

New Directions in Financial Mathematics and Mathematical Economics

July 6-11, 2014

MEALS

*Breakfast (Buffet): 7:00–9:30 am, Sally Borden Building, Monday–Friday

*Lunch (Buffet): 11:30 am–1:30 pm, Sally Borden Building, Monday–Friday

*Dinner (Buffet): 5:30–7:30 pm, Sally Borden Building, Sunday–Thursday

Coffee Breaks: As per daily schedule, in the foyer of the TransCanada Pipeline Pavilion (TCPL)

***Please remember to scan your meal card at the host/hostess station in the dining room for each meal.**

MEETING ROOMS

All lectures will be held in the lecture theater in the TransCanada Pipelines Pavilion (TCPL). An LCD projector, a laptop, a document camera, and blackboards are available for presentations.

SCHEDULE

Sunday

16:00 Check-in begins (Front Desk - Professional Development Centre - open 24 hours)

17:30–19:30 Buffet Dinner, Sally Borden Building

Monday

7:00–8:45 BREAKFAST

8:45–9:00 Introduction and Welcome by BIRS Station Manager, TCPL

9:00–9:30 Guasoni, Paolo (Boston University and Dublin City University): *Shortfall Aversion*

9:45–10:15 Grasselli, Matheus (Fields Institute): *Bringing Tobin back: asset price dynamics and portfolio selection in macroeconomics*

10:15–10:45 COFFEE BREAK

10:45–11:15 Cont, Rama (Imperial College & CNRS): *High frequency trading in limit order markets : multi-scale modeling and asymptotic analysis*

11:30–12:00 Cebiroglu, Goekhan (University of Vienna): *Does Hidden Liquidity Harm Price Efficiency? Equilibrium Exposure under Latent Demand*

12:00–13:00 LUNCH

13:00–14:00 Guided Tour of The Banff Centre; meet in the 2nd floor lounge, Corbett Hall

14:00–14:30 Rockafellar, R.Terry (University of Washington): *GENERAL ECONOMIC EQUILIBRIUM WITH FINANCIAL MARKETS, REMODELED*

14:45–15:15 Horst, Ulrich (Humboldt University): *A law of large numbers for the limit order book*

15:15–15:45 COFFEE BREAK

15:45–16:15 Robertson, Scott (Carnegie Mellon University): *Long Horizon Optimal Investment and Risk-Sensitive Control in Stochastic Volatility Models with Matrix Valued Factors*

16:30–17:00 Donnelly, Ryan (University of Toronto): *Optimal market making under the effects of order imbalance*

17:15–17:45 Frei, Christoph (University of Alberta): *Dynamic Multitasking: Accidents Lead to Non-linear Contracts*

18:00–19:30 DINNER

Tuesday

7:00–9:00	BREAKFAST
9:00–9:30	Bayraktar, Erhan (University of Michigan): <i>Minimizing the Probability of Lifetime Ruin Under Ambiguity Aversion</i>
9:45–10:15	Cartea, Alvaro (University College London): <i>Model Uncertainty in Commodities</i>
10:15–10:45	COFFEE BREAK
10:45–11:15	Hernandez-Hernandez, Daniel (Centro de Investigacion en Matematicas Guanajuato): <i>Games of singular control and stopping driven by spectrally one-sided Lévy processes</i>
11:30–12:00	Hyndman, Cody (Concordia University): <i>Optimal measure transformation problems associated with defaultable bonds, futures prices, and forward prices</i>
12:15–12:45	Sturm, Stephan (Worcester Polytechnic Institute): <i>Funding without Tears. A Unified Approach to XVA</i>
12:45–14:00	LUNCH
16:30–17:00	Capponi, Agostino (Johns Hopkins University): <i>Dynamic Investment under Counterparty Risk</i>
17:15–17:45	Ewald, Christian (University of Glasgow): <i>Peacocks, Lyrebirds and Increasing Risk in the Rothschild Stiglitz Sense</i>
18:00–18:30	Carmona, René (Princeton University): <i>The Master Equation for Mean Field Games</i>
18:45–19:30	DINNER

Wednesday

7:00–9:00	BREAKFAST
9:00–9:30	Muhle-Karbe, Johannes (ETH Zürich): <i>Who should sell stocks?</i>
9:45–10:15	Qiu, Jinniao (Humboldt University): <i>A Functional Limit Theorem for Limit Order Books</i>
10:15–10:45	COFFEE BREAK
10:45–11:15	Moallemi, Ciamac (Columbia University): <i>Dynamic Portfolio Choice with Linear Rebalancing Rules</i>
11:30–12:00	Bichuch, Maxim (Worcester Polytechnic Institute): <i>Portfolio Choice with Liquid and Illiquid Assets</i>
12:15	Group Photo; meet in foyer of TCPL (photograph will be taken outdoors so a jacket might be required).
12:30–14:00	LUNCH
14:00–18:00	Free afternoon
18:00–19:30	DINNER

Thursday

7:00–9:00	BREAKFAST
9:00–9:30	Ludkovski, Michael (University of California, Santa Barbara): <i>Dynamic R&D Games</i>
9:45–10:15	Huang, Minyi (Carelton University): <i>Mean field game modeling for stochastic economic growth</i>
10:15–10:45	COFFEE BREAK
10:45–11:15	Zariphopoulou, Thaleia (University of Texas at Austin): <i>Some new results on forward performance processes</i>
11:30–12:00	Lorig, Matt (Princeton University): <i>Portfolio Asymptotics for Local-Stochastic Volatility Models</i>
12:00–14:00	LUNCH
14:00–14:30	Leung, Tim (Columbia University): <i>Optimal Multiple Trading Times Under Mean Reversion</i>
14:45–15:15	Larsson, Martin (Ecole Polytechnique Federale de Lausanne): <i>Polynomial Commodity Futures Models</i>
15:15–15:45	COFFEE BREAK
15:45–16:15	Ware, Tony (University of Calgary): <i>Reliability-constrained hydropower valuation</i>
16:30–17:00	Jaimungal, Sebastian (University of Toronto): <i>A Mean Field Game approach to Optimal Execution</i>
17:15–17:45	Sircar, Ronnie (Princeton University): <i>Energy Production and Mean Field Games</i>
18:00–19:30	DINNER

Friday (Checkout by 12 noon)

7:00–9:00	BREAKFAST
9:00–9:30	Kallblad, Sigrid (University of Oxford): <i>Optimal Skorokhod embedding given full marginals and Azema-Yor type martingale peacocks</i>
9:45–10:15	Papanicolaou, Andrew (University of Sydney): <i>Control with Partial Information</i>
10:15–10:30	COFFEE BREAK
10:30–11:00	Kinzebulatov, Damir (The Fields Institute): <i>Modeling price dynamics and quote imbalance using pinned Markov chains</i>
11:15–11:45	Praz, Remy (Ecole Polytechnique Fédérale de Lausanne): <i>Asymmetric Information and Inventory Concerns in Over-the-Counter Markets</i>
12:00–12:30	Papapantoleon, Antonis (Technical University Berlin): <i>An equilibrium model for commodity spot and forward prices</i>
12:45–13:30	LUNCH

5-day workshop participants are welcome to use BIRS facilities (BIRS Coffee Lounge, TCPL and Reading Room) until 3 pm on Friday, although participants are still required to checkout of the guest rooms by 12 noon.

New Directions in Financial Mathematics and Mathematical Economics

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ABSTRACTS

1. Bayraktar, Erhan (University of Michigan)

Title: *Minimizing the Probability of Lifetime Ruin Under Ambiguity Aversion*

Abstract: We determine the optimal robust investment strategy of an individual who targets at a given rate of consumption and seeks to minimize the probability of lifetime ruin when she does not have perfect confidence in the drift of the risky asset. Using stochastic control, we characterize the value function as the unique classical solution of an associated Hamilton-Jacobi-Bellman (HJB) equation, obtain feedback forms for the optimal investment and drift distortion, and discuss their dependence on various model parameters. In analyzing the HJB equation, we establish the existence and uniqueness of viscosity solution using Perron's method, and then upgrade regularity by working with an equivalent convex problem obtained via the Cole-Hopf transformation. We show the original value function may lose convexity for a class of parameters and the Isaacs condition may fail. Numerical examples are also included to illustrate our results.

Joint with Yuchong Zhang.

2. Bichuch, Maxim (Worcester Polytechnic Institute)

Title: *Portfolio Choice with Liquid and Illiquid Assets*

Abstract: We find dynamic portfolio strategies for long-term investors with constant relative risk aversion, who trade in a market with three assets, one safe, one risky and liquid, and one risky and illiquid. Investment opportunities are constant and trading is continuous, but the illiquid asset incurs proportional transaction costs. Optimal investment policies entail infrequent trading in the illiquid asset compensated by hedging activity in the liquid asset. Liquid hedging positions are nonlinear, and do not vanish even for independent risky assets. This is a joint work with Paolo Guasoni.

3. Capponi, Agostino (Johns Hopkins University)

Title: *Dynamic Investment under Counterparty Risk*

Abstract: We develop a dynamic credit allocation framework to assess the impact of counterparty risk on optimal investments. The investor can purchase CDS upfronts from a defaultable counterparty, asking her to post collateral to mitigate default related losses. Because of collateral and closeout payments exchanged at the counterparty default time, the wealth process exhibits a non-differentiable concave drift. By viewing it as a continuous function of the admissible controls, we provide an explicit characterization of the optimal swap strategy and show that the value function coincides with the solution of a nonlinear HJB differential equation whose coefficients admit singular growth. By means of a novel truncation technique we establish existence and uniqueness of a global solution to the HJB equation. Our study predicts that the investor does not trade in the risky security when counterparty risk is sufficiently high. Numerical analysis indicates that the investor's desire to take exposure depends on the tradeoff between collateral mitigation and price appreciations due to feedback from default effects.

4. Carmona, René (Princeton University)

Title: *The Master Equation for Mean Field Games*

Abstract:

5. Cartea, Alvaro (University College London)

Title: *Model Uncertainty in Commodities*

Abstract: There is no such concept as the correct model and one way in which agents can address this risk is to acknowledge that the model they use to price instruments and make investment decisions is misspecified. In this talk we discuss how agents consider alternative models when pricing derivative instruments. In particular agents recognise that they do not exactly know the probability laws of the stochastic processes required to price instruments, such as forward contracts, so they must consider other models when calculating prices at which they are willing to buy or sell instruments.

In our framework we assume that agents are ambiguity averse. They start by writing down a model which captures the main elements that they require to price forward electricity contracts but allow the calculation of the forward price to consider alternative models to the reference model they start with. If the agent is extremely confident about her model then any deviations from her reference model are penalised. On the other hand, if the agent is extremely ambiguous about her reference model she will explore many other models which give her a more conservative price, higher if selling or lower if buying.

Our preliminary results show that if the agent writes the usual arithmetic model where spot prices follow a mean reverting jump diffusion, then forward contracts over a delivery period will be priced under a probability law where the jumps and drift of the process of the reference model are altered as follows. If the agent is selling forward contracts then she will use an alternative model which, compared to the reference model, includes a positive drift in the diffusion component, and assumes that the intensity of arrival of jumps up is higher and the average size of the positive jumps is also higher. If the agent is a buyer he will alter the reference model in a similar way, introduce a negative drift and over-emphasise the negative jumps. (Co-authors: Sebastian Jaimungal and Zhen Qin).

6. Cebiroglu, Goekhan (University of Vienna)

Title: *Does Hidden Liquidity Harm Price Efficiency? Equilibrium Exposure under Latent Demand*

Abstract: There is a striking empirical observation in today's electronic limit order book markets: price returns and fluctuations increase subsequent to the submission of hidden orders; not so for displayed orders. Secondly, markets with a higher proportion of hidden liquidity exhibit higher volatility levels. What drives these price fluctuations? Are they driven by information or inefficiencies? We develop a dynamic equilibrium framework to provide partial answers these questions. Our model consists of a public exchange that competes for order flow with off-exchange trading mechanisms. A large investor has the strategic freedom to either trade in the primary or in the off-exchange market. On the other hand, liquidity suppliers in the primary market face a trade-off between the costs and benefits of order exposure. When liquidity suppliers display their orders, they can elicit order flow from the latent investor, leading to mutually beneficial trades. In contrast, hidden orders reduce the likelihood to attract counterparties and thus miss out on "frictionless" trades. Ultimately, hidden traders are forced to switch to more aggressive orders, which not only increases transaction costs for the individual but also leads to price reactions that are not driven by information. The essence of this is that hidden orders can weaken the efficient coordination between the supply and demand side of liquidity, as liquidity demanders do not observe (possible) trading opportunities anymore.

7. Cont, Rama (Imperial College & CNRS)

Title: *High frequency trading in limit order markets : multi-scale modeling and asymptotic analysis*

Abstract: The advent of high frequency trading has changed the landscape of financial markets, leading to a heterogeneous environment where market participants with a wide range of trading frequencies interact through the limit order book.

We propose a stochastic model for dynamics of price and order flow in a limit order market, which captures the coexistence of high frequency and low frequency order flow and examines the consequences of this heterogeneity on price dynamics, volatility and liquidity. Based on a detailed empirical study of high frequency order flow in the SP futures market, we argue that the properties of the order flow point to a multi-scale heavy traffic regime, which we contrast with other scaling regimes studied in

the recent literature.

We show that in this scaling limit the limit order book is a measure-valued Markov process whose dynamics may be described through a (stochastic) free boundary problem, and which provides some insights into how HFT affects price and order book dynamics.

8. Donnelly, Ryan (University of Toronto)
Title: *Optimal market making under the effects of order imbalance*
Abstract: Shortcomings of continuous and static microstructure models are noted with motivation provided by data from the NASDAQ. The influence of order imbalance on microstructure dynamics is incorporated in to a model which allows the market maker to adjust their strategy based on an easily observable quantity. The predictive power of order imbalance allows the MM to decide when they should trade more aggressively to take advantage of beneficial price movements, and when they should trade more conservatively to protect against adverse selection effects. High imbalance results in a stronger inclination to place limit buy orders with the opposite effect on limit sell orders. Also shown is how protecting against the effects of model misspecification change the trading strategy of the MM and impose strong inventory constraints.?
9. Ewald, Christian (University of Glasgow)
Title: *Peacocks, Lyrebirds and Increasing Risk in the Rothschild Stiglitz Sense*
Abstract: We extend the Rothschild and Stiglitz (1970, 1971) notion of increasing risk to families of random variables (X_t) and in this way link their approach to the concept of stochastic processes which are increasing in the convex order. Such processes have recently been referred to as peacocks and received increased attention in the derivatives pricing literature, compare Hirsch et. al. (2011). Originally these processes have been introduced in seminal work by Strassen (1965), Doob (1967) and Kellerer (1972), who showed that such processes have the same marginals as a martingale. As we show, their results in fact include the results of Rothschild and Stiglitz as a special case. However, going far beyond this, the rich theory of martingales in the mathematical literature can uncover important issues in the Rothschild and Stiglitz framework. Further, we demonstrate that it makes sense to look at a larger class of processes, which we refer to as lyrebirds. We present a number of examples from Economics and Finance, including hyperbolic discounting, exotic derivatives, econometrics and inequality.
10. Frei, Christoph (University of Alberta)
Title: *Dynamic Multitasking: Accidents Lead to Nonlinear Contracts*
Abstract: We consider a dynamic multitask principal-agent model in which the agent allocates his resources on two tasks of different types: effort and accident prevention. We explicitly characterize the optimal contract as well as optimal effort and prevention actions applied by the agent. In contrast to the linear incentive scheme for effort, accident prevention leads to a sublinear punishment scheme if the agent is risk averse, becoming linear only if the agent is risk neutral. Accident prevention ties up some of the agent's capacity and induces him to substitute resources away from effort to prevention. This also affects principal's decisions to promote him or liquidate the firm prematurely. The talk is based on joint work with Agostino Capponi.
11. Grasselli, Matheus (Fields Institute)
Title: *Bringing Tobin back: asset price dynamics and portfolio selection in macroeconomics*
Abstract:
12. Guasoni, Paolo (Boston University and Dublin City University)
Title: *Shortfall Aversion*
Abstract: Shortfall aversion reflects the higher utility loss of a spending cut from a reference point than the utility gain from a similar spending increase, in the spirit of Prospect Theory's loss aversion. This paper posits a model of utility of spending scaled by a function of past peak spending,

called target spending. The discontinuity of the marginal utility at the target spending corresponds to shortfall aversion. According to the closed-form solution of the associated spending-investment problem, (i) the spending rate is constant and equals the historical peak for relatively large values of wealth/target; and (ii) the spending rate increases (and the target with it) when that ratio reaches its model-determined upper bound. These features contrast with traditional Merton-style models which call for spending rates proportional to wealth. A simulation using the 1926-2012 realized returns suggests that spending of the very shortfall averse is typically increasing and very smooth. (Joint work with Gur Huberman and Dan Ren)

13. Hernandez-Hernandez, Daniel (Centro de Investigacion en Matematicas Guanajuato)

Title: *Games of singular control and stopping driven by spectrally one-sided Lévy processes*

Abstract: We study a zero-sum game where the evolution of a spectrally one-sided Levy process is modified by a singular controller and is terminated by the stopper. The singular controller minimizes the expected values of running, controlling and terminal costs while the stopper maximizes them. Using the fluctuation theory and the scale function, we derive the saddle point and the associated value function when the underlying process is a spectrally negative/positive Levy process. Joint work with K. Yamazaki.
14. Horst, Ulrich (Humboldt University)

Title: *A law of large numbers for the limit order book*

Abstract: We define a stochastic model of a two-sided limit order book in terms of its best bid [ask] price and the standing buy [sell] volume density. For a simple scaling of the discreteness parameters, that keeps the expected volume rate over the considered price interval invariant, we prove a limit theorem. The limit theorem states that, given regularity conditions on the random order flow, the key quantities converge in probability to a tractable continuous limiting model. In the limit model the buy and sell volume densities are given as the unique solution to first-order linear hyperbolic PDEs, specified by the expected order flow parameters. The talk is based on joint work with Michael Paulsen.
15. Huang, Minyi (Carleton University)

Title: *Mean field game modeling for stochastic economic growth*

Abstract: This work considers stochastic growth optimization with many interacting agents. This leads to a mean field game where each agent's production dynamics and utility receive the aggregate influence of all others. The stochastic control problem with decentralized information is studied via consistent mean field approximations.
16. Hyndman, Cody (Concordia University)

Title: *Optimal measure transformation problems associated with defaultable bonds, futures prices, and forward prices*

Abstract: We associate the prices of defaultable bonds, futures prices, and forward prices with an optimal measure transformation (OMT) problem. The objective function in the OMT problem depends on the aggregate relative entropy of two measures. The solution to the OMT problem is closely related to the forward-backward stochastic differential equation (FBSDE) approach to term-structure modelling of (Hyndman, 2009). We obtain explicit solutions to the related FBSDEs under the optimal measure for both affine and quadratic term-structure models with jumps. In addition, we establish the equivalence between the OMT problem and an optimal stochastic control problem used in (Gombani and Runggaldier, 2013) to study quadratic term-structure models. Joint work with Renjie Wang.
17. Jaimungal, Sebastian (University of Toronto)

Title: *A Mean Field Game approach to Optimal Execution*

Abstract: This paper introduces a mean field game framework for optimal execution with continuous

trading. We generalize the classical optimal liquidation problem to a setting where, in addition to the major agent who is liquidating a large portion of shares, there are a number of minor agents (high-frequency traders (HFTs)) who detect and trade along with the liquidator. Cross interaction between the minor and major agents occur through the impact that each trader has on the drift of the fundamental price. As in the classical approach, here, each agent is exposed to temporary price impact and they attempt to balance their impact against price uncertainty. In all, this gives rise to a stochastic dynamic game with mean field couplings in the fundamental price. We obtain a set of decentralized strategies using a mean field stochastic control approach and explicitly solve for an ϵ -optimal control up to the solution of a deterministic fixed point problem. As well, we present some numerical results which illustrate how the liquidating agents trading strategy is altered in the presence of the HFTs, and how the HFTs trade to profit from the liquidating agents trading. [this is joint work with Mojtaba Nourin, Department of Statistical Sciences, U. Toronto]

18. Kallblad, Sigrid (University of Oxford)

Title: *Optimal Skorokhod embedding given full marginals and Azema-Yor type martingale peacocks*

Abstract: We consider here the optimal Skorokhod embedding problem (SEP) given full marginals over the time interval $[0,1]$. The problem is related to studying the extremal martingales associated to a peacock (process increasing in convex ordering, by Hirsch, Profeta, Roynette and Yor (2011)). A general duality result is obtained by convergence techniques. We then study the case where the reward functions depends on the maximum of the embedding process, which is the limit of the martingale transport problem studied in Henry-Labordere, Obloj, Spoida and Touzi (2013). Under technical conditions, some explicit characteristics of the solutions to the optimal SEP as well as to its dual problem are obtained. We also discuss the associated martingale inequality. The talk is based on joint work with Xiaolu Tan and Nizar Touzi.

19. Kinzebulatov, Damir (The Fields Institute)

Title: *Modeling price dynamics and quote imbalance using pinned Markov chains*

Abstract: We use a generalization of Doob h-transform to develop a model where a trader takes a view on the joint distribution of the asset mid-price at a future time, and the time-weighted average quote imbalance up to this time. As time goes by, the trader updates her prediction in order to adjust her strategy. The trader can choose her prediction based on a directional view, however, she also profits from making a spread. This is a joint work with Sebastian Jaimungal.

20. Larsson, Martin (Ecole Polytechnique Federale de Lausanne)

Title: *Polynomial Commodity Futures Models*

Abstract: Polynomial preserving processes constitute a generalization of the affine class, and have been successfully employed to construct flexible and tractable factor models for the term structure of interest rates. In this talk I will discuss how this class of processes can be used in the context of commodity and energy futures markets.

21. Leung, Tim (Columbia University)

Title: *Optimal Multiple Trading Times Under Mean Reversion*

Abstract: We study the problem of trading under mean-reverting prices subject to transaction costs. An optimal double stopping approach is formulated to analyze the optimal timing to enter and exit the market under the CIR or exponential OU model. In the CIR case, the investors optimal strategy is characterized by a lower level for entry and an upper level for exit. However, in the exponential OU case, it is optimal to delay entry not only when the current price is high, but also when it is sufficiently close to zero. Furthermore, we analyze a related optimal switching problem that maximizes expected returns via an infinite sequence of trades. We compare the optimal trading strategies under these two approaches both analytically and numerically, and point out when they are equivalent.

22. Lorig, Matt (Princeton University)
Title: *Portfolio Asymptotics for Local-Stochastic Volatility Models*
Abstract:
23. Ludkovski, Michael (University of California, Santa Barbara)
Title: *Dynamic R&D Games*
Abstract: We explore optimal investment in Research and Development activities in a competitive market. R&D effort is costly and results in discrete technological advances that gradually lower production costs. Using a Cournot model of competition with substitutable goods (e.g. markets for different energy commodities) we analyze the respective Markov Nash equilibrium strategies for production and R&D effort. Our model represents stages of technological progress by a controlled multi-dimensional counting process. The solution approach is then to study the sequence of the one-step static games arising between R&D successes. We present several numerical examples and some preliminary analysis of the emerging comparative statics. (Joint work with Ronnie Sircar, Princeton)
24. Moallemi, Ciamac (Columbia University)
Title: *Dynamic Portfolio Choice with Linear Rebalancing Rules*
Abstract: We consider a broad class of dynamic portfolio optimization problems that allow for complex models of return predictability, transaction costs, trading constraints, and risk considerations. Determining an optimal policy in this general setting is almost always intractable. We propose a class of linear rebalancing rules. When restricted to this parametric class the stochastic control problem reduces to a tractable, deterministic convex optimization problem in the parameters of the trading strategies. We investigate realistic examples that show that the approach dominates several alternatives, especially in settings where the covariance matrix of returns is stochastic (e.g., when there is a factor structure in returns or when returns have GARCH dynamics) or when transaction costs vary with the level of volatility. Joint work with Pierre Collin-Dufresne (EPFL), Kent Daniel (Columbia), and Mehmet Saglam.
25. Muhle-Karbe, Johannes (ETH Zürich)
Title: *Who should sell stocks?*
Abstract: Never selling stocks is optimal for investors with a long horizon and a realistic range of market and preference parameters, if relative risk aversion, investment opportunities, dividend yields and proportional transaction costs are constant. It is optimal to buy stocks when their portfolio weight is too low, and otherwise hold them, letting dividends rebalance to cash over time rather than selling. With capital gain taxes, this policy outperforms both optimal rebalancing with transaction costs and static buy-and-hold. Selling stocks becomes optimal if either their target weight is low, or intermediate consumption is present. (Joint work with Paolo Guasoni and Ren Liu.)
26. Papanicolaou, Andrew (University of Sydney)
Title: *Control with Partial Information*
Abstract: I will present a partially-informed optimal investment problem for general utility functions (e.g. for mixed power utility of the form $U(x) = \frac{c_1}{1-\gamma_1} x^{1-\gamma_1} + \frac{c_2}{1-\gamma_2} x^{1-\gamma_2}$). The market's single risky asset has unobserved drift that depends on a pair of Ornstein-Uhlenbeck processes Y and Z where Y is fast mean reverting and Z is slow mean reverting. A Kalman filter tracks the hidden states from the history of asset prices, and then is used as input for a portfolio problem with the objective of maximizing expected terminal utility. The multiple time scales are used to compute a perturbation expansion of the optimal value function, which we use in a numerical study of the information premium in the market.
27. Papapantoleon, Antonis (Technical University Berlin)
Title: *An equilibrium model for commodity spot and forward prices*
Abstract: The aim of this project is to determine the forward price of a consumption commodity via

the interaction of agents in the spot and forward commodity market. We consider a market model that consists of three representative agents: producers of the commodity, consumers and financial investors (sometimes also called speculators). Producers produce a fixed amount of the commodity at each time point, but can choose how much they offer in the spot market and store the rest for selling at the next time period. They also have a position in forwards in order to hedge the commodity price uncertainty. Consumers are setting the spot price of the commodity at each time point by their demand. Finally, investors are investing in the financial markets and, in order to diversify their portfolios, also in the forward commodity market. The equilibrium prices for the commodity are the ones that clear out the spot and forward markets. We assume that producers and investors are utility maximizers and have exponential preferences, while the consumers' demand function is linear. Moreover, the exogenously priced financial market and the demand function are driven by Lévy processes. We solve the maximization problem for each agent and prove the existence of an equilibrium. This setting allows to derive explicit solutions for the equilibrium prices and to analyze the dependence of prices on the model parameters and the agent's risk aversion. Joint work with Michail Anthropolos and Michael Kupper

28. Praz, Remy (Ecole Polytechnique Fédérale de Lausanne)

Title: Asymmetric Information and Inventory Concerns in Over-the-Counter Markets

Abstract: We study how transparency, modeled as information about one's counterparty liquidity needs, affects the functioning of an over-the-counter market. In our model, investors hedge endowment risk by trading bilaterally in a search-and-matching environment. We construct a bargaining procedure that accommodates information asymmetry regarding investors' inventories. Both the trade size and the trade price are endogenously determined. Increased transparency improves the allocative efficiency of the market. However, it simultaneously increases inventory costs, and leads to a higher cross-sectional dispersion of transaction prices. For investors with large risk exposure, the increase of the inventory costs dominates the benefits of the market efficiency. We link the model's predictions to recent empirical findings regarding the effect of the TRACE reporting system on bond market liquidity. This is joint work with Julien Cujean (Smith School of Business, University of Maryland).

29. Qiu, Jinniao (Humboldt University)

Title: A Functional Limit Theorem for Limit Order Books

Abstract: This work is concerned with a stochastic model for the dynamics of the two-sided limit order book (LOB). For the joint dynamics of best bid and ask prices and the standing buy and sell volume densities, we derive a functional limit theorem, which states that our LOB model converges to a continuous-time limit when the order arrival rates tend to infinity, the impact of an individual order arrival on the book as well as the tick size tend to zero. The limits of the standing buy and sell volume densities are described by two linear stochastic partial differential equations, which are coupled with a two-dimensional reflected Brownian motion that is the limit of the bid and ask price processes. This work is joint with Christian Bayer and Ulrich Horst.

30. Robertson, Scott (Carnegie Mellon University)

Title: Long Horizon Optimal Investment and Risk-Sensitive Control in Stochastic Volatility Models with Matrix Valued Factors

Abstract: In this talk, we consider the problems of long-horizon optimal investment and risk-sensitive control in a stochastic volatility model where the underlying factors take values in the space of positive definite matrices. Convergence of optimal policies (controls) is shown by analyzing the large time behaviour of solutions to the associated semi-linear Cauchy problem. Specifically, two types of convergence are obtained: 1) point-wise convergence of the solution and its gradient; 2) convergence of associated backward stochastic differential equations. For power utility investors, these results imply that for large horizons, the optimal policy is approximately the optimal long-run policy. Additionally, these results yield portfolio turnpikes, in which optimal policies and wealth

processes for a general utility function converge to the long run policy for an appropriate power utility. As an example, we consider when the underlying factor follows the Wishart process. Here, precise, easy to verify, conditions upon the model coefficients are given under which the above convergence results holds true.

31. Rockafellar, R. Terry (University of Washington)

Title: *GENERAL ECONOMIC EQUILIBRIUM WITH FINANCIAL MARKETS, REMODELED*

Abstract: The classical Arrow-Debreu model of general equilibrium focused on a single time period with no past or future. Financial markets are inevitably involved with planning for the future, but extending classical theory to cover them has been problematical. The incompleteness of such markets, i.e., the unavailability of instruments able to hedge exactly against every contingency, can interfere even with existence of equilibrium. Up to now, only generic existence has mainly been established — under very strong assumptions on agent preferences and with an astonishing peculiarity in the modeling of prices. The prices are in so-called units of account, which are not tied to any currency and suffer degeneracy in being subject to an arbitrary scaling factor in each economic state.

A different approach, to be explained in this talk, brings money prices into the model from the start. This enables coverage, for the first time, of financial instruments for which the pay-offs may depend on the money prices of various items in future markets, as with typical options. An essential feature is that agents can, to some degree, retain resources from present to future and gain utility from that as an alternative to consuming them. Retention of money yields utility for reasons of distrust over uncertainty that were very much emphasized by Keynes. In line with those ideas, a different interpretation is also given to future prices so as to loosen the doomsday effects of a finite-horizon model and capture economic activity that comes from a past and proceeds to an indefinitely prolonged future. Another feature is the introduction of variational inequality methodology in the proof of equilibrium, which has potential for advances in stability analysis and computation.

This model comes from joint work with Alejandro Jofre and Roger Wets.

32. Sirbu, Mihai (The University Of Texas at Austin)

Title: *Zero-sum games, strategies and dynamic programming*

Abstract: We take a new look at the problem of zero-sum stochastic differential games. We consider a symmetric formulation over feed-back strategies, restricted to provide strong solutions of the state equation. The problem is then studied using a dynamic programming approach based on different modifications of Perron's method. We also explore the relation to control problems with model uncertainty, in strong formulation.

33. Sircar, Ronnie (Princeton University)

Title: *Energy Production and Mean Field Games*

Abstract: One way to view energy markets is as competition between producers from different fuels and technologies with markedly varied characteristics. For instance, oil is relatively cheap to extract, but in diminishing supply and polluting. Solar power is more expensive to set up, but essentially inexhaustible and clean. We construct dynamic oligopoly models of competition between heterogeneous energy producers to try and understand how the changing landscape may affect energy prices and supply. We discuss how continuous time Bertrand and Cournot competitions, in which firms producing similar goods compete with one another by setting prices or quantities respectively, can be analyzed as continuum dynamic mean field games under the constraint of finite supplies (or exhaustible resources). The continuum game is characterized by a coupled system of partial differential equations: a backward HJB PDE for the value function, and a forward Kolmogorov PDE for the density of players. We find that, in accordance with the two-player game, a large degree of competitive interaction causes firms to slow down production. The continuum system can therefore be used as an effective approximation to even small player dynamic games.

34. Sturm, Stephan (Worcester Polytechnic Institute)

Title: *Funding without Tears. A Unified Approach to XVA*

Abstract: The financial crisis lead to an opening of the LIBOR-OIS spread. Default risk has become a real possibility and banks can no longer borrow and lend at the same rate. Also traders face different rates when financing their hedging positions. Therefore, hedging can no longer be done assuming a constant risk free rate and details of the actual procedure (collateralization, repointing) have to be taken into account.

Many large banks have created unified XVA desks to centrally manage the total credit risk (default and funding risk). We propose a BSDE based unified methodology for the calculation of the total value adjustment (XVA) and provide a detailed study of (super-)hedging a stock option with defaultable corporate bonds. This is joint work with Maxim Bichuch and Agostino Capponi.

35. Ware, Tony (University of Calgary)

Title: *Reliability-constrained hydropower valuation*

Abstract: Maximizing the long-term value of hydropower generation requires management of uncertain reservoir inflows, potentially variable constraints on outflows, and exposure to possibly wildly varying power prices. In this talk we present a stochastic dynamic programming approach to the quantification of reservoir reliability (for example, measures of the risk of over-topping the reservoir or failing to satisfy downstream flow requirements) and a related approach to determining the reservoir flow strategy that maximizes expected revenue, subject to defined target reliability levels.

36. Zariphopoulou, Thaleia (University of Texas at Austin)

Title: *Some new results on forward performance processes*

Abstract: Using results from ergodic and infinite horizon BSDE, we produce new characterizations for power, exponential and logarithmic forward performance processes in stochastic factor models. We also provide a connection among them and the classical maximal expected utility. Related results on turnpike properties of the optimal portfolios are also discussed. (Joint with Gechun Liang)