Confernece on the Mathematics of Energy Markets

List of abstracts

Wolfgang Pauli Institute, Vienna, 5-7 July 2016

Plenary speakers

Giorgia Callegaro, Padova University, Italy

Title: Utility Indifference Pricing and Hedging for Structured Contracts in Energy Markets

Abstract: In this paper we study the pricing and hedging of structured products in energy markets, such as swing and virtual gas storage, using the exponential utility indifference pricing approach in a general incomplete multivariate market model driven by finitely many stochastic factors. The buyer of such contracts is allowed to trade in the forward market in order to hedge the risk of his position. We fully characterize the buyers utility indifference price of a given product in terms of continuous viscosity solutions of suitable nonlinear PDEs. This gives a way to identify reasonable candidates for the optimal exercise strategy for the structured product as well as for the corresponding hedging strategy. Moreover, in a model with two correlated assets, one traded and one nontraded, we obtain a representation of the price as the value function of an auxiliary simpler optimization problem under a risk neutral probability, that can be viewed as a perturbation of the minimal entropy martingale measure. Finally, numerical results are provided.

Matt Davison, Western University, Canada

Title: A Real Options Analysis of the Relation between Ethanol Producers and Corn and Ethanol Markets

Abstract: In recent years, for a variety of reasons, it has become popular in North American to produce Ethanol (for blending with gasoline) from Corn. The resulting industrial process can be modelled as an option on the "crush spread" between Ethanol and Corn. Under a price - taker assumption, real options models of ethanol production can be made incorporating random corn and ethanol prices.

In the first part of my talk I will report work done in my group, together with Natasha Burke and Christian Maxwell, on creating and solving real options models of the corn-ethanol industry. These models provide interesting insights about the relationship between corn prices, ethanol prices, and their correlation with valuations and operational decisions. Using a jump process, we are also able to incorporate the impact of random changes in government subsidies on the valuation and operation of ethanol facilities.

However, while in the relatively fragmented US corn ethanol market it might be (just) reasonable to model any given ethanol producer as a price taker, all producers taken together do have market impact. In the second part of my talk I report work, joint with Nicolas Merener (Universidad Torcuata di Tella, Buenos Aires) on creating tractable models for this price impact. I will also sketch our progress toward solving the models and confronting them with data.

Archil Gulisashvili, Ohio University, US

Title: Peter Laurence as Friend and Collaborator

Abstract: My talk is dedicated to the memory of Peter Laurence, whose untimely death has left a void in many peoples hearts. Peter was a truly great mathematician and a wonderful person. In the first part of the talk, Peter's scientific biography will be presented. I will also share personal recollections of my meetings with Peter face-to-face and in the skype world. The second part of the talk will be more mathematical. I will speak about my joint work with Peter on Riemannian geometry of the Heston model, which is one of the classical stock price models with stochastic volatility. My collaboration with Peter resulted in the paper "The Heston Riemannian distance function", which was published in 2014 by "Journal de Mathématiques Pures et Appliquées". In the paper, we found two explicit formulas for the Riemannian Heston distance, using geometrical and analytical methods. Geometrical approach is based on the study of the Heston geodesics, while the analytical approach exploits the links between the Heston distance function and a similar distance function in the Grushin plane. We also proved a partial large deviation principle for the Heston and the Grushin models. After completing our work on the paper, we started discussing future projects, but fate interfered. I will finish the talk by briefly presenting my recent results on the distance to the line in the Heston plane, and how such results can be used in financial mathematics. Peter's scientific influence continues after his untimely departure from this world.

Valery A. Kholodnyi, Verbund, Austria

Title: Extracting Forward-Looking Marked-Implied Risk-Neutral Probabilities for the Intraday Power Spots in the Unified Framework of the Non-Markovian Approach

Abstract:

- Benefits of a unified modeling framework
- The non-Markovian approach as a unified framework for the consistent modeling of power spots, forwards and swaps
- Extracting forward-looking market-implied risk-neutral probabilities for the intraday hourly and intra-hourly power spots from a single or multiple market forward curves
- Taking into account:
  - daily, weekly, annual and meta-annual cyclical patterns,
  - linear and nonlinear trends,
  - upwards and downwards spikes,
  - positive and negative prices
- Interpolating and extrapolating power market forward curves:
  - intra-hourly, hourly, daily, weekly and monthly power forward curves,
  - extending power market forward curves beyond their liquidity horizons
- Modeling the German Intraday Cap Week Futures as an hourly strip of Asian call options on forwards on the intraday hourly power spots

Georg Pflug, University of Vienna, Austria

Title: Pricing of Electricity Contracts

Abstract: It is typical for electricity contracts, that the time of concluding the contract and the time of delivery are quite different. For this reason, these contracts are subject to risk and risk premia are and must be part of the pricing rules. In the first part of the talk, we investigate electricity futures to find out pricing rules, which the market is applying, such as the distortion priciple, the certainty equivalence priciple or the ambiguity priciple. We then investigate a no-arbitrage principle in the presence of capacity contraints on production and storage. We review then the idea of acceptance pricing and indifference pricing using a concrete model. Finally we present a bilevel problem, where the pricing decision depends on the behavioral pattern of the counterparty. Some algorithmic aspects will be discussed as well. Joint work with Raimund Kovacevic

Ehud Ronn, University of Texas at Austin, US

Title: Risk and Expected Return in the Oil-Futures Market

Abstract: This paper considers two elements of the oil-futures markets: Expected return and risk.

With respect to expected return, the paper presents a parsimonious and theoretically-sound basis for extracting forward-looking measures of equity and commodity betas, and the risk-premium on crude-oil futures contracts. Defining forward-looking betas as perturbations of historical estimates, we use the market prices of equity, index and commodity options under a single-factor market model to estimate the appropriate forward-looking perturbation to apply to the historical beta. This permits us to compute forward-looking term structures of equity and commodity betas. In the commodity arena, we use both one- and two-factor models to obtain estimates of a forward-looking measure of the correlation between crude-oil and the S&P 500. Combining these with forward-looking (i.e., implied) volatilities on commodities and stock-market indices, we utilize these forward-looking betas and correlations to provide an ex-ante estimate of the expected future crude-oil spot price through the use of an equity ex-ante risk premium and the conditional CAPM.

With respect to risk, we use the market prices for crude-oil futures options and the prices of their underlying futures contracts to calibrate the volatility skew using the Merton (1976) jump-diffusion option-pricing model. We demonstrate the jump-diffusion parameters bear a close relationship to concurrent economic, financial and geopolitical events. This produces an informationally-rich structure covering the time period of the turbulent post-2007 time period.

Thorsten Schmidt, Freiburg University, Germany

Title: Fundamentals of Energy Markets

Abstract: We review current approaches of energy markets and start by studying absence of arbitrage in an infinite-dimensional setting. Once this is achieved we consider also structural frameworks for electricity forwards, taking into account relevant risk factors, like capacity and fuels prices. In a polynomial framework we obtain tractable pricing formulas. This is joint work with Christa Cuchiero and Julian Wergieluk

Almut Veraart, Imperial College, London UK

Title: Ambit stochastics in Energy Markets

Abstract: This talk gives an introduction to the area of ambit stochastics with a particular focus on applications in energy markets. In particular, we will describe models for energy spot and forward prices based on so-called ambit fields. These models are very flexible and at the same time highly analytically tractable making them interesting from a mathematical perspective, but also very useful for applications.

Contributed speakers

Thomas Deschatre, EDF, France

Title: On the Control of the Difference between two Brownian Motions: A Dynamic Copula Approach.

Abstract: We propose new copulae to model the dependence between two Brownian motions and to control the distribution of their difference. Our approach is based on the copula between the Brownian motion and its reflection. We show that the class of admissible copulae for the Brownian motions are not limited to the class of Gaussian copulae and that it also contains asymmetric copulae. These copulae allow for the survival function of the difference between two Brownian motions to have higher value in the right tail than in the Gaussian copula case. We derive two models based on the structure of the Reflection Brownian Copula which present two states of correlation ; one is directly based on the reflection of the Brownian motion and the other is a local correlation model. These models can be used for risk management and option pricing in commodity energy markets.

Pierre Erwan, EDF, France

Title: Numerical Approximation of a Cash-Constrained Firm Value with Investment Opportunities.

Abstract: We consider a singular control problem with regime switching that arises in problems of optimal investment decisions of cash-constrained firms. The value function is proved to be the unique viscosity solution of the associated Hamilton-Jacobi-Bellman equa- tion. Moreover, we give regularity properties of the value function as well as a description of the shape of the control regions. Based on these theoretical results, a numerical deter- ministic approximation of the related HJB variational inequality is provided. We finally show that this numerical approximation converges to the value function. This allows us to describe the investment and dividend optimal policies. Joint work with Stephane Villeneuve and Xavier Warin.

Jhonny Gonzalez, University of Manchester, UK

Title: Bayesian Calibration and Number of Jump Components in Electricity Spot Price Models

Abstract: The price spikes observed in electricity spot markets may be understood to arise from fundamental drivers on both the supply and demand sides. Each driver can potentially create spikes with different frequencies, height distributions and rates of decay. This behaviour can be accounted for in models with multiple superposed components, however their calibration is challenging. Given a price history we apply a Markov Chain Monte Carlo (MCMC)

based procedure to generate posterior samples from an augmented state space comprising parameters and multiple driving jump processes. This also enables posterior predictive checking to assess model adequacy. The procedure is used to determine the number of signed jump components required in two different markets, in time periods both before and after the recent global financial crises. Joint work with John Moriarty and Jan Palczewski.

Pierre Gruet, EDF, France

Title: Efficient Estimation in a Two-Factor Model from Historical Data: Application to Electricity Prices

Abstract: We aim at modeling the prices of forward contracts on electricity, by adopting a stochastic model with two Brownian motions as stochastic factors to describe their evolution over time. In contrast to the model of (Kiesel et al., 2009), the diffusion coefficients are stochastic processes; the one of the first factor is left totally unspecified, and the other one is the product of an unspecified process and of an exponential function of time to the maturity of the forward contract, which allows to account for some short-term effect in the increase of volatility. We will consider that price processes following this model are observed simultaneously, at n observation times, over a given time interval $[0, T]$. The time step T/n between two observation times is small with respect to T, in the asymptotics $n \to \infty$. We estimate some parameter of the exponential factor in volatility, with the usual rate, and we explain how it can be estimated efficiently in the Cramr-Rao sense. We are also able to estimate the trajectories of the two unspecified volatility processes, using nonparametric methods, with the standard rate of convergence. Numerical tests are performed on simulated data and on real prices data, so that we may see how appropriate our two-factor model is when applied to those data. Joint work with Olivier Féron (EDF, France) and Marc Hoffmann (Universite Paris-Dauphine).

Maciej Kostrzewski, Cracow University, Poland

Title: Bayesian Analysis of Electricity Spot Price under SVLEJX Model

Abstract: In the study, the Bayesian stochastic volatility model with normal errors, a leverage effect, a jump component and exogenous variables (SVLEJX) is proposed. This Bayesian framework, founded upon the idea of latent variables is computationally facilitated with Markov Chain Monte Carlo methods. In this paper, the Gibbs sampler is employed. The SVLEJX structure is applied to model electricity spot price. The results of Bayesian estimation, jump detection and forecasting are presented and discussed. The series of waiting times between two consecutive jumps is also of interest in the paper. Periods of no jumps alternating with the ones of frequent jumps could be indicative of existence of the jump clustering phenomenon. The impact of exogenous variables on

electricity spot price dynamic is explored. Moreover, the leverage effect and the stochastic volatility clustering are tested.

Paul Krühner, Technical University Vienna, Austria

Title: Representation of Infinite Dimensional Forward Price Models in Commodity Markets.

Abstract: The Heath Jarrow Morton (HJM) approach treats the family of futures - written on a commodity as primary assets and models them directly. This approach has been used for the modelling of future prices in various markets by several authors and it has found its use by practitioners. We derive several representations of possible future dynamics and implications on futures and the spot from an infinite dimensional point of view. To be more specifically, let us denote the spot price by S_t and the future prices by $f_t(x) := E(S_{t+x}|F_t), x, t \geq 0$. Due to the well-known Heath Jarrow Morton Musiela drift condition the dynamics of f_t cannot be specified arbitrarily under the pricing measure. We model it by $df_t = \partial_x f_t dt + \Psi_t dL_t$ in a suitable function space where L is some Lévy process. Then we derive a series representation for the futures in terms of the spot price process and Ornstein-Uhlenbeck type processes, we represent the spot as a Lévy-semistationary process and find formulae for the correlation between the spot and futures.

Nina Lange, University of Sussex, UK

Title: Presence of Joint Factors in Term Structure Modelling of Oil Prices and Exchange Rates

Abstract: The paper studies the time-varying correlation between oil prices and exchange rates and their volatilities. Generally, when the value of the dollar weakens against other major currencies, the prices of commodities tend move higher. The significance of this relationship has increased since 2000 with indications of structural breaks around the beginning of the so-called financialization of commodity markets-regime and again around the beginning of the financial crisis. Also the correlation between the volatility of oil prices and the volatility of exchange rates seems to experience the same behaviour as the returns correlation. This paper introduces and estimates a term structure model for futures contracts and option contracts on WTI crude oil and EURUSD. The model is fitted a panel data of futures prices covering 2000-2013. The model allows for stochastic volatility and correlation and identifies how the number of joint factors increases over time.

Yves Lässig, Freiburg University, Germany

Title: Optimal Control of an Energy Storage under Stochastic Consumption

Abstract: We consider a typical optimal control problem from the viewpoint of an energy utility company. The company faces a varying energy demand of its associated consumers, modelled by a stochastic process. Demands can be satisfied by either buying energy at an exchange or the utilisation of an energy storage system. Furthermore the company is able to buy energy on a larger scale - than needed to satisfy demands - and enlarge the storage level or respectively sell energy from the storage directly to the market. In contrast to previous literature the storing facility therefore serves as a hedge against market price and demand volume risks and is not considered isolated from other market activities of the operator. Therefor the value function - which can be interpreted as a real option value of the storage - differs from classical optimal storage control problems and delivers a better quantification of the storage value for a specific user. We formulate a stochastic control problem including these features and pay particular attention to the operational constraints of the storage. Furthermore we will introduce methods to model the energy spot price and the consumption rate stochastically. Subsequently we will derive a candidate for the optimal policy, verify its optimality and solve the arising Hamilton-Jacobi-Bellman equation for the value function numerically using a novel finite elements discretization.

Andres Mora-Valencia, Universidad de los Andes, Colombia

Title: Risk Quantification for Commodity ETFs: Backtesting Value-at-Risk and Expected Shortfall

Abstract: This paper studies the risk assessment of alternative methods for a wide variety of Commodity ETFs. We implement well-known as well as and recently proposed backtesting techniques for both value-at-risk (VaR) and expected shortfall (ES) under extreme value theory (EVT), parametric, and semi-nonparametric techniques. The application of the latter to ES was introduced in this paper and for this purpose we derive a straightforward closed form of ES. We show that, for the confidence levels recommended by Basel Accords, EVT and Gram-Charlier expansions have the best coverage and skewed-t and Gram-Charlier the best relative performance. Hence, we recommend the application of the above mentioned distributions to mitigate regulation concerns about global financial stability and commodities risk assessment. Joint work with Esther Del Brio and Javier Perote.

Jan Palczewski, University of Leeds, UK

Title: Energy Imbalance Market Call Options and the Valuation of Storage

Abstract: In this paper we assess the real option value of operating reserve provided by an electricity storage unit. The contractual arrangement is a series of American call options in an energy imbalance market (EIM), physically covered and delivered by the store. The EIM price is a general regular one-dimensional

diffusion. Necessary and sufficient conditions are provided for a unique optimal strategy and value. We provide a straightforward procedure for numerical solution and several examples. Joint work with John Moriarty.

Carlo Sgarra, Politecnico di Milano, Italy

Title: A Branching Process Approach to Power Markets

Abstract: Energy markets, and in particular, electricity markets, exhibit very peculiar fea- tures. The historical series of both futures and spot prices include seasonality, mean- reversion, spikes and small uctuations. Very often a stochastic volatility dynamics is postulated in order to explain their high degree of variability. Moreover, as it also appears in other kind of markets, they exhibit also the USV (Unspanned Stochastic Volatility) phaenomenon [7].

After the pioneering paper by Schwartz, where an Ornstein-Uhlenbeck dynamics is assumed to describe the spot price behavior, several different approaches have been investigated in order to describe the price evolution. A comprehensive presentation of the literature until 2008 is offered in the book by F.E. Benth, J. Saltyte-Benth and S. Koekebakker [4].

High frequency trading, on the other hand, introduced some new features in com- modity prices dynamics: in the paper by V. Filimonov, D. Bicchetti, N. Maystre and D. Sornette [5] evidence is shown of endogeneity and structural regime shift, and in order to quantify this level the branching ratio is adopted as a measure of this endoge- nous impact and a Hawkes processes dynamics is assumed as a reasonable modelling framework taking into account the self-exciting properties [1].

The purpose of the present paper is to propose a new modeling framework including all the above mentioned features, still keeping a high level of tractability. The model considered allows to obtain the most common derivatives prices in closed or semi-closed form. Here with semi-closed we mean that the Laplace transform of the derivative price admits an explicit expression.

The models we are going to introduce can describe the prices dynamics in two different forms, that can be proved to be equivalent: the first is a representation based on random fields, the second is based on Continuous Branching Processes with Immigration (CBI in the following). The idea of adopting a random fields framework for power prices description is not new: O.E. Barndorff-Nielsen, F.E. Benth and A. Veraart introduced the Ambit Fields to this end, showing how this approach can provide a very flexible and still tractable setting for derivatives pricing [2], [3].

A model based on CBI has been proposed recently by Y. Jiao, C. Ma and S. Scotti in view of short interest rate modelling, and in that paper it was shown that, with a suitable choice of the Levy process driving the CBI dynamics, the model can offer a significant extension of the poular CIR model [6].

We shall propose two different types of dynamics for the prices evolution. The first class will be named the Arithmetic models class, and the second will be named the Geometric model class; in adopting the present terminology we

are following the classification proposed in [4]. We shall compare the advantages and the limitations implied by each model class and we shall investigate the risk premium behavior for each of the classes considered. The paper will be organized as follows: in the first Section we introduce the stochas- tic processes we are going to consider, while in the second Section we discuss how these processes can be successfully applied to power markets description. In the third Sec- tion we derive some closed formulas for Futures and Option prices when the underlying dynamics is assumed to be given by the model introduced. In the fourth Section we shall investigate the risk premium term structure for the models under consideration. In the fifth Section, we provide some suggestions about estimation and/or calibration methods for the same model. We complete our presentation with a statistical analysis on the two cases and some numerical illustrations of the results obtained. In the final section we provide some concluding remarks and discuss futures extensions of the present work. Joint work with Ying Jiao, Chunhua Ma and Simone Scotti.

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Tiziano Vargiolu, Padova University, Italy

Title: Additive Models for Forward Curves in Multicommodity Energy Markets

Abstract: In contrast to geometric models, additive models in energy markets, in particular in markets where forward contracts are delivered during a period like electricity and natural gas, allows easily the computation of forward prices in closed form. Moreover they naturally allow the presence of negative prices, which start to appear more and more frequently in electric markets.

In this paper we present an additive multicommodity model which allows for mean-reverting dynamics consistent with no-arbitrage, based on the observed prices of forward contracts based on the mean on a period, which are the most liquid instruments in natural gas and electricity markets. This allows to compute

the price of more complex derivatives and of risk measures of portfolios in a way which is consistent with market data. Joint work with Luca Latini.

Ralf Wunderlich, Brandenburg University of Technology, Germany

Title: Partially Observable Stochastic Optimal Control Problems for an Energy Storage

Abstract: We address the valuation of an energy storage facility in the presence of stochastic energy prices as it arises in the case of a hydro-electric pump station. The valuation problem is related to the problem of de- termining the optimal charging/discharging strategy that maximizes the expected value of the resulting discounted cash ows over the life- time of the storage. We use a regime switching model for the energy price which allows for a changing economic environment described by a non-observable Markov chain. The valuation problem is formulated as a stochastic control prob- lem under partial information in continuous time. Applying filtering theory we find an alternative state process containing the filter of the Markov chain, which is adapted to the observable filtration. For this alternative control problem we derive the associated Hamilton- Jacobi-Bellman (HJB) equation which is not strictly elliptic. Therefore we study the HJB equation using regularization arguments. We use numerical methods for computing approximations of the value function and the optimal strategy. Finally, we present some numerical results. Joint work with Anton Shardin.

Florian Ziel, Europa-Universität Viadrina Frankfurt (Oder), Germany

Title: Electricity Price Forecasting using Sale and Purchase Curves: The X-Model

Abstract: Our paper aims to model and forecast the electricity price in a completely new and promising style. Instead of directly modeling the electricity price as it is usually done in time series or data mining approaches, we model and utilize its true source: the sale and purchase curves of the electricity exchange. We will refer to this new model as X-Model, as almost every deregulated electricity price is simply the result of the intersection of the electricity supply and demand curve at a certain auction. Therefore we show an approach to deal with a tremendous amount of auction data, using a subtle data processing technique as well as dimension reduction and lasso based estimation methods. We incorporate not only several known features, such as seasonal behavior or the impact of other processes like renewable energy, but also completely new elaborated stylized facts of the bidding structure. Our model is able to capture the non-linear behavior of the electricity price, which is especially useful for predicting huge price spikes. Using simulation methods we show how to

derive prediction intervals. We describe and show the proposed methods for the day-ahead EPEX spot price of Germany and Austria. Joint work with Rick Steinert.