Mathematisches Forschungsinstitut Oberwolfach

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Stochastic Analysis in Finance and Insurance

March 2nd – March 8th, 2003

This meeting was organised by Darrell Duffie (Stanford), Paul Embrechts (ETH Zürich) and Martin Schweizer (LMU München). It brought together 46 participants from 11 countries. After a very high success rate in the first round of invitations, additional emphasis was placed on having a substantial number of younger participants. This group was also well represented with 12 out of a total of 27 talks which provided an exceptional wealth of new and stimulating ideas.

The main focus of the meeting was on mathematical methods and problems from the fields of finance and insurance. This included new results on classical problems in very general market settings as well as challenges for future mathematical research directions induced by questions motivated by practice. In some more detail, talks and discussions included the following topics:

- risk measures: fundamental mathematical structure questions as well as their use in risk management and security design
- new models for financial markets (large markets, diverse markets, illiquid markets) and associated mathematical problems in stochastic analysis
- credit risk: general models as well as more applied questions
- incomplete markets
- utility maximisation and transaction cost problems in very general settings
- new stochastic representation problems arising from optimisation questions
- links to applications in insurance, and to numerical questions

Both the talks and the intensive discussions during and between them covered a wide range of topics. There were many discussions in the evenings as well, and these interactions led to many new contacts between participants, initiating collaborations on topics of joint interest.

Reactions from participants to the meeting were very positive, and the atmosphere of Oberwolfach was felt to be uniquely stimulating. This meeting can be expected to influence the mathematical development of the field in a substantial way.

Abstracts

Gittins indices for American options: a new approach to optimal stopping

Peter Bank, Humboldt University of Berlin

We describe a new approach to the problem of optimally stopping a stochastic payoff process. In this approach, the role of the usually employed concept of Snell envelope is taken over by the solution of a stochastic representation problem for the given payoff process. More precisely, this solution provides a level process whose passage times turn out to be the optimal stopping times for the payoff process considered.

As an application, we show how to characterize and construct algorithmically a universal exercise signal for American put options which allows to determine optimal exercise rules simultaneously for all possible strikes.

Hedging and valuation in financial models with interacting Itô and point processes

Dirk Becherer, Imperial College London
(joint work with M. Schweizer)

We study a Markovian model for an incomplete financial market with an Itô process

$$\frac{dS_t}{S_t} = \gamma(t, S_t, \eta_{t-})\, dt + \sigma(t, S_t, \eta_{t-})\, dW_t$$

and a further finite state process

$$d\eta_t = \sum_{k \neq j} 1_{\{k\}}(\eta_{t-})(j-k)\, dN_t^{kj}$$

in a finite state space $k, j \in \{0, 1, \ldots, m\}$. The process η is driven by a multivariate point process (N^{kj}) whose intensities satisfy

$$N^{kj} \text{ has intensity } \lambda^{kj}(t, S_t).$$

We construct such a model by a change of measure argument, and establish uniqueness from uniqueness and existence results for the corresponding class of Cauchy problems. Special cases of this model are the conditional Markov chain (Cox process) model, or a Markov chain modulated diffusion type model. In the latter cases either the process S or the process η would be given autonomously, while in the Itô and point process model we have a mutual dependence structure. A possible interpretation is to consider S as a stochastic index and η as the joint default/rating process of several firms. In this context, the model permits for simultaneous joint defaults, correlation between individual defaults because of joint state variables (S), but also for counterparty credit risk since the individual default intensities can jump when other firms default.

Let us consider S now as a tradable asset, while η is not tradable (directly). We study the hedging and valuation problem in this incomplete market. Solutions for the valuation and for the hedging strategy are derived for the approaches of

1) Risk-minimization (à la Föllmer/Sondermann/Schweizer)
2) (exponential) Utility-indifference (à la Hodges/Neuberger)

and given in terms of interacting systems of semi-linear parabolic PDE systems, which are linear in all derivatives. Existence and uniqueness of those are shown under only local conditions of the coefficients for S, basically.

Estimating the term structure of credit spreads: callable corporate debt

Antje Berndt, Stanford University

In this work I extract credit pricing information from the prices of callable corporate debt, by disentangling the components of callable corporate bond prices associated with discounting at market interest rates, discounting for default risk, and optionality. The value of the call option is sensitive to both interest rate risk and to the risk of changes in credit quality. The results include the first empirical analysis, in the setting of standard arbitrage-free term-structure models, of the time-series behavior of callable corporate bond yield spreads, explicitly incorporating the valuation of the American call options. As an application, I consider medium-quality callable issues of Occidental Petroleum Corporation, using a three-factor model for the term structures of benchmark (LIBOR-dollar) swap rates and for Occidental yield spreads. I study the correlations of these Occidental spreads with various macroeconomic and firm-specific time series, and discuss the implications of the estimated model for the current market practice of pricing callable corporate debt.

On the use of Wick products in finance

Tomas Björk, Stockholm School of Economics
(joint work with H. Hult)

We discuss the use of the Wick product and the Wick integral in mathematical finance. By a concrete counterexample we prove the existence of a simple portfolio strategy which is obviously self-financing in the naive sense, while it is not self-financing in the Wick sense. This shows that the Wick self-financing concept has no economic interpretation.

On the Malliavin approach to Monte Carlo estimation of conditional expectations and discrete time approximation of BSDE

Bruno Bouchard, Université Paris 6
(joint work with I. Ekeland and N. Touzi)

Given a multidimensional Markov diffusion X, the Malliavin integration by parts formula provides a family of representation of conditional expectations of the form $E[f(X_2) \mid X_1]$ in terms of the ratio of two unconditional expectations. We first investigate variance reduction methods based on "localizing functions". We prove existence of an optimal localizing function in the sense that it minimizes the integrated mean square of the Monte Carlo estimator. In the class of separable localizing functions, we show that the infimum is attained by exponential type functions that can be computed explicitly.

We next investigate the application of these results to the approximation of BSDE. In the Malliavin case, we obtain a bound on the L^p error and prove that L^p convergence holds.

Representation of money based utility functions on the space of bounded adapted càdlàg processes

Freddy Delbaen, ETH Zürich
(joint work with M. Kupper and P. Cheridito)

We consider a utility function $\Psi : \mathcal{R}^\infty \mapsto \mathcal{R}$ where $\mathcal{R}^\infty$ is the space of bounded adapted (to $(\mathcal{F}_t)_{0\leq t\leq 1}$) càdlàg processes. Ψ satisfies

$$\Psi(X+a) = \Psi(X) + a; \quad \Psi(X+Y) \geq \Psi(X) + \Psi(Y); \quad \Psi(\lambda X) = \lambda\Psi(X) \ \ (\lambda \geq 0),$$

as well as $\Psi(X) \geq 0$ for $X \geq 0$. (We may in more generality assume that Ψ is quasi-concave.) Ψ also satisfies a continuity property in the sense that for a sequence of processes X^n, uniformly bounded and converging to X in the sense $(X^n - X)^* \xrightarrow{\mathbb{P}} 0$, we must have $\Psi(X) \geq \limsup \Psi(X^n)$. The idea is to find a representation for such functional Ψ. This is a generalisation of the one period case where such a utility function was introduced on the space L^∞ of bounded random variables. The present case is more difficult since $\mathcal{R}^\infty$ is not a dual space and hence the techniques of the one period case do not apply. The representation problem is important to understand problems from risk management/measurement.

Optimal design of derivatives with respect to dynamic risk measures

Nicole El Karoui, Ecole Polytechnique Paris
(joint work with P. Barrieu)

We study the problem to optimally design a financial issue F to hedge non tradable risk X on a financial market. An investor I enters in the transaction if her risk level remains below a given threshold, when the issuer B (the bank) wants to optimally reduce her risk exposure. Both agents have also the opportunity to invest their residual wealth on financial market.

In the first part, we show that in an entropic framework, it is optimal to do nothing if $X = 0$ or to transfer a constant fraction of the initial risk, where this fraction only depends on the risk aversion coefficients of the agents. The key assumption is that both agents may invest in the same market.

In the second part, we suppose both agents have access to different markets. By using a dynamic point of view (dynamic risk measure), we characterize the optimal issue through the solution of quadratic BSDEs.

Credit migration and spread curves in an affine framework

Damir Filipovic, Princeton University

We propose and examine an affine factor model $Y = (Y^1, Y^2)$ for credit migration and spread curves. The credit rating of a firm is modelled by one of the factors, say Y^2, which takes values in $[0, \infty]$: 0 is the best rating and ∞ (absorbing state) is default. Due to the affine structure we find explicit expressions for default probabilities and yield spread curves. Empirical tests show that the model performs similarly well as what has been in the literature so far.

Markov models for interacting defaults and counterparty risk

Rüdiger Frey, Universität Leipzig

We study models for portfolio credit risk, where the default of one company affects the default intensity of other firms in the portfolio. Such interaction could be due to direct business relations. In contrast to most recent papers we study these models using Markov process techniques. We study the impact of interaction on default correlation and analyze properties and asymptotics of a model with mean-field interaction.

The interplay between preferences and: arbitrage, super-replication and risk measures

Marco Frittelli, Florence University
(joint work with S. Biagini (2) and B. Rosazza (3))

(1) We introduce the notion of a Market Free Lunch that depends on the preferences of the agents. In a semimartingale model of a securities market, we characterize No Arbitrage (NA) and No Free Lunch with Vanishing Risk (NFLVR) in terms of Market Free Lunch and show that the difference between NA and NFLVR consists in the selection of the class of monotone, respectively monotone and continuous utility functions.

We also provide a direct proof of the equivalence between the absence of a Market Free Lunch with respect to monotone concave preferences and the existence of an equivalent martingale measure.

(2) We define the notion of the weak super-replication price $\hat{f}_\phi$ for a claim f satisfying only integrability conditions and we show that $\hat{f}_\phi$ coincides with $\sup_{Q\in M_\phi} E_Q[f]$, where M_ϕ is the class of pricing measures with finite generalized entropy ϕ and ϕ is the conjugate of the utility function.

(3) We introduce a set of axioms that define convex risk measures. Duality theory provides the representation theorem of these measures and the link with indifferent pricing rules.

On the consistency of two desks

David Heath, Carnegie Mellon University

We consider two trading desks, each of which trades claims in some space (different for each desk) of bounded random variables at prices determined by (different) probability measures. We discuss necessary and sufficient conditions under which a trader, trading with both desks, cannot build an arbitrage.

Stochastic volatility, correlation and the q-optimal measure

David Hobson, University of Bath

Consider a stochastic volatility model of the form (under P)

$$\frac{dS_t}{S_t} = Y_t(\, dB_t + \lambda_t\, dt), \quad dY_t = a_t\, dW_t + b_t\, dt$$

where B and W are correlated Brownian motions with correlation ρ_t. This model is incomplete and there are infinitely many equivalent martingale measures. One choice of

measure is the q-optimal measure which minimises the distance $E\left[\frac{q}{q-1}|\frac{dQ}{dP}|^q\right]$ between the martingale measure and the original real world measure.

We show that there is a representation equation which characterises the q-optimal measure.

Furthermore in the case where Y is an autonomous diffusion, ρ is constant and the Sharpe ratio is a function of the volatility, we can give a stochastic representation for the solution of the representation equation.

A general formula for valuing defaultable securities

Julien Hugonnier, HEC Montréal

Previous research has shown that under a suitable "no-jump" condition, the price of a defaultable security is equal to its risk-neutral expected value if a modified discount rate is introduced to account for the probability of default. We generalize this result by demonstrating that we can always value claims using risk-adjusted discounting provided that the expectation is computed under a slightly modified probability measure. This new measure puts zero mass on the paths where default happens prior to maturity and is thus only absolutely continuous with respect to the risk-neutral probability measure. After establishing the main result we investigate a number of examples which demonstrate the power of our general formula. In particular, we show that a defaultable bond can be worth more than the corresponding default-free bond.

A portfolio choice under transaction costs

Yuri Kabanov, Université Besançon

We consider a continuous time stochastic optimization problem with infinite time horizon, linear dynamics, and some constraints which includes as a particular case portfolio selection problems under transaction costs for models of a currency market as well as a stock market. Using an appropriate geometric formalism we show that the Bellman function is the unique viscosity solution of a HJB equation.

Pricing derivatives of American and game type in incomplete markets

Jan Kallsen, Universität Freiburg im Breisgau

In this talk the neutral valuation approach is applied to American and game options in incomplete markets. Neutral prices occur if investors are utility maximizers and if derivative supply and demand are balanced. Game contingent claims are derivative contracts that can be terminated by both counterparties at any time before expiration. They generalize American options where this right is limited to the buyer of the claim. It turns out that as in the complete case, the price process of American and game contingent claims corresponds to a Snell envelope or to the value of a Dynkin game, respectively.

Diversity and arbitrage in equity markets

Ioannis Karatzas, Columbia University
(joint work with E. R. Fernholz and C. Kardaras)

A financial market is called "diverse" if no single company is ever allowed to dominate the entire market in terms of relative capitalization. We formulate this property, as well as the allied but progressively weaker notions of "weak diversity" and "asymptotic weak diversity" in precise mathematical terms, within the context of the standard Itô-process model initiated by Samuelson. We show that diversity is indeed possible, though rather delicate, to achieve. Several illustrative examples are provided, including two which demonstrate that weakly-diverse equity markets contain arbitrage opportunities: it is possible to outperform such markets significantly over sufficiently long time-horizons, and to underperform them significantly over arbitrary time-horizons. However, the existence of such arbitrage is shown not to interfere with the development of option pricing or of portfolio optimization.

Multivariate regular variation for additive processes

Filip Lindskog, ETH Zürich
(joint work with H. Hult)

We study the joint tail behavior of heavy-tailed R^d-valued additive processes, i.e. stochastically continuous processes with independent increments, and the joint tail behavior of vectors of functionals acting on each component of such processes. More precisely we consider additive processes which at some fixed time $t > 0$ satisfy a multivariate regular variation condition. Tail equivalence between the process at time t and its Lévy measure, in the sense of having the same multivariate regular variation limit measure, is established. We also derive regular variation limit measures for vectors consisting of the componentwise suprema, the componentwise suprema of the jumps and the componentwise integrals over the time interval $[0, t]$. In order to derive the limit measure for the vector of componentwise integrals we study convergence of the appropriately scaled probability that the process reaches sets in the product space $[0, t] \times R^d$, and we establish several equivalent formulations of this convergence.

Quadratic hedging and stochastic orders in dynamic reinsurance markets

Thomas Møller, University of Copenhagen

We consider a dynamic reinsurance market, where the traded risk process is driven by a jump-diffusion and where claim amounts are unbounded. These markets are incomplete, and there are typically infinitely many martingale measures. In this case, no-arbitrage pricing theory can typically only provide wide bounds on prices of reinsurance claims. Optimal measures such as the minimal martingale measure and the minimal entropy martingale measure are determined, and some comparison results for prices under different martingale measures are provided. This leads to a simple stochastic ordering result for the optimal martingale measures. Moreover, these optimal measures are compared with other martingale measures known from the literature on dynamic reinsurance markets.

Wealth path dependent utility maximization in incomplete markets

Huyên Pham, Université Paris 7
(joint work with B. Bouchard)

Motivated by an optimal investment problem under time horizon uncertainty and when default may occur, we study a general structure for an incomplete semimartingale model extending the classical terminal wealth utility maximization problem. The modelling leads to the formulation of a wealth-path dependent utility maximization problem. Our main result is an extension of the well-known dual formulation to this context. The important novel feature is the asymmetric bipolar relation between the primal and dual variables. The classical dual approach does not work anymore and we show how to overcome this difficulty by deriving directly on the primal problem. Sufficient conditions for characterizing the optimal solution are also provided in the case of complete markets, and are illustrated by examples.

Utility maximization with infinitely many assets

Maurizio Pratelli, Pisa University

In order to formulate the classical "Utility Maximization Problem" in a "large market" (modeled by a sequence of semimartingales), one needs to define a stochastic integral with respect to a sequence of semimartingales and to select a proper class of "admissible" strategies.

The existing theories on infinite dimensional stochastic integration do not include this case: we propose a theory of stochastic integration with respect to a sequence of semimartingales. This integral (which extends to the general case a cylindrical stochastic integral introduced by Mikulevicius and Rozovskii for the case of a sequence of square integrable martingales) has some good properties such as invariance with respect to a change of probability and mainly the so called "Mémin's theorem" (limit of stochastic integrals in the semimartingale topology is still a stochastic integral).

There are however some "bad properties" (e.g. the "Ansel-Stricker theorem" does not hold true in the infinite dimensional setting): therefore some care is needed in order to define the "admissible" strategies.

To this end, we give a definition which maintains the "polarity relation" and allows to extend the duality approach to the infinite dimensional setting.

Liquidity risk and arbitrage pricing theory

Philip Protter, Cornell University
(joint work with U. Çetin and R. Jarrow)

Classical theories of investment finance assume an infinitely liquid market and that all traders are price takers. We propose a new model that takes into account illiquidities, while extending the classical model. Our approach hypothesizes a stochastic supply curve for a security's price as a function of trade size. This leads to natural restrictions on hedging strategies and a consequent new notion of approximate completeness, under which the two fundamental theorems of asset pricing can be established.

Progressive enlargement of filtrations and investment opportunities

Thorsten Rheinländer, ETH Zürich

We consider two filtrations $\mathcal{F} \subset \mathcal{G}$. Hypothesis (H) is said to be satisfied if every $\mathcal{F}$-martingale is also a $\mathcal{G}$-martingale. We link, via the theory of optimal martingale measures, this hypothesis to the measurability properties of the solution to a certain equation. We also study whether it is possible to benefit from additional information in case (H) is not satisfied. As an example we study the correlated Stein/Stein-model, where $\mathcal{F}$ is the filtration generated by the price process and $\mathcal{G}$ the filtration generated by the driving Brownian motions. In case the correlation between the BM's is nonzero, it turns out that there is some benefit if the investor (unrealistically) has access to the information contained in the Brownian filtration.

Efficient hedging when there is model risk and asset prices are discontinuous

Wolfgang Runggaldier, University of Padova
(joint work with M. Kirch (the latter part))

We consider efficient hedging when:

(i) The market model is not fully known (model risk).

(ii) The values of the underlying assets change only at discrete random points in time.

A preliminary discussion concerns possible ways to deal with model risk. We then concentrate on an approach based on piecewise deterministic control under partial information.

Modelling dynamic portfolio credit risk

Philipp Schönbucher, ETH Zürich

In this talk we present and analyse the copula approach to portfolio credit risk modelling. The copula model allows to introduce default dependency in a separate step after modelling the marginal default and survival probabilities of the individual obligors. We analyse the dynamics that copula models entail; for Gaussian copula functions these dynamics turn out to involve a weak singularity at $t = 0$. We therefore present an alternative class of copula functions which are a generalisation of the Archimedean copulae to the non-exchangeable case.

The dynamics of credit spreads and default hazard rates in this setup can be interpreted as a case of "information driven default contagion", i.e. the default risk of one obligor i depends on the default- and survival-behaviour of all other obligors $j \neq i$.

Asymptotic analysis with transaction costs

Steven Shreve, Carnegie Mellon University
(joint work with K. Janecek)

Consider an agent who invests in a stock and a money market and consumes in order to maximize the utility of consumption over an infinite planning horizon in the presence of a proportional transaction cost $\lambda > 0$. The utility function is of the form

$$U(c) = c^{1-p}/(1-p) \quad \text{for } p > 0, p \neq 1.$$

We provide a heuristic and rigorous derivation of the asymptotic expansion of the value function in powers $\lambda^{1/3}$, and we also obtain asymptotic results on the boundary of the "no-trade" region.

Gamma constraints and super-replication

H. Mete Soner, Koç University Istanbul
(joint work with N. Touzi and P. Cheridito)

We show that the minimal super-replication cost in a financial market with gamma constraints is the unique viscosity solution of a quasi-variational inequality. The "intuitive" equation is not parabolic and the correct equation is the parabolic majorant of this "intuitive" equation. This property is proved by a detailed analysis of double stochastic integrals.

Edited by Filip Lindskog

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