leverage swap in the rough Heston model.

On the Joint Calibration of SPX and VIX Options

Julien Guyon[1]

[1] Bloomberg, USA

Since VIX options started trading in 2006, many researchers have attempted to build a model for the SPX that jointly calibrates to SPX and VIX options. In 2008, Jim Gatheral showed that a diffusive model could approximately, but not exactly, fit both markets. Later, others have argued that jumps in the SPX were needed to jointly calibrate both markets. We revisit this problem, asking the following questions: Does there exist a continuous model on the SPX that jointly calibrates to SPX options, VIX futures, and VIX options? If so, how to build one such model? If not, why? We present a novel approach based on the SPX smile calibration condition $E[\sigma_t^2|S_t] = \sigma_{lv}^2(t, S_t)$. In the limiting case of instantaneous VIX, the answers are clear and involve the timewise convex ordering of two distributions (local variance and instantaneous variance) and a novel application of martingale transport to finance. The real case of a 30-day VIX is more involved, as time-averaging and projection onto a filtration can undo convex ordering. We show that in usual market conditions, for short maturities, the distribution of VIX^2 in the local volatility model is NOT smaller than the market-implied distribution of VIX^2 in convex order, and we explain that fast mean-reverting volatility models and rough volatility models are able to reproduce this surprising behavior. In particular, we prove two conjectures to be wrong: among all continuous models on the SPX calibrated to the SPX smile, the local volatility model does NOT produce the maximum value of VIX futures, nor does it produce the minimum value of options on VIX2.

Option Implied Dependence

Jan Obloj[1]

[1] University of Oxford

I discuss implementation and performance of non-parametric methods for computing arbitrage bounds given market data. In the robust approach both time series data as well as market prices for options are taken into the account. This is novel in comparison to the classical approach where these two types of data are usually considered under different probability measures (real world vs risk neutral).

Using option prices data is linked with the so-called Skorokhod embedding problem, a problem that Bruno Dupire has looked over a decade ago. More recently, this led to the so-called martingale optimal transport (MOT) problem. We prove that the MOT problem can be approximated through a sequence of linear programming (LP) problems which result from a discretisation of the marginal distributions combined with a suitable relaxation of the martingale constraint. We also develop an implementation using Deep Neural Nets.

Using time-series data, I consider the toy problem of using historical returns to estimate the superhedging price of an option in a one-step model. We introduce several estimators and discuss their consistency and robustness, both statistical as well as financial. We discuss in detail the natural plug-in estimator, show it is consistent and estimate its rates of convergence, but also show that it is not robust. To address this, we propose estimators obtained using Wasserstein balls which turn out to be (in a suitable sense) statistically robust and also, under some regularity of option's payoff, financially robust. At the end I present outlook for merging different numerical techniques into a single comprehensive approach.

Based on joint works with Stephan Eckstein, Gaoyue Guo, Tongseok Lim and Johannes Wiesel.

On Fairness of Systemic Risk Measures

Jean-Pierre Fouque[1]

[1] University of California Santa Barbara

In our previous paper "A Unified Approach to Systemic Risk Measures via Acceptance Set" to appear in Mathematical Finance, we have introduced a general class of systemic risk measures that allow random allocations to individual banks before aggregation of their risks. In the present paper, we address the question of fairness of these allocations and propose a fair allocation of the total risk to individual banks. We show that the dual formulation of the minimization problem identifying the systemic risk measure provides a valuation of the random allocations, which is fair both from the point of view of the society/regulator and from the individual financial institutions. The case with exponential utilities which allows for explicit computation is treated in details.

Joint work with Francesca Biagini, Marco Frittelli, and Thilo Meyer-Brandis

Scenario generation by machine learning techniques

Josef Teichman[1]

[1] ETH Zürich

We introduce the paradigm of reservoir computing, show several connections to rough path theory and develop a scenario generator from thoses insights. The scenario generator is surprisingly model-free and easy to estimate.

On Dupire's local volatility model

Jorge P. Zubelli[1]

[1] IMPA

In this talk we shall briefly review some of Dupire's seminal contribution to Quantitative Finance. More precisely, we shall start by reviewing Dupire's local volatility model and Dupire's equation. Then we shall discuss the issue of calibration and some extensions.

On the Determination of the Lévy Exponent in Asset Pricing Models

Lane Hughston[1]

[1] Goldsmiths College, University of London

We consider the problem of determining the Lévy exponent in a Lévy model for asset prices given the price data of derivatives. The model, formulated under the real-world measure $\mathbb{P}$, consists of a pricing kernel $\{\pi_t\}_{t\geq 0}$ together with one or more non-dividend-paying risky assets driven by the same Lévy process. If $\{S_t\}_{t\geq 0}$ denotes the price process of such an asset then $\{\pi_t S_t\}_{t\geq 0}$ is a $\mathbb{P}$-martingale. The Lévy process $\{\xi_t\}_{t\geq 0}$ is assumed to have exponential moments, implying the existence of a Lévy exponent $\psi(\alpha) = t^{-1}\log\mathbb{E}(\mathrm{e}^{\alpha\xi_t})$ for α in an interval $A \subset \mathbb{R}$ containing the origin as a proper subset. We show that if the initial prices of power-payoff derivatives, for which the payoff is $H_T = (\zeta_T)^q$ for some fixed time $T > 0$, are given for a range of values of q, where $\{\zeta_t\}_{t\geq 0}$ is the so-called benchmark portfolio defined by $\zeta_t = 1/\pi_t$, then the Lévy exponent is fully determined, up to an irrelevant linear term. In such a setting, derivative prices embody complete information about asset price jumps: in particular, the spectrum of the asset price jumps can be worked out from current market prices of derivatives. More generally, if $H_T = (S_T)^q$ for a general non-dividend-paying risky asset driven by a Lévy process, and if we know that the pricing kernel is driven by the same Lévy process, up to a constant factor of proportionality, then from the current prices of power-payoff derivatives we can infer the structure of the Lévy exponent up to a transformation of the form $\psi(\alpha) \to \psi(\alpha+\mu) - \psi(\mu) + c\alpha$, where c and μ are constants. (Based on work carried out in collaboration with George Bouzianis, Goldsmith's College, University of London.)

Strategic Fire-Sales and Price-Mediated Contagion in the Banking System

Lakshithe Wagalath[1]

[1] IÉSEG, France

We consider a price-mediated contagion framework in which each bank, after an exogenous shock, may have to sell assets in order to comply with regulatory constraints. Interaction between banks takes place only through price impact. We first characterize the equilibrium of the strategic fire sales problem and define measures of contagion. We then calibrate our model to publicly-available data – the US banks that were part of the 2015 regulatory stress-tests – and quantify contagion effects. We finally show how our framework may be used to draw regulatory measures such as the systemic risk capital surcharge for large banks. This is joint work with Y. Braouezec.

Fast Hybrid Schemes for Fractional Riccati Equations (Rough is not so Tough)

Martino Grasselli[1], Giorgia Callegaro[2], Gilles Pàges[3]

[1] Padova University, Italy & Devinci Research Center, France

We solve a family of fractional Riccati differential equations with constant (possibly complex) coefficients. These equations arise, e.g., in fractional Heston stochastic volatility models, that have received great attention in the recent financial literature thanks to their ability to reproduce a rough volatility behavior. We first consider the case of a zero initial value corresponding to the characteristic function of the log-price. Then we investigate the case of a general starting value associated to a transform also involving the volatility process. The solution to the fractional Riccati equation takes the form of power series, whose convergence domain is typically finite. This naturally suggests a hybrid numerical algorithm to explicitly obtain the solution also beyond the convergence domain of the power series representation. Our numerical tests show that the hybrid algorithm turns out to be extremely fast and stable. When applied to option pricing, our method largely outperforms the only available alternative in the literature, based on the Adams method.

Climate Change, Finance, and Macroeconomics

Matheus Grasselli[1]

[1] McMaster University, Canada

Most integrated assessment models (IAM) for climate change, such as the Dynamic Integrated Climate-Economic (DICE) model popularized by Nobel laureate William Nordhaus, have at their core an economic module that is based on the mainstream macroeconomic paradigm of Dynamic Stochastic General Equilibrium (DSGE) models. These economic models have been the subject of intense criticism since the last financial crisis not only for their inability to predict or explain financial instabilities, but also for their adherence to "micro-foundations" that are at odds with observed behaviour of agents and lack of rigour in statistical validation.

In this talk I'll review some recent work that proposes new integrated assessment models for climate change where the DSGE core is replaced by stock-flow consistent (SFC) macroeconomic models. These alternative models have much richer dynamic outcomes and allow the exploration of nonlinear feedback loops that are entirely absent from DICE models, in particular the crucial interaction between private debt, economic activity, and global temperature.

Dynamic mean-variance optimization problems with deterministic information

Martin Schweizer[1]

[1] ETH Zürich

We solve the problems of mean-variance hedging (MVH) and mean-variance portfolio selection (MVPS) under restricted information. We work in a setting where the underlying price process S is a semimartingale, but not adapted to the filtration G which models the information available for constructing trading strategies. We choose as $G = F^det$ the zero-information filtration and assume that S is a time-dependent affine transformation of a square-integrable martingale. This class of processes includes in particular arithmetic and exponential Levy models with suitable integrability. We give explicit solutions to the MVH and MVPS problems in this setting, and we show for the Levy case how they can be expressed in terms of the Levy triplet. Explicit formulas are obtained for hedging European call options in the Bachelier and Black–Scholes models. This is based on joint work with Danijel Zivoi and Mario Sikic.

Pricing options with non-uniform Fourier transform

Max Souza[1]

[1] UFF

We discuss how to price a class of European options using Fourier transforms efficiently and accurately. This will be achieved by providing very accurate approximations to some Fourier Integral Operators (FIO). These approximations can then be efficiently implemented using the NUFFT. This is joint work with L. Muller & J.P. Zubelli.

Regime switching market evolution and calibration, relations to polymodels

Raphael Douady[1]

[1] SUNY Stony Brook

Regime switching models, also known as hidden Markov models, represent market evolution as a random sequence of steps following a Markov chain of randomly selected different random generators, chosen among a finite set of possibilities. While, in simulations, the display a behavior that is a good representation of the observed market evolution, their calibration for risk and investment purposes is a challenge we shall address. We shall also show how, in this context, nonlinear polymodels can be used for regime identification and crisis anticipation.

The impact of the freedom of the press on risk

Rodrigo Targino[1]

[1] Fundação Getúlio Vargas

We provide empirical evidence that changes in the level of the freedom of the press have a substantial impact on risk measures. Using data from the Freedom of the Press annual report to capture how freely the news media can operate, we investigate how changes in the freedom of the press impact financial market volatility and the economic policy uncertainty index. We provide the analysis for eight of the OECD countries (Australia, Canada, France, Germany, Great Britain, Korea, Japan, and the United States of America) and the BRIC countries (Brazil, Russia, India, and China). Our results indicate that the BRIC measurements of risk are more sensitive to changes in the environment in which the media operates than their OECD counterparts. Surprisingly, the effect of the freedom of the press shocks on the economic policy uncertainty index is the opposite of the financial markets volatility, providing further evidence that both measures of risk capture different dimensions of uncertainty. In addition, we provide evidence that the freedom of the press deteriorates during economic recessions relative to economic expansions. Keywords: Freedom of the Press, Economic Policy Uncertainty, Volatility, Financial Markets.

Uncertainty Quantification for XVA Applications

Stéphane Crépey[1], Emmanuel Gobet[2], Gersende Fort[3], Uladzislau Stazhynski[4]

[1] Université Evry Val d'Essonne

We analyze the uncertainty quantification for the limit $\phi^\star$ of a Stochastic Approximation (SA) algorithm, covering value-at-risk and expected shortfall with uncertain parameters as a special case. In general the limit $\phi^\star$ is defined as the zero of an intractable function and is modeled as uncertain through a parameter θ: we aim at deriving the probabilistic distribution of $\phi^\star(\theta)$, given a probability distribution π for θ. We introduce the so-called Uncertainty for SA (USA) algorithm, an SA algorithm in increasing dimension for computing the basis coefficients of a chaos expansion of $\phi^\star(\cdot)$ on an orthogonal basis of a suitable Hilbert space. USA returns a finite set of coefficients, providing an approximation $\widehat{\phi^\star}(\cdot)$ of $\phi^\star(\cdot)$; for a convenient choice of the basis, it also provides an approximation of the expectation, of the variance-covariance matrix, and of higher order moments of $\{\widehat{\phi^\star}(\theta); \theta \sim \pi\}$. The almost-sure and L^p-convergences of USA, in the Hilbert space, are established under mild, tractable conditions. The role of the USA design parameters is discussed through a numerical analysis. Versatile applications to x-Valuation Adjustments (XVAs) model risk, sensitivities, and second generation XVAs (involving not only conditional expectation but also conditional value at risk and/or expected shortfall computations) are presented.

Mean Field Games with Differing Beliefs for Algorithmic Trading

Sebastian Jaimungal[1]

[1] Univ. of Toronto

Even when confronted with the same data, agents often disagree on a model of the real-world. Here, we address the question of how-interacting heterogenous agents, who disagree on what model the real-world follows, optimize their trading actions. The market has latent factors that drive prices, and agents account for the permanent impact they have on prices. This leads to a large stochastic game, where each agents' performance criteria is computed under a different probability measure. We analyse the mean-field game (MFG) limit of the stochastic game and show that the Nash equilibria is given by the solution to a non-standard vector-valued forward-backwardstochastic differential equation. Under some mild assumptions, we construct the solution in terms of expectations of the filtered states. We prove the MFG strategy forms an ϵ-Nash equilibrium for the finite player game. Lastly, we present a least-squares Monte Carlo based algorithm for computing the optimal control and illustrate the results through simulation in market where agents disagree on the model.

This is joint work with Philippe Casgrain, U. Toronto

Double auctions in welfare economics

Teemu Pennanen[1]

[1] King's College London

Welfare economics argues that competitive markets lead to efficient allocation of resources. The classical theorems are based on the Walrasian market model which assumes the existence of market clearing prices. The emergence of such prices remains debatable. We replace the Walrasian market model by double auctions and show that the conclusions of welfare economics remain largely the same. Double auctions are not only a more realistic description of markets but they explain how equilibrium prices and efficient allocations may emerge in practice.

Geometry of Distribution-Constrained Optimal Stopping Problems

Uwe Schmock[1]

[1] Vienna University of Technology

We adapt ideas and concepts developed in optimal transport (and its martingale variant) to give a geometric description of optimal stopping times of Brownian motion subject to the constraint that the distribution is a given probability measure. These problems are motivated by actuarial science, in particular to treat unit-linked insurance products with guarantees. They can also serve as benchmark models to account for customer behaviour, when the treatment as American option is not appropriate. Our continuous-time methods work for a large class of cost processes. (At a minimum we need the cost process to be measurable and adapted. Continuity assumptions can be used to guarantee existence of solutions.) We find that for many of the cost processes one can come up with, the solution is given by the first hitting time of a barrier in a suitable phase space. As a by-product we recover classical solutions of the inverse first passage time problem/Shiryaev's problem. (This talk is based on joint work Mathias Beiglböck, Manuel Eder and Christiane Elgert, see PTRF, Vol. 172, pp. 71-101 and arXiv 1612.01488.)

On Dupire's Itô functional calculus

Yuri Saporito[1]

[1] FGV

In this talk we will review the recent developments on Functional Itô calculus, FITO in short. Created (or discovered) by Bruno Dupire and published in a seminal paper in 2009, this calculus is a generalization of Itô's classical theory and allows us to examine models where the history of certain factors plays an important role. We will present the general theory and survey the theoretical unfolding of FITO and different applications in Finance.

Implications of International Trade Agreements

Alberto A. Pinto[1], Jorge Zubelli[2], Filipe Martins[3]

[1] LIAAD-INESC TEC and Department of Mathematics, University of Porto, Portugal

[2] IMPA, Brasil

[3] LIAAD-INESC TEC, University of Porto, Portugal

We study a classic international trade model consisting of a strategic game in the tariffs of the governments. The model is a two-stage game where, at the first stage, governments of each country use their welfare functions to choose their tariffs either (i) competitively (Nash equilibrium) or (ii) cooperatively (social optimum). In the second stage, firms choose competitively (Nash) their home and export quantities. We compare the competitive (Nash) tariffs with the cooperative (social) tariffs and we classify the game type according to the coincidence or not of these equilibria as a social equilibrium (when they coincide), a prisoner's dilemma (when they do not coincide and the competitive outcome is dominated by the social) or a lose-win dilemma (when they do not coincide but one of the countries is damaged in terms of welfare in the social optimum). The lack of coincidence of these equilibria for the welfare of the governments is a main difficulty in international trade that can be partially dealt with the use of trade agreements that impose the social tariffs and rule the distribution of the corresponding welfare gains and try to mitigate the externalities that could arise among the two countries. We conclude that in the classic model, the enforcing of a trade agreement may be a difficult issue because of some powerful externalities that might arise. For this we consider a welfare balanced trade agreement that has the feature of maintaining the Nash welfare shares of the two countries when the social tariffs are enforced. We study the gains obtained by the countries by using such a trade agreement as well as changes in the shares of other relevant quantities such as profits, consumer surplus and total output of the countries and the possible implications and externalities that may be caused by changes in these quantities.

Contributed Talks

Simultaneous Multi-Parameter Choice with Applications in Inverse Option Pricing

Christopher Hofmann[1], Bernd Hofmann[1], Alois Pichler[1]

[1] Chemnitz University of Technology, Germany

The recovery of implied volatility and interest rate functions over a finite time interval from observed option prices is used as a benchmark problem with nonlinear forward operator to study the simultaneous recovery of multiple unknowns from given (noisy) data. We operate in the classical Black-Scholes model and recover a pair of unknowns (i.e. volatility and interest functions) from a pair of data functions, in this case the prices of the respective call- and put options. The injectivity of the forward operator in L^2-spaces is proven and therefore guarantees the identifiability of the unknowns. Tikhonov regularization using two separate penalty terms is employed to overcome the ill-posedness and existing heuristic parameter choice rules were adapted and generalized for this particular problem with two regularization parameters. Numerical examples are provided to demonstrate these findings.

Vanishing Contagion Spreads

Diogo Duarte[a], Rodolfo Prieto[b], Marcel Rindisbacher[c], Yuri F. Saporito[d]

[a]*Florida International University*
[b]*INSEAD*
[c]*Boston University*
[d]*Fundação Getúlio Vargas*

Abstract

We study default in a multi-firm equilibrium setting with incomplete information. Defaults are modeled to be consistent with the firm's balance sheet and aggregation over firms. Market prices and quantities of risk are derived in closed form. If the number of firms increases, the market prices of risk converge to a well-defined limit while the endogenous volatility and jump size of debt and equity generated by other firms' shocks vanish, so that credit spreads depend asymptotically only on the firms' own cash flow risk. This novel contagion result calls into question recent results based on production economies, where quantities of risk are specified exogenously, that attribute credit spreads mostly to contagion.

Keywords: Credit Spreads, Contagion, Exchange Economy, Equilibrium, Incomplete information, Risk Premia Representation.
JEL: G12, G13, G30

Can We Save The Recovery Theorem?

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Ross proposed a remarkable theorem that, under strong market and risk preference assumptions, made it possible to recover the physical probabilities and the pricing kernel simultaneously using only a set of option prices. Since its introduction, a number of researchers have extended the original theorem to apply under more general and realistic market settings. Despite these successful theoretical generalisations, several recent studies have questioned the validity of the theorem's application. Numerical instability plagues the unconstrained recovery algorithm, while constrained versions lead to recovered physical probabilities being too similar to risk-neutral probabilities. In its stated form, then, the recovery theorem does not seem to work empirically.

In this contribution we use the theorem by making its output semi-parametric. We therefore assume that one, or both, of the physical density and pricing kernels is described by a parametric function and then look to recover only the necessary function parameters. This increases numerical stability and ensures economically sensible output. We apply the recovery theorem under the assumption that the physical density follows a lognormal-mixture model.

A three-factor model of commodity prices

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This paper analyzes a three-factor model for commodity prices. We expand the Gibson and Scwhartz (1990) [3] model introducing a third factor. In the two-factor model the authors use the spot price and convenience yield as non-observable variables. We include the long-run average of the convenience yield as a third stochastic factor. It was modeled as a mean-reverting process. The final model is affine and Gaussian. We proceeded the calibration using the Kalman filter. The hyperparameters and the latent variables were estimated. Finally, we compared the two and three-factor models regarding the term structure of future prices and volatilities.

Multilevel Monte-Carlo method and lower and upper bounds for Initial Margin computations

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Using the multilevel Monte-Carlo method, we improve the computational cost of estimating nested expectations involving functions possibly possessing a finite number of singular points. Alternatively, we also approximate these nested expectations using upper and lower bounds, similarly to American option pricing. We apply these techniques to option pricing under initial margin requirements, and illustrate numerically their efficiency.

The relative trading activity in options and stocks in Brazil and US for Brazilian stocks

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We investigate the trading volume in options relative to the volume in underlying stocks. Using a panel data of stocks and their options we study the impact of several determinants such as delta, analyst forecast dispersion and earnings announcements. The result is similar to the international evidence that suggests part of the pre-announcement options trading is informed. We also compare the international trading activity for Brazilian ADRs traded in Brazil and US.

Does left jump volatility predict the cross-section of equity returns?

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The cross section of stock returns has substantial exposure to risk captured by left jump volatility (LJV). We estimate this series from daily Standard & Poor's 500 index option data. Buying stocks in the lowest LJV decile and selling stocks in the highest LJV decile generates a statistical significant average return of 20 basis points the following month. This result is robust across a wide variety of implementations and is not captured by the Fama-French and Carhart factors.

Pricing Path-dependent Derivative Securities: A New Approach

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We propose a new method to pricing path-dependent derivatives either in stock markets or fixed income markets. The idea is to produce a time and value discretization of the stochastic process that represents the underlying in conjunction with a novel way to benefit from the Feynman-Kac formula. Our method provides a formula, numerically solved, that deals with continuous time as well as discrete monitoring path-dependent derivatives on diffusions and Levy processes. It admits parallel computing, which is not the case of most standard methods. We price a Brazilian Asian type interest rate option, called IDI, discretely updated.

Behavioral Finance and its Applications

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Classical economics prescribes how agents should behave, while behavioral economics describes how agents do behave. Seemingly rational behaviors actually follow their own rationality and numerous cognitive biases, such as endowment effect, disposition effect, herding, and sunk cost have been reported and analyzed. We examine the consequences in the world of investing. We review the elements that differentiate prospect theory from utility theory, namely change of wealth as opposed to absolute wealth, loss aversion as opposed to risk aversion and distortion of small probabilities. Then we present our 4-step Learning Curve Model for information perception, and show how it alters our decision-making patterns and we apply this theory to crypto currency trading.

Portfolio selection under Cramer-Lundberg dynamic

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In this work, we examine the combined problem of optimal portfolio selection rules for an insurer in a continuous-time model where the surplus of an insurance company is modelled as a compound Poisson process. The ruin probability of this process is minimized by the choice of a suitable investment strategy for a capital market index. Also, we present numerical solutions in some cases.

Portfolio Optimization for Cointelated Pairs: SDEs vs. Machine Learning

Konul Mustafayeva[1], Babak Mahdavi-Damghani[2], Stephen Roberts[2], Cristin Buescu[1]

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We investigate the problem of dynamic portfolio optimization in a continuous-time, finite-horizon setting for a portfolio of two stocks and one risk-free asset. The stocks follow cointelation model introduced in [1]. The proposed optimization methods are twofold. In what we call an SDE approach, we compute the optimal weights using mean-variance criterion and power utility maximization. We show that dynamically switching between these two optimal strategies via introducing a triggering function can further improve the portfolio returns. We contract this with the machine learning clustering methodology inspired by the band-wise Gaussian mixture model. The first benefit of the machine learning over the SDE approach is that we were able to achieve the same results though a simpler channel. The second advantage is a flexibility to regime change. The easiest way to understand this is to take a look at the world of interest rates. Indeed up to 2014, it was assumed that interest rates could never become negative and a similar SDE approach would have enforced a Cox–Ingersoll–Ross (CIR) like model and would not have therefore been able to accommodate the regime change towards negative interest rates. These types of transitions are easy to handle for the machine learning methodology and the adaptation is almost immediate through, for example, a simple filtering process.

Regime switching rough Heston model

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The regime switching rough Heston model has two important features on different time scales. The regime switching is motivated by changes in long term behaviour. We introduce a Markov chain to model the switches in the long term mean of the volatility. The rough behaviour is a more local property and is motivated by the stylized fact that volatility is less regular than Brownian motion. Therefore the driving noise in the volatility equation is now a fractional Brownian motion. The techniques are much more involved than for standard Heston model, since the rough processes are neither Markovian nor semi-martingales. The regime switches introduce an additional time inhomogeneity.

Quant Factor investing in Emerging Markets: the magnified problem of crowding and the case for a Long Volatility Overlay strategy.

Luca Parlamento

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After the academic introduction of risk-based investing, factor investing has been the fastest growing segment in the asset management industry since the 2008 global financial crisis. As pensions schemes and endowments have allocated hundreds of billions into this strategy, the problem of crowding on quant strategies has become the top priority for any asset allocators; the issue is particularly magnified in Emerging Markets given liquidity and investable universe are thinner than in US. In this article we examine the problem of crowding and we propose a novel Long-Volatility strategy which exploits information on factor crowding.

Learning Interest Rate Interpolation

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The usual methods for interest rate interpolation consider only the values and time to maturity of spot rates as the inputs, and differ mainly on the continuity of the implied forward rates. We treat the interpolation problem as a replication problem, where a bond (or interest rate future/swap) is priced as a function of the minimum variance replicating portfolio of the traded bonds (or derivatives). In this view, the hedging ratios determined by the interpolation are as important (if not more) than getting the "right" interpolated rate; this is similar to the adjustments to the Black and Scholes delta as a consequence of the joint dynamics of the asset price and volatility in the different volatility models. We show how to learn the parameters of the weight functions and apply this method to the overnight rate indexed interest rates derivatives in Brazil. We then extend the concept from interpolating broken dates to the market references, in order to determine which points are key to the shape and dynamics of the curve and which points can be replicated by these real anchors.

Empirics on CPPI Design Risk

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This study aims to critically analyse *design risk* associated with some portfolio insurance strategies. Although the focus is on constant proportion portfolio insurance (CPPI) structures, we also look at other portfolio insurance strategies.

The paper is based upon real market data on several markets indices representing a variety of different risky assets, both from stock and corporate bond markets. Concretely, we rely on observed daily returns over the past 20 years on the indices – SP500 (SPX), Euro Stoxx 50 (SX5E), MSCI World (MXWO), MSCI Emerging Market (MXEF) and iBoxx EuroCorp TR (QW5A). The criteria was to choose indices that have been used in real life CPPI products, either as the risky underlying or as a proxy to the underlying risk portfolio.

In this paper each of indices is considered as the *underlying risky asset* of a possible CPPI structure. Using bootstrapping techniques we are able to empirically simulate daily returns for the assumed *underlying risky asset*. The empirical approach of this study is different from what has been done in the literature as we make *no assumption* on a particular model for the underlying risky asset dynamics, while most studies assume either a geometric brownian motion or a more general model that include jumps. Our results, are thus, *model free and based upon real observed data*.

Using Monte Carlo simulation on the empirical distribution of the underlying asset, we can not only easily find the empirical payoff distribution of portfolio insurance strategies, but we are also able to compute all relevant statistics, not only at maturity but also during the product's life span.

We look into CPPI strategies with different multipliers, but also into the classical option based portfolio insurance (OPBI) and some naive strategies such as the stop loss portfolio insurance (SLPI). A typical portfolio insurance strategy provides a capital guarantee F at maturity T and some possible participation in the upside potential of a risky underlying asset, if the underlying performs well.

As expected the value of portfolio insurance strategies depend on: (i) F the level of capital guarantee, (ii) T the maturity, or (iii) the value at maturity of the underlying risky asset S_T or, if path dependent, on the actual evolution of the underlying risky asset, $\{S_t, 0 \leq t \leq T\}$.

However in the case of CPPIs, the structure's performance depends strongly (iv) on the multiplier m; (v) the rebalancing frequency, (vi) any possible deductions from the investment (namely fees and/or coupons). We call the dependence of CPPI structures no these variables (iv)-(vi) which are unrelated to the underlying risky asset: *design risk*.

Overall, this study strengths the ideia that CPPI strategies suffers from a serious design problem, making it uninteresting to almost all investors.

A user-friendly simulation model for pensions risk management

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We describe a stochastic model for some of the most important risk factors affecting a typical pension insurer. The selection of the risk factors is motivated by the need to financially hedge defined benefit pension liabilities. On the asset side, we model the investment returns on equities as well as fixed-rate, index-linked and corporate bonds. On the liability side, the risks are driven by future mortality developments as well as price and wage inflation. All the risk factors are described as a multivariate stochastic process (time series model) that captures the dynamics and the dependencies among the risk factors. The model is easy to simulate and to calibrate to historical data and user's views. We use the model to analyze the assets and liabilities of a UK pensions insurer.

Masked financial instability caused by wealth inequality

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We investigate masked financial instability caused by wealth inequality. When an economic sector is decomposed into two subsectors that possess a severe wealth inequality, the sector in entirety can look financially stable while the two subsectors possess extreme financially instabilities of opposite nature, one from excessive equity, the other from lack thereof. The unstable subsector can result in further financial distress and even trigger a financial crisis. The market instability indicator, an early warning system derived from dynamical systems applied to agent-based models, is used to analyze the subsectoral financial instabilities. Detailed mathematical analysis is provided to explain what financial instabilities can arise amid seemingly stable economy and positive market data. The theoretical conjecture is verified by historical macroeconomic time series of the United States households among whom a substantial wealth inequality has been officially confirmed.

Posters

Arbitrage-Free Pricing of XVA

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We review the framework for computing the total valuation adjustment (XVA) of an European option claim accounting for funding spread and collateralization in one period model, based on non-arbitrage arguments. The replicating portfolios of long and short positions in the claim, lead to the definition of buyer's and seller's XVA, which in turn identify a non-arbitrage interval.

This poster is a ongoing work towards a construction of an XVA framework for derivative pricing in discrete time.

Efficient Solutions for Pricing and Hedging IDI Options with Jumps and Stochastic Volatility

Allan Jonathan da Silva [1,2], Jack Baczynski[1], José V. M. Vicente[3]

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[2] Federal Center for Technological Education, CEFET.

[3] Central Bank of Brazil.

We derive closed-form series representations for option prices on Interest Rate Index with the COS method [1]. This includes European vanilla and digital IDI options. We developed analytical solutions for models with jumps and stochastic volatility which have known characteristic function for the integrated process. In a numerical study, we show that option prices can be accurately and efficiently approximated by truncating their series representations. To the best of authors' knowledge, the price is fastest calculated when compared to any existing numerical pricing method. We also study possible implications in the volatility smile surface.

Pricing Multi-Asset Options with Hyperplane Barrier

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[1,2] National Laboratory for Scientific Computing

This work contributes, theoretically, in the multi-asset scenario with closed-form expressions of no-arbitrage prices, as well as estimates, for two types of up-and-out call barrier options, namely, hyperplane type barriers placed on the collection of stock prices. For the estimates we combine ideas of convex analysis with tools of stochastic theory. We consider uncorrelated risky assets and deterministic time dependent volatilities. Quoting [2], we have that deriving prices in the multi-asset case poses significant difficulties that do not appear in the single-asset case. A preliminary version of these results was presented in [1].

Pricing equity options with slippage cost

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Slippage can be defined as the difference between the price of a security when an order is established and its price when the order is actually executed. In practice, it is an important component of the total cost function that investors face when hedging financial derivatives, which could lead to disturbances in the standard hedging strategy "*à-la-Black-Scholes*". The scarce literature on this topic has reached solutions by incorporating this effect as a liquidity cost. Our objective here is to explore different alternatives to those already studied by, for example, implementing stochastic delay differential equations (SDDEs), among others.

Numerical Solution of PDE's Using Deep Learning and Applications in Finance

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[1] FGV | EMAp - School of Applied Mathematics

This work presents a method for the solution of PDE's using deep learning, a neural network with many hidden layers. The main idea behind the method, based on [1], is using a norm of the PDE itself as the loss function, while each iteration considers a different batch of points in the domain, together with the boundary conditions. We present some applications to well-known PDE's, including examples from finance.

Price Impact of Large Orders Using Hawkes Processes

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Abstract

In this paper we introduce a model to be used in the execution of large market orders in limit order books. We use a linear combination of self-exciting Hawkes processes to model asset-price dynamics, as done in [Bacry et al., 2013a] with the addition of a price-impact function that is concave in the order size. We introduce a criterion for a general price-impact function, which we then use to show how specification of a concave impact function affects order execution. With our framework we examine the immediate and permanent impacts of large orders, we look at the potential for price manipulation, and we show the effectiveness of strategies such as time-weighted average price (TWAP). Our model is such that price will depend on the balance between the intensities of the Hawkes process, which can be interpreted as a dependence on order-flow imbalance (OFI). Overall this paper contributes toward an ongoing discussion on price impact for models with Hawkes processes.

Keywords: *price-impact function, limit order books, execution of large orders, Hawkes processes.*
AMS Subject Codes: *60G55, 91B26, 91B70.*

Hawkes-type stochastic volatility model

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We introduce a Hawkes-like process and study its scaling limit as the system becomes increasingly endogenous. Then, we introduce a high-frequency model for the price of traded asset in which the nearly unstable regime leads to a Heston-type process in which the negative correlation between the price and the volatility can be caused by relatively high variance of the sell side intensity.

Pricing non-traded assets using indifference

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Pricing contingent claims in incomplete markets can be a challenge, since not all claims are perfectly replicable. We used the indifference pricing method to compute the price of a claim in a time-discrete environment, where the non-traded asset is observable, and the traded one follows, necessarily, an atomic model. We implemented a multiperiod, time consistent, pricing algorithm using lattices for both assets (traded & non-traded) to obtain a non-arbitrage price for the claim.

An application of the fast Fourier transform to option pricing

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We review a couple of numerical methods based on the Fast Fourier Transform (FFT) for option pricing when the asset dynamics follows a Lévy process. Following [1], we expose an approach that allows one to harness the computational power of the FFT. We proceed by treating the option price analogous to a probability density function, which in turn allows it to be obtained for various strikes through FFT calculations. In addition, we illustrate the method with the Variance Gamma model.