UNIVERSITY OF OXFORD

Mathematical Institute

Robust Techniques in Quantitative Finance

3rd – 7th September 2018
University of Oxford

Oxford Mathematics

Welcome

On behalf of the Mathematical Institute, it is our great pleasure to welcome you to the University of Oxford for the **Robust Techniques in Quantitative Finance** conference.

Since the seminal work of Knight, the distinction between risk and uncertainty has played a crucial role in Economics and Finance. Robust methods address the latter and, in the wake of the financial crisis, their importance has been increasingly appreciated. In particular, such questions and the corresponding mathematical techniques became one of the most active fields in Mathematical Finance.

This meeting follows in the footsteps of three previous meeting which we organised in Oxford in 2010, 2016 and 2017. While the previous meetings were two days long, focused workshops, this time we are excited to welcome you for this much larger and broader gathering. For 5 days, we are bringing together an interdisciplinary group of researchers with interests in Financial Mathematics, Finance and Economics, with model uncertainty as the unifying theme. We look forward to the program of talks as well as the accompanying discussions. The schedule allows for ample questions time after each talk as well as many breaks to facilitate interactions.

Last, but not least, we would like to express our gratitude to the Mathematical Institute and St John's College which are hosting the event, as well as the European Commission who is providing core funding through an ERC grant.

We hope you enjoy a productive meeting in Oxford.

Conference organisers

Gaoyue Guo and Jan Obłój

on behalf of the **Scientific Committee**

Beatrice Acciaio, Bruno Bouchard, Michael Kupper, Jan Obłój, Frank Riedel, Alexander Schied and Nizar Touzi

Essential Information

Venue
All talks take place in Lecture Room L3 on the mezzanine level in the Andrew Wiles Building. Two classrooms, C3 and C4, across on the other side of the staircase, are reserved for conference participants as discussion and personal work space.

The conference reception desk is located near the entrance to the lecture room and will be staffed Mon-Tue. Delegates arriving at later dates should help themselves to the their packs. Delegates with limited mobility are advised to contact the Mathematical Institute's Reception Desk on the ground floor for assistance. Please note that the Andrew Wiles Building opening hours are 08:00 – 18:00.

Wi-Fi is available in the Andrew Wiles Building. Our preferred method of connection is eduroam. However, if you do not have eduroam, you can sign up for a free 'The Cloud' account. Please contact the conference reception desk for an account if you need one.

Smoking is only permitted in designated external smoking areas. Please ask at the conference reception desk for directions.

Presentations
All plenary talks are 45min long followed by 15min for discussion. Other talks are either 30+10 or 20+10. The lecture room is equipped with a computer, data projector, and whiteboards. If using the data projector, we strongly recommend you bring your talk on a USB stick and use the computer provided. Please upload your talk as a PDF file to the computer well before your session starts.

Posters
Posters will be displayed in cases on the walls in the proximity of the lecture room. There are three dedicated poster sessions in the program.

Online Resources
Up-to-date information can be found at http://people.maths.ox.ac.uk/obloj/RT2018.html.

Refreshments
Lunch, as well as coffee/tea breaks will be provided on the mezzanine level. Wine reception will be in the Common Room on the first floor.

Apart from the dinner on Tuesday, no evening meals are provided but there is a wide variety of food offered by the pubs, restaurants and cafés in the local area that you could sample. A map showing local restaurants is included on page 26. Café π in the Andrew Wiles Building is open each day from 08:30 – 16:00 for those who wish to buy extra food.

Social Events
We will have a drinks reception in the Common Room (Mathematical Institute, 1st floor) on Monday at 18:00 (after the last talk).

On Tuesday night, it is our pleasure to invite you to St John's College for the conference dinner. Pre-dinner drinks will be served from 19:00 and dinner will start at 19:30. Please enter through the main lodge and follow the signs.

On Thursday afternoon, weather permitting, you are invited to punting. This requires no prior experience and is a lot of fun. Please meet us at Magdalen bridge at 18:00.

Assistance
If you have any queries or concerns, please speak to any of the conference organising team; we can also be contacted at RobustQF18@maths.ox.ac.uk or by telephone +441865280612. In addition, student volunteers will be happy to assist with any queries you may have.

Schedule

Day 1: Monday, September 3rd

10:30 -- 12:00 : Registration, Coffee and Tea

12:00 -- 12:20 : Jan Obłój -- ***Welcome and Opening Statements***

12:20 -- 13:20 : Ruodu Wang -- ***Robustness issues on regulatory risk measures***

13:20 -- 14:20 : Lunch

14:20 -- 15:00 : Dirk Becherer -- ***Good deal hedging and valuation under combined uncertainty about drift and volatility***

15:00 -- 15:40 : Sojung Kim -- ***Robust copula modeling for assessing conditional VaR via stochastic gradient descent optimization***

15:40 -- 16:20 : Coffee Break

16:20 -- 17:00 : Tao Chen -- ***Parametric optimization, robust stochastic control and statistical surrogates***

17:00 -- 17:30 : Samuel Cohen -- ***Paradoxes in data driven robustness***

17:30 -- 18:00 : Andrew Allan -- ***Parameter uncertainty in the Kalman-Bucy filter***

18:00 -- 19:00 : Drinks Reception

Day 2: Tuesday, September 4th

9:10 -- 10:10 : Massimo Morini -- ***Model Risk: a practitioner's point of view in 2018***

10:10 -- 10:50 : Vilen Abramov -- ***A practical guide to market risk model validations***

10:50 -- 11:30 : Coffee Break

11:30 -- 12:30 : Laurence Carassus -- ***Pricing without martingale measure***

12:30 -- 13:00 : Poster Session

13:00 -- 14:00 : Lunch

14:00 -- 14:40 : Frank Riedel -- ***Viability and Arbitrage under Knightian Uncertainty***

14:40 -- 15:20 : Ngoc Huy Chau -- ***Robust utility maximization in markets with transaction costs***

15:20 -- 16:00 : Coffee Break

16:00 -- 16:30 : Johannes Wiesel -- ***A unified framework to robust modelling of financial markets in discrete time***

16:30 -- 17:00 : Felix-Benedikt Liebrich -- ***Uncertainty robust spaces***

17:00 -- 17:30 : Yufei Zhang -- ***A penalty scheme and policy iteration for nonlocal HJB variational inequalities with monotone drivers***

19:00 -- 21:30 : Conference Dinner

Day 3: Wednesday, September 5th

9:10 -- 10:10 : Rama Cont -- ***Pathwise integration and functional calculus for irregular paths with finite p^{th} variation***

10:10 -- 10:50 : David Prömel -- ***Pathwise pricing-hedging duality via Vovk's sub-linear integrals***

10:50 -- 11:30 : Coffee Break

11:30 -- 12:30 : Marco Maggis -- ***Topological issues arising in Pricing Theory under Model Uncertainty***

12:30 -- 13:00 : Poster Session

13:00 -- 14:00 : Lunch

14:00 -- 14:40 : Michael Kupper -- ***A semigroup approach to nonlinear expectations***

14:40 -- 15:20 : Tolulope Fadina -- ***Affine processes under parameter uncertainty***

15:20 -- 16:00 : Coffee Break

16:00 -- 16:30 : Henry Chiu -- ***On pathwise quadratic variation for càdlàg functions***

16:30 -- 17:00 : Stephan Eckstein -- ***Superhedging and distributionally robust optimization with neural networks***

17:00 -- 17:30 : Pietro Siorpaes -- ***Structure of martingale transports in Banach spaces***

Day 4: Thursday, September 6th

9:10 -- 10:10 : Fabio Maccheroni -- ***Absolute and relative ambiguity aversion: a preferential approach***

10:10 -- 10:50 : Matteo Burzoni -- ***Robust martingale selection problem and its connections to the no-arbitrage theory***

10:50 -- 11:30 : Coffee Break

11:30 -- 12:30 : Marcel Nutz -- ***Convergence to the mean field game limit: a case study***

12:30 -- 13:00 : Poster Session

13:00 -- 14:00 : Lunch

14:00 -- 14:40 : Eyal Neuman -- ***Protecting target zone currency markets from speculative investors***

14:40 -- 15:20 : Patric Beissner -- ***The term structure of sharp ratios and arbitrage-free asset pricing in continuous time***

15:20 -- 16:00 : Coffee Break

16:00 -- 16:40 : Daisuke Yoshikawa -- ***Pairs trading under model uncertainty***

16:40 -- 17:10 : Anna Aksamit -- ***Dynamic extension for American option's pricing--hedging duality***

18:00 -- 19:00 : Punting

Day 5: Friday, September 7th

9:10 -- 10:10 : Mathias Beiglböck – ***Causal transport and its role in mathematical finance***

10:10 -- 10:50 : Hadrien De March -- ***Local structure of multi-dimensional martingale optimal transport***

10:50 -- 11:30 : Coffee Break

11:30 -- 12:00 : Dominykas Norgilas -- ***The left-curtain martingale coupling in the presence of atoms***

12:00 -- 12:30 : Martin Brückerhoff-Plückelmann -- ***A left-monotone solution to the peacock problem***

12:30 -- 13:00 : Sigrid Källblad -- ***Measure-valued martingales and optimality of Bass-type solutions to the Skorokhod embedding problem***

13:00 -- 14:00 : Lunch

Abstracts

Plenary Talks

Mathias Beiglböck -- *Causal transport and its role in mathematical finance*
Causal transport plans generalize adapted processes in the same way as usual transport plans are a relaxed form of Monge-mappings. Correspondingly, one obtains an adapted / causal variant of the usual Wasserstein distance. We will review these concepts and explain why they are relevant for mathematical finance and in particular the problem of model-uncertainty.

Laurence Carassus – *Pricing without martingale measure*
For several decades, the no-arbitrage (NA) condition and the martingale measures have played a major role in the financial asset's pricing theory. Here, we propose a new approach based on convex duality instead of martingale measures duality: our prices will be expressed using Fenchel conjugate and bi-conjugate. This naturally leads to a weak condition of (NA) called Absence of Immediate Profit (AIP). It asserts that the price of the zero claim should be zero or equivalently that the super-hedging cost of some call option should be non-negative. We propose several characterizations of the (AIP) condition and also study the relation with (NA) and a stronger notion of (AIP) linked to the no-free lunch condition. We show in a one step model that under (AIP) the super-hedging cost is just the payoff's concave envelop. In the multiple-period case, for a particular, but still general setup, we propose a recursive scheme for the computation of a the super-hedging cost of a convex option. We also give some promising numerical illustrations.
Joint work with Julien Baptiste and Emmanuel Lépinette.

Rama Cont -- *Pathwise integration and functional calculus for irregular paths with finite p^{th} variation*
Hans Föllmer's pathwise Ito formula (1981) may be used as a building block for constructing a strictly pathwise theory of integration and calculus for path-dependent functionals of trajectories with finite quadratic variation. This theory provides a flexible theoretical framework for model-free approaches in finance. We present some recent results on this pathwise calculus [Ananova & Cont 2017] and its extensions to less regular paths with finite pth order variation for p>2 [Cont & Perkowski 2018], focusing on the case of continuous paths.

Fabio Maccheroni -- *Absolute and Relative Ambiguity Aversion: A Preferential Approach*
We study from a preferential viewpoint absolute and relative attitudes toward ambiguity determined by wealth effects. We provide different characterizations of these attitudes for a large class of preferences: monotone and continuous preferences which satisfy risk independence. We specify our results for different subclasses of robust preferences.

Marco Maggis -- *Topological issues arising in Pricing Theory under Model Uncertainty*
Abstract : Many troublesome functional analytical issues arise when we try to tackle the pricing-hedging duality in a robust framework where a family of non dominated measures is given. We propose a topological approach in order to obtain a version of the Fundamental Theorem of Asset Pricing for a discrete market model. The main result can be proved by the mean of a classical hyperplane separation argument in an opportune infinite dimensional space of quasisure bounded random variables.

Massimo Morini -- *Model Risk: a practitioner point of view in 2018*
- The role of capital and benchmarks in current model risk management
- Links (and clashes) between theory and practice
- Systemic model risk: the trend of standardizing models
- Perspectives in the transition of quants towards machine learning

Marcel Nutz -- *Convergence to the Mean Field Game Limit: A Case Study*
We study the convergence of Nash equilibria in a game of optimal stopping. If the mean field game has a unique equilibrium, any sequence of n-player equilibria converges to it as $n \to \infty$. However, both the finite

and infinite player versions of the game often admit multiple equilibria. We show that mean field equilibria satisfying a transversality condition are limits of n-player equilibria. But we also find mean field equilibria that are not limits, thus questioning their interpretation as "large n" equilibria.

Ruodu Wang -- *Robustness issues on regulatory risk measures*
Over the past few years, there have been extensive debates on the desirability of regulatory risk measures in both academia and industry of finance and insurance. We discuss some progress in the recent research trend on the comparative advantages of Value- at-Risk (VaR) and Expected Shortfall (ES, or TVaR). In particular, we focus on (statistical) robustness issues in the aggregation and the optimization of risks. In contrast to the classic notion that VaR is statistically more robust than ES, we discuss some perspectives on advantages of ES in robust aggregation and optimization.
This talk is partially based on joint work with Paul Embrechts and Alex Schied.

Contributed Talks

Vilen Abramov -- *A Practical Guide to Market Risk Model Validations*
The VaR (Value at Risk) concept emerged back in 1994 when J.P. Morgan started routinely using it in its daily reporting. The VaR metric became an industry standard for measuring market risk because it is intuitive and easy to interpret. This led to the adaptation of VaR for market risk capital calculations in the 1996 market risk amendment (also known as Basel II). Following the failure of this capitalization approach during the 2008 financial crisis, Basel Committee strengthened capital requirements by introducing stressed VaR (in Basel 2.5) and TVaR (in Fundamental Review of the Trading Book) metrics. In this presentation we will focus on VaR/TVaR estimation techniques. We will discuss a major VaR model risk event that played an important role in the $6.2 billion loss caused by the former J.P. Morgan trader know as "London Whale." We will categorize all VaR models, discuss VaR/TVaR model performance criteria and specifications, present robust techniques for estimating VaR/TVaR. The nonparametric estimators of VaR/TVaR are commonly used by the industry practitioners. This presentation will demonstrate that the nonparametric estimators of VaR/TVaR have large asymptotic variance relative to optimal parametric estimators that can be constructed given some knowledge about the underlying distribution.
Joint work with Kazim Khan.

Anna Aksamit -- *Dynamic extension for American option's pricing--hedging duality*
We investigate pricing--hedging duality for American options in discrete time financial models where some assets are traded dynamically and others, e.g. a family of European options, only statically. Our first insight is that by considering an enlargement of the space, we can see American options as European options and recover the pricing--hedging duality, which may fail in the original formulation. Our second insight is that a duality gap arises from the lack of dynamic consistency and hence a different enlargement which reintroduces dynamic consistency is sufficient to recover the pricing--hedging duality: it is enough to consider fictitious extensions of the market in which all the assets are traded dynamically.
This is a joint work with Shuoqing Deng, Jan Obłój and Xiaolu Tan.

Andrew Allan -- *Parameter Uncertainty in the Kalman–Bucy Filter*
In this talk I will propose an approach to construct stochastic filters which are robust with respect to model uncertainty, specifically, with respect to uncertainty in the parameters of the continuous time Kalman–Bucy filter. We use a nonlinear expectations approach, where our uncertainty is represented by a penalty function which may be propagated through time alongside the filter. We show how this penalty may be characterised as the value function of a pathwise stochastic optimal control problem, and may thus be computed by solving the associated HJB type PDE.

Dirk Becherer -- *Good deal hedging and valuation under combined uncertainty about drift and volatility*
We study robust notions of good-deal hedging and valuation under combined uncertainty about the drifts and volatilities of asset prices. Good-deal bounds are determined by a subset of risk-neutral pricing measures such that not only opportunities for arbitrage are excluded but also deals that are too good, by restricting instantaneous Sharpe ratios. A non-dominated multiple priors approach to model uncertainty (ambiguity) leads to worst-case good-deal bounds. Corresponding hedging strategies arise as minimizers of a suitable coherent risk measure. Good-deal bounds and hedges for measurable claims are characterized by solutions to second-order backward stochastic differential equations whose generators are non-convex in the volatility. These hedging strategies are robust with respect to uncertainty in the sense that their tracking errors satisfy a supermartingale property under all a-priori valuation measures, uniformly over all priors.

Patrick Beissner -- *The term structure of Sharpe ratios and arbitrage-free asset pricing in continuous time*
Recent empirical studies suggest a downward sloping term structure of Sharpe ratios. We present a theoretical framework in continuous time that can cope with such a non-flat forward curve of risk prices. The approach departs from an arbitrage-free and incomplete market setting when different pricing measures are possible. Involved pricing measures now depend on the time of evaluation or the maturity of payoffs. This results in a time inconsistent pricing scheme. The dynamics can be captured by a time-delayed backward stochastic Volterra integral equation, which to the best of our knowledge, has not yet been studied.

Martin Bruckerhoff-Pluckelmann -- *A left-monotone solution to the peacock problem*
A family of probability distributions on R that is increasing in convex order is called a peacock. Given a peacock $(\mu_t)_{t\in[0,1]}$, the peacock problem is to construct a martingale such that its marginal distributions coincide with $(\mu_t)_{t\in[0,1]}$. We construct a new solution to this problem that has two distinguishing properties. Firstly, it is a simultaneous minimizer of $\mathrm{E}[c(X_0,X_t)]$ for all $t \in [0,1]$ among all solutions to the peacock problem and for all functions c satisfying the martingale Spence-Mirrlees condition $\partial_{xyy}c < 0$. Secondly, alongside our solution the mass is transported in a left-monotone way, i.e. our solution is the simultaneous minimizer of $\mathrm{Law}(X_0 \le a, X_t \in \cdot)$ w.r.t. convex order for all $t \in [0,1]$ and $a \in \mathrm{R}$ among all solutions to the peacock problem. Moreover, we show that these two properties are equivalent and provide additional properties of our solution for a special class of peacocks.

Matteo Burzoni -- *Robust Martingale Selection Problem and its Connections to the No-Arbitrage Theory.*
Given a collection of random sets $V = (V_t)$ the martingale selection problem consists in finding a stochastic process S taking values in V and such that S is a martingale under a measure Q. We derive conditions for the solvability of this problem in a pointwise framework and show how this is related to the no-arbitrage theory. We obtain versions of the Fundamental Theorem of Asset Pricing in examples spanning frictionless, proportional transaction cost and illiquidity markets with possible trading constraints. We also discuss how the martingale selection problem is related to the superhedging duality.
Talk based on a joint work with Mario Šikic´ and some recent results with Erhan Bayraktar.

Chau Ngoc Huy -- *Robust utility maximization in markets with transaction costs*
We consider a continuous-time market with proportional transaction costs. Under appropriate assumptions we prove the existence of optimal strategies for investors who maximize their worst-case utility over a class of possible models. We consider utility functions defined either on the positive axis or on the whole real line.

Tao Chen -- *Parametric optimization, robust stochastic control and statistical surrogates*
We study numerical implementation of the adaptive robust stochastic control method. In parametric Markovian control, reduction of model uncertainty is expressed via shrinking collections of potential true values of the underlying system parameters. In the discrete time setup, computation boils down to recursive multi-step optimization via a generic min-max formulation. Traditionally, the problem is about repeated optimization and it involves interpolation over gridded designs which is computationally expensive. We adopt the paradigm of statistical learning, recasting the task of approximating optimal value function and control as a machine learning problem. Our main strategy is to achieve substantial speed-ups by capturing the spatial dependence inherent in the min-max problem, so that we can leverage

already obtained solutions of similar optimization problems. Such spatial borrowing of information is done via a Gaussian Process (GP) regression approach, which allows us to predict the optimal control without directly optimizing.
This is a joint work with Michael Ludkovski.

Henry Chiu -- *On pathwise quadratic variation for càdlàg functions*
We revisit Föllmer's concept of pathwise quadratic variation of a càdlàg function along a sequence of time partitions and discuss its relation with the Skorokhod topology. We show that in order to obtain a robust notion of pathwise quadratic variation applicable to sample paths of càdlàg processes, one may reformulate the definition of pathwise quadratic variation as a limit in Skorokhod topology of a certain sequence of functions. The definition then simplifies and one obtains the Lebesgue decomposition of the pathwise quadratic variation as a result, rather than requiring it as an extra condition.
Joint Work with Rama Cont.

Samuel Cohen -- *Paradoxes in data driven robustness*
A common way of building, from data, a 'robust' expectation, is to use confidence intervals for an underlying parameterization. In this talk we will look at some paradoxes which arise in this setting, and how they can be addressed in either parametric or nonparametric ways.

Hadrien De March -- *Local structure of multi-dimensional martingale optimal transport*
This paper analyzes the support of the conditional distribution of optimal martingale transport couplings between marginals in $\mathbb{R}^d$ for arbitrary dimension $d \geq 1$. In the context of a distance cost in dimension larger than 2, previous results established by Ghoussoub, Kim & Lim [11] show that this conditional distribution is concentrated on its own Choquet boundary. Moreover, when the target measure is atomic, they prove that the support of this distribution is concentrated on $d + 1$ points, and conjecture that this result is valid for arbitrary target measure. We provide a structure result of the support of the conditional distribution for general Lipschitz costs. Using tools from algebraic geometry, we provide sufficient conditions for finiteness of this conditional support, together with (optimal) lower bounds on the maximal cardinality for a given cost function. More results are obtained for specific examples of cost functions based on distance functions. In particular, we show that the above conjecture of Ghoussoub, Kim & Lim is not valid beyond the context of atomic target distributions.

Stephan Eckstein -- *Superhedging and distributionally robust optimization with neural networks*
Solving robust optimization problems over sets of measures is inherently difficult due to the infinite-dimensionality of the space of measures. To make these problems tractable numerically, the usual approach is to solve approximative problems where measures live on discrete spaces. In this talk, we instead present an approach that is based on the respective dual formulations and parametrization by neural networks. Theoretical as well as numerical features are illustrated, with a focus on the interplay between primal and dual solutions.
Based on a joint work with Michael Kupper and Mathias Pohl.

Tolulope Rhoda Fadina -- *Affine processes under parameter uncertainty*
In this talk we develop the theory of non-linear affine processes and draw connections to affine processes under model risk. The idea is to introduce parameter uncertainty for this class of Markov processes and to extend over non-linear Lévy processes. This non-linear affine process yields a tractable model for Knightian uncertainty, especially for modelling interest rates under ambiguity.

Sigrid Källblad -- *Measure-valued martingales and optimality of Bass-type solutions to the Skorokhod embedding problem*
In this paper we consider (probability-)measure valued processes, which we call MVMs, which have a natural martingale structure. Following previous work of Eldan and Cox-Källblad, these processes are known to have a close connection to the solutions to the Skorokhod Embedding Problem. In this paper, we consider properties of these processes, and in particular, we are able to show that the MVMs connected to the Bass and Root embeddings have natural measure-valued analogues which also possess natural optimality properties. We also introduce a new MVM which is a generalisation of both the Bass and Root MVMs.

Sojung Kim -- *Robust copula modeling for assessing conditional Value-at-Risk via stochastic optimization*
This work proposes a framework to construct a copula model that is robust to model misspecification for assessing the Conditional Value-at-Risk (CVaR). In particular, we focus on the misspecification of tail dependence because it is often a major troublesome with little data in rare events. We assume that the set of candidate copulas is available for modeling the tail part. To formulate the complete copula, we employ the Distorted Mix (DM) method by combining distorted margins and convex sums over the set. Then we try to solve the optimization problem to find the worst-case CVaR and set the robust copula as the DM copula attaining the worst-case CVaR. Both the stochastic gradient descent method and the sample average approximation method are provided and the combination of the two algorithms is finally suggested. Numerical experiments validate how the proposed framework yields tractable and practical robust copula modeling.

Michael Kupper -- *A semigroup approach to nonlinear expectations*
We provide representation results for nonlinear semigroups with focus on their characterization in terms of the infinitesimal generator. In particular, we study the relation between nonlinear Lévy processes and nonlinear Markovian convolution semigroups. The results are illustrated with several examples.
The talk is based on joint works with Daniel Bartl, Robert Denk and Max Nendel.

Felix-Benedikt Liebrich -- *Uncertainty robust spaces*
Over the past few years, there have been numerous attempts to embed problems of financial mathematics and risk theory in model spaces of random variables which are more uncertainty robust than the usual Lebesgue spaces over a probability space. However, their analytic structure has been frequently observed to differ drastically from L^p-spaces. In this talk, we present the construction of an uncertainty robust model space from a general capital requirement whose analytic structure fully captures the ambiguity attitude expressed by the capital requirement. We discuss its particular properties and why it qualifies as a canonical model space for the capital requirement. These results will be complemented with observations concerning the order structure of model spaces arising from a fully undominated set of priors.
The talk is based on joint work with Cosimo Munari and Gregor Svindland.

Eyal Neuman -- *Protecting target zone currency markets from speculative investors*
We consider a stochastic game between a trader and the central bank on target zone markets. In this type of markets the price process is modeled as a diffusion which is reflected at one or more barriers. Such models arise when a currency exchange rate is kept above a certain threshold due to central bank intervention. We consider a trader who wishes to liquidate a large amount of currency, where for whom prices are optimal at the barrier. The central bank, who wishes to keep the currency exchange rate above this barrier, therefore needs to buy its own currency. The permanent price impact, which is created by the transactions of both sides, turns the optimal trading problems of the trader and the central bank into coupled singular control problems, where the common singularity arises from a local time along a random curve. We first solve the central bank's control problem by means of the Skorokhod map and then derive the trader's optimal strategy by solving a sequence of approximated control problems, thus establishing a Stackelberg equilibrium in our model.

Dominykas Norgilas -- *The left-curtain martingale coupling and the American put in the presence of atoms.*
In a two-period setting we derive the model-independent upper bound of the American put option. The model associated with the highest price of the American put is the extended left-curtain martingale coupling. Moreover we derive the cheapest superhedge.

David Prömel -- *Pathwise pricing-hedging duality via Vovk's sub-linear integrals*
We provide model-free pricing-hedging dualities in a continuous-time and frictionless market consisting of finitely many risky assets. The minimal super-hedging price is defined via Vovk's sub-linear integrals. For path-dependent European option, the minimal super-hedging price is shown to have the same value as the supremum of the expectations of the option over all martingale measures.

Frank Riedel -- Viability and Arbitrage under Knightian Uncertainty
We reconsider the microeconomic foundations of financial economics under Knightian Uncertainty. We do not assume that agents (implicitly) agree on a common probabilistic description of the world. We rather base our analysis on a common ordering of contracts, a much weaker requirement. The economic viability of asset prices and the absence of arbitrage are equivalent; both are closely related to the existence of *nonlinear* pricing measures. We show how the different versions of the Efficient Market Hypothesis are related to the assumptions we are willing to impose on the market's ordering of contracts. Our approach also unifies recent versions of the Fundamental Theorem of Asset Pricing under a common framework.
Joint work with Matteo Burzoni and Mete Soner.

Pietro Siorpaes -- *Structure of martingale transports in Banach spaces*
In 2015 Beiglböck, Nutz and Touzi studied the martingale optimal transport problem and showed that in dimension one there is no duality gap and that the dual problem admits an optimizer. In two recent preprints, De March and Touzi and De March obtained similar results in finite dimension. A key step towards these achievements is the characterization of the polar sets of the family of all martingale couplings. Here we study this characterization in Banach spaces, using different techniques.
Based on a joint work with Jan Obłój.

Johannes Wiesel -- *Robust Modelling of Financial Markets in Discrete time*
We unify and establish equivalence between the pathwise and quasi-sure approach to robust modelling of financial markets in discrete time. In particular, we prove a Fundamental Theorem of Asset Pricing and a Superhedging Theorem which both encompass the formulations of Bouchard and Nutz (2015) and Burzoni et al. (2016).
Based on a joint work with Jan Obłój.

Daisuke Yoshikawa -- *Pairs trading under model uncertainty*
Since the introduction of pairs trading, this method has undergone considerable development. This method uses the mean reversion of the pair value and the point further most from this point. The correct estimation of these parameters leads the stable profit. However, the misspecification of the parameters may result in the big loss. This possibility is due to the model uncertainty. To avoid this, we derive the optimal points for pairs trading taking into account the model uncertainty, especially setting the finite horizon of the period of pairs trading. Further, for the validation of our results, we show a few numerical examples using market data.

Yufei Zhang -- *A penalty scheme and policy iteration for nonlocal HJB variational inequalities with monotone drivers*
We propose a class of numerical schemes for nonlocal HJB variational inequalities (HJBVIs) with monotone drivers. The solution and free boundary of the HJBVI are constructed from a sequence of penalized equations, for which a continuous dependence result is derived and the penalization error is estimated. The penalized equation is then discretized by a class of semi-implicit monotone approximations. We present a novel analysis technique for the well-posedness of the discrete equation, and demonstrate the convergence of the scheme, which subsequently gives a constructive proof for the existence of a solution to the penalized equation and variational inequality. We further propose an efficient iterative algorithm with local superlinear convergence for solving the discrete equation. Numerical experiments for an optimal investment problem under ambiguity are presented to illustrate the effectiveness of our schemes.

Poster Presentations

Farid AitSahlia -- *American Options under Stochastic Volatility: Parameter Estimation and Pricing Efficiency*
The stochastic volatility model of Heston (1993) is widely popular for its ability to capture many stylized facts of asset returns and for its resulting closed-form expressions for European option prices. However, its parameter estimation is challenging, and so is its application to the pricing of American options. In this paper, we present evidence that American option prices are insensitive to the accuracy of spot and long–term volatility estimates in the Heston (1993) model, for which drastically different parameter values can be obtained. Our results derive from a new accurate pricing technique that we provide and which is based on a well-developed and efficient procedure for the constant volatility model of Black and Scholes. In addition, through an out–of–sample validation based on S&P 100 data, we also show that our method generates prices close to market values. In essence, our approach is predicated upon the classical Chernoff concentration bounds and the robustness of the Black-Scholes formula relative to misspecified stochastic volatility as shown by El Karoui et al. (1998).

Andro Mercep -- *Deep self-normalizing networks for credit risk assessment*
Credit risk assessment process includes evaluation of loan applications using application models, as well as monitoring behavior of existing clients using behavioral models (in order to identify ones that are likely to default). In this article we propose a deep self-normalizing neural network behavioral model trained on a large contract-level dataset. The proposed deep learning model showed significant performance improvement in comparison to conventional models. Moreover, when comparing accuracy scores with regard to actual month of default in the future, deep model once again exhibits higher predictive power.

Max Nendel -- *Markov chains under nonlinear expectation*
We consider continuous-time Markov chains with finite state space. In the linear case, every continuous-time Markov chain can be related to a so-called Q-Matrix and vice versa. Moreover, it can be shown that the dynamics of the Markov chain are being described by a linear ODE. We extend this relation to the convex case by considering continuous-time Markov chains under convex expectations and so-called Q-operators. We will finally show that every continuous-time Markov chain describes the dynamics of solutions to a certain fully-nonlinear ODE, which is given by the Q-operator belonging to the Markov chain.

Matteo Ottaviani -- *Modern tools for agent-based model sensitivity analysis*
Sensitivity analysis (SA) constitutes an open challenge for Agent-Based Models (ABM) in economics and finance. SA is central to effective model design and intuitive evaluation, where one aims to rank parameter importance when explaining output variance or "sensitivity" to changes in the input parameters (or initial conditions) of the model. This sensitivity to input parameters represents a response for how the model (approximately) behaves when input parameters are changed. Understanding the model's response to (possibly joint) changes in parameter values forms the basis for assessing model robustness and drawing robust implications from policy exercises Salle (2014). Unfortunately, as ABMs become more realistic, they require an increasing number of parameters. This results in highly prohibitive computational costs when assessing ABM sensitivities. Surrogate meta-models offer a solution to this computational burden Lamperti (2017).
We propose a wide sensitivity analysis of the Brock and Hommes asset-pricing model Brock and Hommes (1998) directly and on a variety of surrogate meta-models using two well-known approaches to SA and go through comparisons among machine-learning surrogate models and kriging method, widely used by agent-based modelers Dosi et al. (2016) .

Vladimir Petrov -- *Multidimensional Directional–Change Intrinsic Time*
Equidistant time-stamps—synchronized with the flow of physical time and used to make snapshots of the market states—are either (1) too sparse and do not capture all the available high-frequency information or are (2) too dense which results in superfluous noisy events in the final time series. Directional-change intrinsic time in which ticks happen when the price experiences alternating reversals of a fixed relative size from local extremes is one of the first endeavors to overcome the stiffness of the traditional approach and to provide a new concept devoid of the mentioned shortcomings. The concept is sensitive to the

markets' activity and registers more ticks in periods of soaring volatility while rarely ticking over weekends. We extend the definition of directional-change intrinsic time to a multidimensional space, where the dimensions are formed by orthogonally placed exchange rates. The new method is tested on tick-by-tick historical prices from Forex market. All details required for deriving the new algorithm are provided. The exact description of the multidimensional dissection procedure is outlined. We uncover two scaling laws (directional change count and overshoot move) in the multidimensional space and explain their dependence on the number of time series forming the space.

Martin Tegner -- *A probabilistic approach to local volatility*
The local volatility model is a celebrated model widely used for pricing and hedging financial derivatives. While the model's main appeal is its capability of reproducing any given surface of observed option prices—it provides a perfect fit—the essential component of the model is a latent function which can only be unambiguously determined in the limit of infinite data. To (re)construct this function, numerous calibration methods have been suggested involving steps of interpolation and extrapolation, most often of parametric form and with point-estimates as result. We seek to look at the calibration problem in a probabilistic framework with a fully nonparametric approach based on Gaussian process priors. This immediately gives a way of encoding prior believes about the local volatility function and a hypothesis model which is highly flexible whilst being prone to overfitting. Besides providing a method for calibrating a (range of) point-estimate, we seek to draw posterior inference on the distribution over local volatility to better understand the uncertainty attached with the calibration in particular, and with the model in general. Further, we seek to understand dynamical properties of local volatility by augmenting the hypothesis space with a time dimension. Ideally, this gives us means of inferring predictive distributions not only locally, but also for entire surfaces forward in time.

Lukasz Treszczotko -- *From Hawkes-type processes to stochastic volatility*
We introduce a Hawkes-like process and study its scaling limit as the system becomes increasingly endogenous. We derive functional limit theorems for intensity and fluctuations. Then, we introduce a high-frequency model for a price of a liquid traded financial instrument in which the nearly unstable regime leads to a Heston-type process where the negative correlation between the noise driving the proce of the instrument and the volatility can be viewed as a result of high variance of the sell-side order arrivals.

Tao Wu -- *A multi-curve random field LIBOR market model*
A multi-curve random field LIBOR market model is proposed by extending the LIBOR market model (LMM) with uncertainty modelled by a random field to the multicurve framework, where the forward LIBOR curve for projecting future cash flows and the curve for discounting are modelled distinctively but jointly. The multi-curve methodology is introduced recently in the literature to account for the increased basis among closely related interest rates since the 2007-2009 credit crisis. Closed-form formulas for pricing caplets and swaptions are derived. Then the multi-curve random field LIBOR market model is integrated with the local and stochastic volatility models (lognormal-mixture, SABR, Wu and Zhang (2006)) to capture the implied volatility skew/smile. Finally, we estimate various models from market data. Empirical results show that for both in-sample and out-of-sample pricing, the random field LIBOR Market Model outperforms the Brownian motion LIBOR Market Model. Moreover, their corresponding multi-curve variations outperform their single-curve counter-parts respectively.

Hai Zhang -- *Liquidity risks, transaction costs and online portfolio selection*
The performance of online (sequential) portfolio selection (OPS), which rebalances a portfolio in every period (e.g. daily or weekly) in order to maximise the portfolio's expected terminal wealth in the long run, has been overestimated by the ideal assumption of unlimited market liquidity (i.e. no market impact costs). Therefore, a new transaction cost factor model that considers both market impact costs, estimated from limit order book data, and proportional transaction costs (e.g. brokerage commissions or transaction taxes in a fixed percentage) has been proposed in this paper to measure existing OPS strategies performance in a more practical way as well as to develop a more effective OPS method. Backtesting results from the historical limit order book (LOB) data of NASDAQ-traded stocks show both the performance deterioration of existing OPS methods by the market impact costs and the superiority of our proposed OPS method in the environment of limited market liquidity.

Venues

Conference venue – Mathematical Institute, Radcliffe Observatory Quarter, Woodstock Road, Oxford OX2 6GG
Dinner venue – St John's College, St Giles', Oxford OX1 3JP
Punting – Magdalen Bridge Boathouse, High St, Oxford OX1 4AU

Travel information

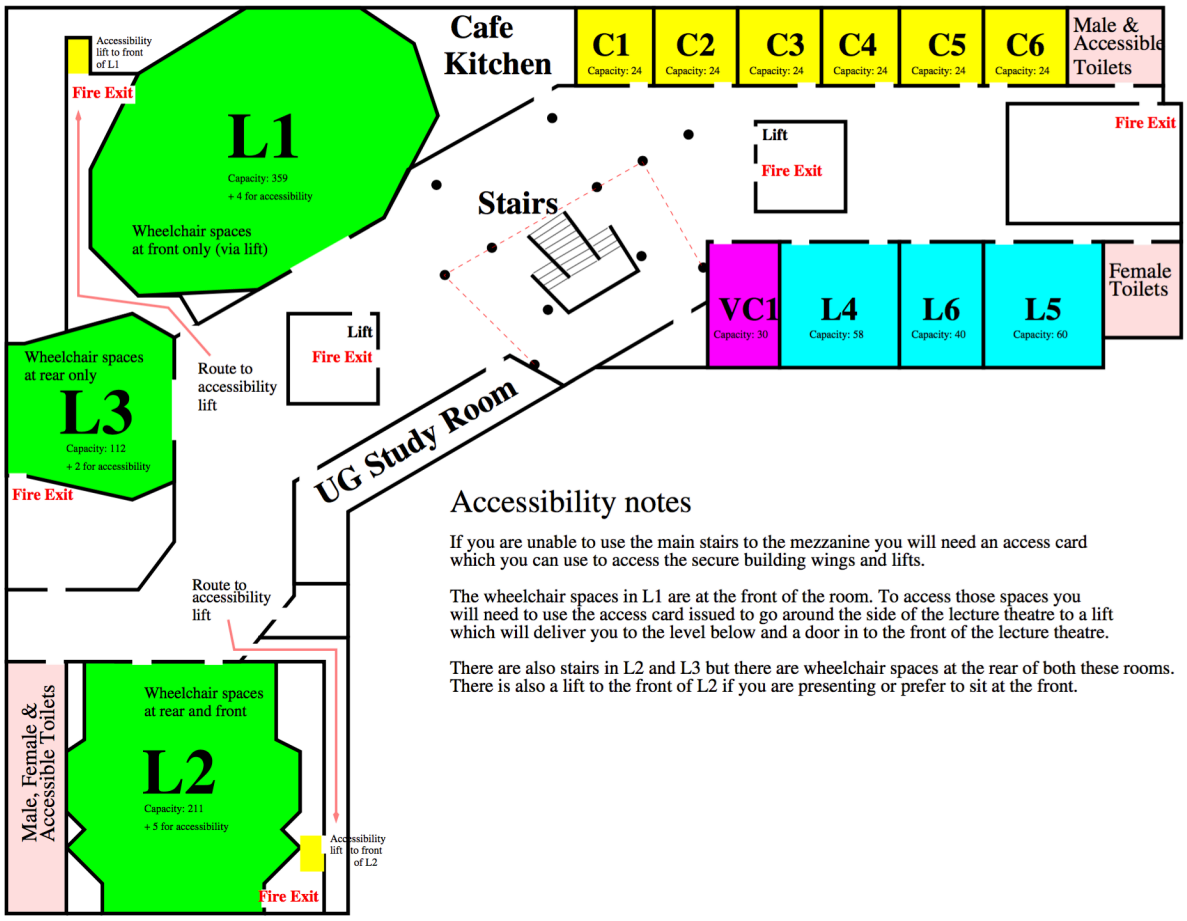
Air. From London Heathrow and Gatwick airports, take The Airline coach service, which runs 24 hours a day. You can also get to Oxford by train from Heathrow via London, and from Gatwick via Reading.
From London Stansted airport, take the Stansted Express train service to Liverpool Street and then take the tube to either Paddington or Marylebone for direct trains to Oxford.
Alternatively there is a National Express 757 coach service.

Trains. Direct services run from London Paddington (serving Oxford station) and London Marylebone (serving Oxford and Oxford Parkway stations). Other services operate from the north via Birmingham New Street; from the south via Reading; and from the west via Didcot or Reading. For details and to plan your journey, see contact National Rail Enquiries.
Oxford Railway Station is a 15 minutes walk from the Mathematical Institute.

Please see http://www.ox.ac.uk/visitors/visiting-oxford/how-get-oxford for further information.

Layout of mezzanine level of the Mathematical Institute, Andrew Wiles Building

Mezzanine Plan



Accessibility notes

If you are unable to use the main stairs to the mezzanine you will need an access card which you can use to access the secure building wings and lifts.

The wheelchair spaces in L1 are at the front of the room. To access those spaces you will need to use the access card issued to go around the side of the lecture theatre to a lift which will deliver you to the level below and a door in to the front of the lecture theatre.

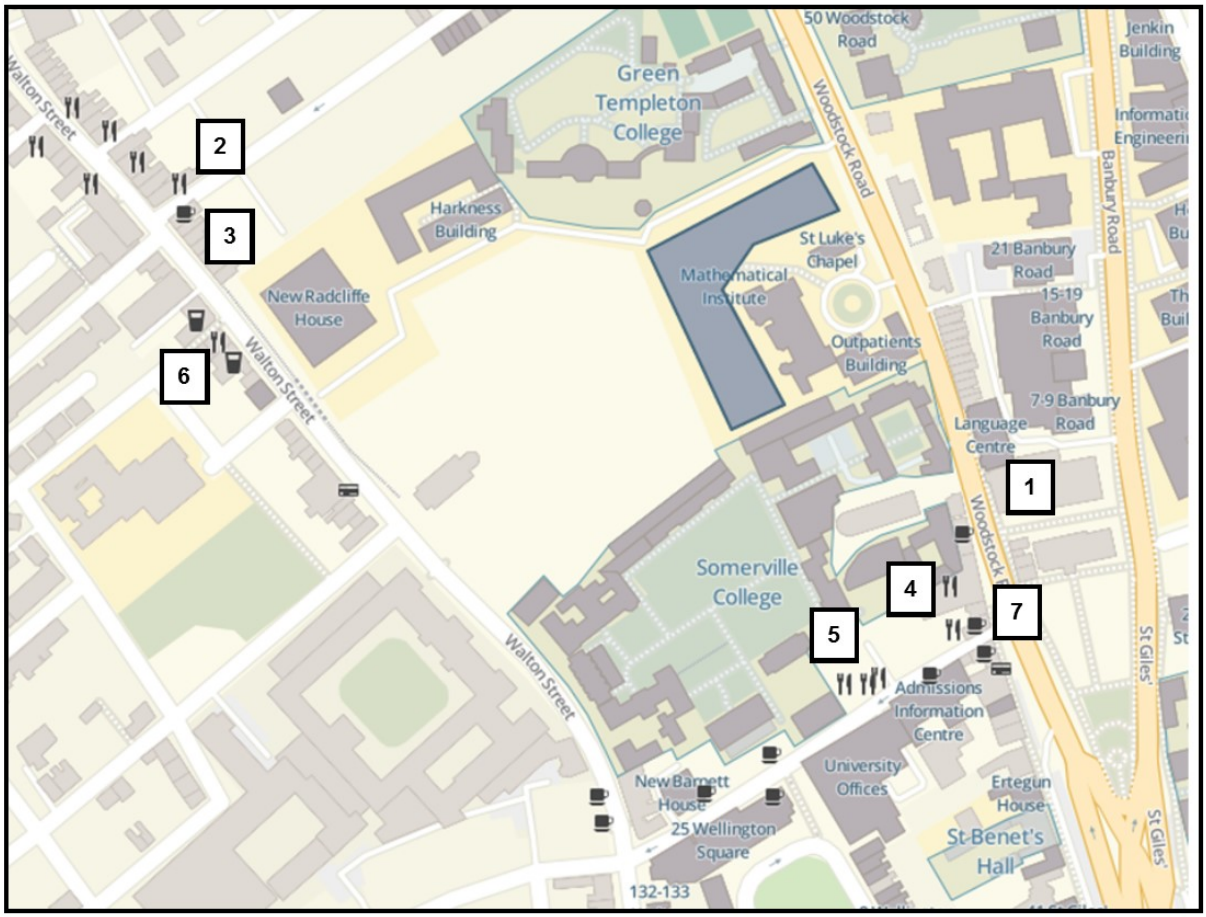
There are also stairs in L2 and L3 but there are wheelchair spaces at the rear of both these rooms. There is also a lift to the front of L2 if you are presenting or prefer to sit at the front.

All conference talks are held in L3.

C3&C4 are available for discussion and personal use.

Local Information

Restaurants, Pubs and Cafés



1.The Royal Oak Pub

42-44 Woodstock Road OX2 6HT

Mo-Sa 12:00-23:30
Su 12:00-22:30

2. Branca

111 Walton Street OX2 6AJ

Mo-Su 10:00-23:00

3. The Jericho Cafe

112 Walton Street OX2 6AJ

Mo-Sa 08:00-21:30
Su 09:30-20:00

4 Browns

5-11 Woodstock Road OX2 6HA

Mo-Th 09:30-23:00
Fr-Sa 09:30-23:30
Su 09:30-22:30

5a. Café Rouge

Little Clarendon Street

Mo-Sa 09:00-23:00
Su 9:30-22:30

5b. Pierre Victoire

Little Clarendon Street

Mo-Sa 12–14:30, 18:00–23:00
Su 12:00 - 22:00

6. Loch Fyne

55 Walton Street

Mo-Fri 12–22:00
Sa-Su 10:00 - 22:00

7. Taylors

31 Saint Giles

Mo-Fri 7:15–19:00
Sa 8:00 - 17:30

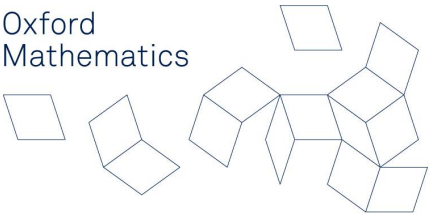
Map Symbol Key

Pub

Restaurant

Café

ATM



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